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Survey of Energy Resources

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The World Energy Council

Promoting the sustainable supply and use of energy for the greatest benefit of all.

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Survey of Energy Resources

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Finally, the WEC thanks the Joint Editors Judy Trinnaman and Alan Clarke for compiling, validating and formatting the data. Once again they have successfully and professionally completed this enormous task, both achieving an excellent quality and keeping to the planned schedule. The WEC is grateful to them for their knowledge, dedication, tenacity and inspiration.

FOREWORD

This 19th WEC Survey of Energy Resources contains a chapter for each energy resource, ranging from the conventional fossil fuels to the renewables, both new and traditional. Marine current energy has been covered for the first time. Generally, the coverage of each resource comprises a commentary by a leading expert in the field, data tables and country notes. The tables summarise the worldwide resources, reserves, production and consumption of fossil fuels and comparable data for non-fossil energy sources, as applicable. The country notes aim to highlight the main features of the resource and its utilisation. In addition, definitions pertinent to the resource in question are set out to aid the reader's understanding.

- **Reserves/Resources** - where relevant, tables of fossils fuels provide reserve statistics (covered globally from WEC and non-WEC sources) and amounts in place (as reported by WEC Member Committees).

- **Tabulations** – data tables are arranged on a standard regional basis throughout.

- **Units** – where relevant, data have been provided in alternative units (cubic feet as well as cubic metres, barrels as well as tonnes) in order to facilitate use of survey data in an industry context.

- **References and Sources** – as far as possible, these have been consolidated in the introductory notes to the data tables and the country notes.

Any review of energy resources is critically dependent upon the availability of data, and reliable, comprehensive information does not always exist. While the basis of the compilation was input provided by WEC Member Committees, completion necessitated recourse to a multitude of national and international sources and in some cases estimation. The difficulty in obtaining information has been compounded by recent trends in the energy sector. The availability of data has been reduced with the process of deregulation and privatisation, as data-reporting channels have been lost or more data becomes confidential. In addition, problems in the quantification of energy resources persist, in particular for those universally-found resources: solar energy, wind power and biomass, owing to their evolutionary state. Despite growth of such capacity throughout the world, installations are frequently on an extremely small scale, often leading to great difficulties in their identification and enumeration. Another problematical area is that of the definitions relating to resources and reserves: it is well recognised that each country tends to have its own notion of what constitutes resources and reserves. A continued effort has been made in order to maximise harmonisation and comparability.

As editors we strive to develop and maintain contacts in the energy world and hope that in time the availability of data will not only improve but expand to cover those energy resources that presently go unrecorded (e.g. coal bed methane).

We are grateful to all those who have helped to produce this Survey: we extend our thanks to the WEC Member Committees, to the authors of the Commentaries, to Keiichi Yokobori for guidance and for writing the Overview and to Ann Fewster for her much-appreciated administrative support. We would also like to thank the WEC London office for overseeing the production and the Argentine Member Committee for the production of the CD-Rom.

Judy Trinnaman and Alan Clarke
Editors

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OVERVIEW

This is the 19th edition of the Survey of Energy Resources produced by the World Energy Council since 1934. The 2001 Survey, which will be released in conjunction with the 18th World Energy Congress in Buenos Aires in October 2001, provides a review of world energy resources, mainly as of the end of 1999.

The main findings of the Survey confirm that conventional commercial fossil fuels, encompassing coal, oil and natural gas, remain in adequate supply, with a substantial resource base. Compared to the 1998 Survey, coal and natural gas reserves increased somewhat, while those of oil declined slightly. Within the total coal reserves, both sub-bituminous coal and lignite reserves declined from the previously reported levels by 15% and 3% respectively, but bituminous coal reserves increased by 2%.

While **Coal** supply in the medium and long term is assured, the future prospects for delivery and use of coal will largely depend on the impact of deregulation of electricity markets, policies to reduce greenhouse gases, and technological advances (cleaner use of coal and carbon sequestration). Coal could contribute in a sustainable way to satisfying demand for energy from the two billion people in the world who today still depend on traditional fuels.

In the commentary on **Oil** the pessimistic and optimistic reserve assessments have been propounded and appear to incline towards the former, for the following reasons:

- proved recoverable reserves of oil, which are largely concentrated in the Middle East, declined, while those of gas, which are more evenly spread, increased;
- fewer giant fields were discovered in the 1990’s than in the 1960’s (albeit a larger proportion were in deeper offshore waters);
- the discoveries of new oil fields were concentrated in a smaller number of countries in the 1990’s than in the earlier periods;
- more recently the additional discoveries have been less than the oil produced;
- the oil industry’s technological challenges posed by the ultra-deep offshore have not yet been met satisfactorily.

The commentary is confined to reserve assessments and some of the supply aspects, and does not discuss oil demand. Thus the implications of environmental concerns, such as climate change, on the supply and demand for oil have not been addressed. This may imply a more optimistic outlook for future oil demand growth, given a growing world population and rising energy demand, despite a possible tightening of environmental laws.

Natural gas, on the other hand, confidently appears as a cleaner fossil fuel set to play a greater role in satisfying increasing energy demand. However, addressing the issue of air quality has become a priority for the natural gas industry. Encouraged by the recent steady increase in gas production and demand in the Asia Pacific region, (particularly in China) and also in Africa, as well as by the prospect of market incentives promoted by the Clean Development Mechanism, it is assumed that the current increase in demand for natural gas is an indication of a long-term trend. Advanced technologies such as combined-cycle power plants, acid gas re-injection, hydrogen fuel cells, etc. could expand the frontiers of both natural gas demand and supply. Challenges facing the gas industry today include a further reduction of emissions, higher efficiencies in production and consumption and the expansion of appropriate infrastructure, including cheaper and more advanced technologies for liquefied natural gas (LNG). The transfer of technology from developed to developing countries will also be essential.

The expected continued dominance of conventional fossil fuels makes it seem unlikely that certain non-conventional or renewable energy sources will play an important role in balancing energy demand and supply in the foreseeable future, despite their technical feasibility or plentiful resource bases. This is the case with oil shale, natural bitumen and extra-heavy oil, peat, tidal energy, wave energy, ocean thermal energy conversion and marine current energy.

- Oil obtained from **Oil shale** is sometimes called the “elusive energy”, mainly because of its high energy demand for blasting, transport, crushing, heating, adding hydrogen, and the safe disposal of huge quantities of waste.

- Technological advances have been reported for both **Natural bitumen** (tar sand) in Alberta, Canada (through the development of steam-assisted gravity drainage and horizontal well drilling) and **Extra-heavy oil** in the Orinoco Oil Belt (through the manufacture of Orimulsion® emulsion). However, since the Canadian natural bitumen deposits and the Venezuelan extra-heavy crude oil deposits account for 85% and 90% respectively of the world resources, there is limited scope for their use in other parts of the world.

- Various aspects of the use of **Peat** have been highlighted: the shrinking peatlands of Western Europe during the 1970’s and more recently peat’s greater role in the environmental protection in Europe, but also the failure to develop the use of peat as fuel in Central Africa and South-East Asia because of its drainage for agricultural purposes. Despite the European Union’s ongoing attempt to classify this fuel as renewable, and some initiatives, for example, co-combustion of peat with wood in Combined Heat and Power plants (especially in Finland), the overall use of peat as a fuel in Europe remained insignificant in 1999.

- Despite the high predictability of **Tidal energy’s** resource and timing, long construction times, high capital intensity and low load factors are thought likely to rule out significant cost reductions in the near term.

- Recent favourable developments in **Wave energy** have been listed: increased focus on climate change, technological developments in Scotland, Australia, Denmark and the USA, a high potential for energy supply – it could provide 10% of the current world electricity supply (if appropriately harnessed) - and the potential synergies with the offshore oil and gas industry. However, there are still a number of necessary technological improvements. The possibility of wave energy unit costs falling to 2-3 pence/kWh within 3 to 5 years mentioned in the commentary is derived from experience of onshore wind energy costs, not from experience in wave energy. Nevertheless, the full utilisation of wave energy potential appears to be some way off.

- The many benefits of **Ocean thermal energy conversion (OTEC)** are set out: small seasonal and daily variations in availability, benign environmental performance and by-products in a family of deep ocean water applications, for example food (aquaculture and agriculture) and potable water, and improving economics as a result of higher oil prices. However, a number of key component technologies and further R&D are still needed, in order to be able to build a representative pilot plant to demonstrate OTEC's advantages to prospective investors.

- It is acknowledged that there has been little research into utilising **Marine current energy** for power generation and today no commercial turbines are in operation (thus making the assessment of production costs difficult). There is, however, a large global marine current resource potential which possesses a number of advantages over other renewables, such as its higher energy density, highly predictable power outputs, independence from extreme atmospheric fluctuations and a zero or minimal visual impact.

It is expected that **Uranium** will remain in ample supply over the next decade despite an 8% decline between 1 January 1997 and 1 January 1999 in known world uranium resources (recoverable at US$ 130/kgU or less). From 1991 through 1999 over 40% of the total world uranium requirements were met from non-mine supplies, more than half of which came from the Russian Federation's stockpiles. Another important supply source has been from dismantled nuclear weaponry. Additionally, the re-enrichment of tails from the enrichment of uranium, the use of mixed oxide (MOX) fuel and the reprocessing of uranium have all supplemented the supply.

On the **Nuclear power** generation side, it is reported that there has been a virtual stagnation in the number of nuclear power plants in North America and Western Europe, a slow growth in Eastern Europe and an expansion in East Asia. Both the International Energy Agency (IEA) and the International Atomic Energy Agency (IAEA) expect that in the coming two decades the current and new additions in Asia and in countries with economies in transition would roughly balance those being retired. Major recent developments include the significant economic advantage of fully depreciated nuclear power plants, which encourages life extension programmes in liberalised power markets such as the US; moves towards earlier closures of nuclear power plants by anti-nuclear governments in Europe; the shorter construction periods and lower operating costs of recent standardised plants, as in France, Japan and the Republic of Korea; important steps taken towards nuclear waste disposal in the USA, Sweden and Finland and ongoing worldwide efforts to develop new reactor technologies, evolutionary and innovative reactor designs . Nuclear is expected to play an important role in ensuring secure and sustainable electricity supply and in reducing global greenhouse gas emissions.

Hydropower accounts for 19% of the world electricity supply, utilising one third of its economically exploitable potential. Hydro projects have the advantage of avoiding emissions of greenhouse gases, SO_2 and particulates. Their social impacts, such as land transformation, displacement of people, and impacts on fauna, flora, sedimentation and water quality can be mitigated by taking appropriate steps early in the planning process. Whilst a question remains over the advantage of smaller hydro schemes over larger ones (owing to the former's greater total reservoir area requirement), it is believed that generally hydro power is competitive, when all factors are taken into account.

The production of **Woodfuels** is estimated to cover nearly 6% of the world energy requirement, although there are undoubtedly some difficulties in quantification. Woodfuels' share is thus larger than that of hydro and other renewable energy resources, but smaller than that of nuclear. A re-evaluation of woodfuels has shown that considerable amounts are now estimated to come from non-forest sources. Woodfuels continue to be used traditionally in rural areas of developing countries where they remain a burden for women and children to collect and, owing to their incomplete and inefficient combustion, also hazardous to health. Whilst rising income levels and urbanisation in developing countries have resulted in a reduced share of woodfuels in their overall energy use, changes in energy and environmental policies, such as global warming mitigation, in developed countries have led to an increased use of woodfuels, often as modern biomass. A special Report on Emissions Scenarios produced by the Intergovernmental Panel on Climate Change (IPCC) has concluded that although the longer-term maximum technical energy potential of biomass could be large (around 2 600 EJ), this potential is constrained by competing agricultural demands for food production, low productivity in biomass production, etc.

Despite a growing interest in **Biomass (other than wood)**, as a result of energy market reforms, environmental concerns, and technological advances, the major remaining challenges are the low combustion efficiency and health hazards associated with traditional use of bio-energy. Because of the many difficulties in assessing the energy potential of residues, it is suggested that the focus should be on the most successful forms such as sugar cane bagasse in agriculture, pulp and paper residues in forestry and manure in livestock residues. The modernisation of biomass use relates to a range of technological options, such as gasification, co-firing with fossil fuels, micro-power, tri-generation, and ethanol. It is argued that biomass can directly substitute fossil fuels, as more effective in decreasing atmospheric CO_2 than carbon sequestration in trees. The Kyoto Protocol encourages further use of biomass energy.

The **Solar energy** commentary states that raising the contribution of solar and other renewable resources to 50% of world energy use by 2050, as suggested in the Shell Renewables report, would require sweeping changes in the energy infrastructure, a new approach to the environment and the way that energy is generated and used. Despite the development of modern solar energy over the past forty or fifty years, the technology still needs a higher profile and more involvement from scientists, engineers, environmentalists, entrepreneurs, financial experts, publishers, architects, politicians and civil servants. A new generation of solar-energy pioneers has to be nurtured.

Since the 1998 Survey there has been an increase in world **Geothermal** plant capacity and utilisation, for both power generation and direct heat supply, but the pace of growth in power generation has slowed compared to the past, while that of direct heat uses has accelerated. Over-exploitation of the giant Geysers steam field has caused a decline in geothermal capacity in the USA in recent years, which has been partly offset by important capacity additions in other countries. A large increase in the number of geothermal (ground-source) heat pumps has contributed to the increase in direct heat application. Although the short- to medium-term future of geothermal energy looks encouraging, its long-range prospects depend on the technological and economic viability of rock heat (HDR).

There has been a steady growth in the size and output of **Wind** turbines, now available with capacities of up to 3 MW for offshore machines. The support provided by national governments influences development patterns: for example, wind farms in the USA and the United Kingdom and single machines (or clusters of two or three) in Denmark and Germany. Environmental issues surrounding wind energy pertain to noise, television and radio interference, danger to birds, and visual effects, but in many cases, sensitive siting can solve these problems. Many utility studies have indicated that wind can be readily absorbed in an integrated power network until its share reaches 20% of maximum demand. It is expected that due to the rapid capacity growth in many countries and regions, global installed wind capacity may reach 150 GW by 2010, depending on political support, both nationally and internationally, and further improvements in performance and costs.

The 2001 Survey portrays a broadly similar picture as other recent WEC Surveys. It continues to report the adequacy of the world's total energy resource base and highlights the implications of environmental concerns, especially those over carbon dioxide and other greenhouse gas emissions, for each fuel. The global trend of increased energy sector competition, promoted by regulatory reforms such as privatisation of public energy services, is becoming an important factor in the choice of preferred fuel in many countries and regions.

Keiichi Yokobori
Chairman
Survey of Energy Resources Committee
Tokyo

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Chapter 1

COAL (INCLUDING LIGNITE)

In writing the commentary to accompany the latest analysis of proved recoverable reserves of coal, there is the opportunity to provide a narrative that deals with the results on two very distinct levels. On one level, a review in terms of reserves, their location, notable reassessments from past surveys and the relationship between reserves and production/consumption, regional balance and trade flows.

But there is also a broader debate … what do ‘proved recoverable reserves of coal’ mean in terms of energy resources for today and tomorrow, in terms of energy availability and coal use?

We have seen some very significant changes within the coal industry since the last WEC Survey published in September 1998. Many of these changes reflect broader global issues, including trade competitiveness, global concentration, and market restructuring (particularly at country level, with continuing shifts from command to market economies for some major players).

The point was made in the 1998 Survey that the size of the resource base is not the restraining factor for coal to be able to continue supplying a considerable portion of world primary energy demand. At that time the restraining factor on coal’s participation in the supply of the world’s primary energy demand was identified as a question of the development of production facilities and infrastructure.

Looking now both with hindsight and from an assessment of the contemporary policy setting, the issues currently facing coal are much more in the context of international, regional and national environmental policy conditions relating to the use of coal.

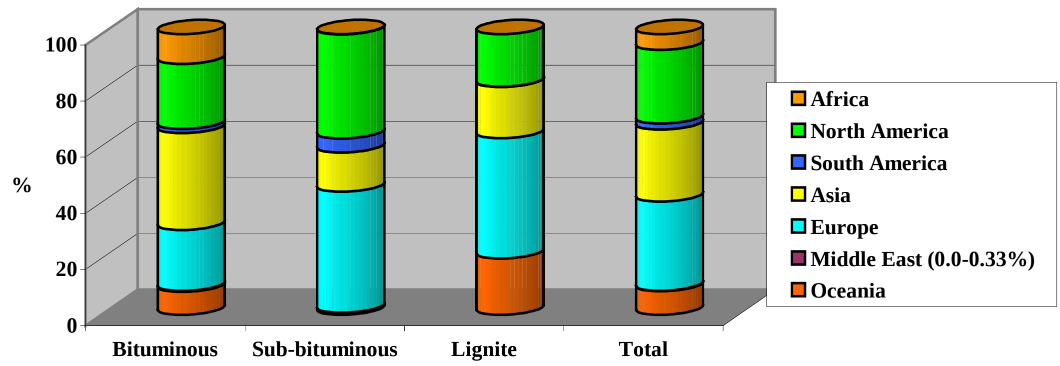
In dealing with the specific reserves of coal, there is little change in the total world figures, just a slight overall increase on the previous Survey. This is a predictable outcome, given the maturity of the industry and the large amount of reserves relative to current rates of exploitation. The rough and ready explanation of a production level showing that exploitation can continue at current levels in excess of 200 years is correct in arithmetic terms, but of little consequence or value given the size of this number. The world is not going to run out of physically-available supplies of coal.

Any limit on coal use will not be imposed by a limit on the availability of physical resources of coal – but coal use could face limits and restrictions in the future which would affect the availability and price of energy. These changes in the relative market value of coal compared with other energy sources will impact on recoverable reserves when the economic impact is taken into account by individual countries when assessing their coal reserves.

Within the total world reserves, there was a slight adjustment between the three primary categories with the bituminous increasing by 2%, while sub-bituminous declined by 1% and lignite reserves by around 3% below the previous recorded levels.

The top ten countries accounted for 95% of the reserves of bituminous coal – which was equal to 53% of total coal reserves. These same ten countries also held over 85% of the sub-bituminous and lignite reserves. In total, these top ten countries on a reserves basis held just over 90% of the total reported coal reserves at the end of 1999.

Figure 1.1: Proved coal reserves at end-1999 - regional distribution



On a geographic basis, South America is the one continent with little in the way of coal reserves – only 2.2% of total reserves and only 1.5% of the bituminous reserves. Africa has less than 6% of total reserves with these reserves concentrated in the bituminous category and dominated by South Africa with about 90% of the total. Botswana and Zimbabwe have the only significant reserves outside South Africa.

Both North America and Asia have over 25% each of total reserves. While the reserves in North America are almost equally split between bituminous coal and sub-bituminous/lignite, Asia has a significantly higher proportion of reserves in the bituminous classification, accounting for around 35% of total bituminous reserves worldwide.

Total coal reserves held by Europe were slightly over 30% of the world total, while the individual categories show a higher share of world sub-bituminous and lignite reserves and a lower proportion of bituminous (22%).

European reserves are dominated by two countries: Germany (21%) and the Russian Federation (50%). In respect of bituminous reserves, Germany, Poland, Russian Federation and the Ukraine account for over 95% of the European total.

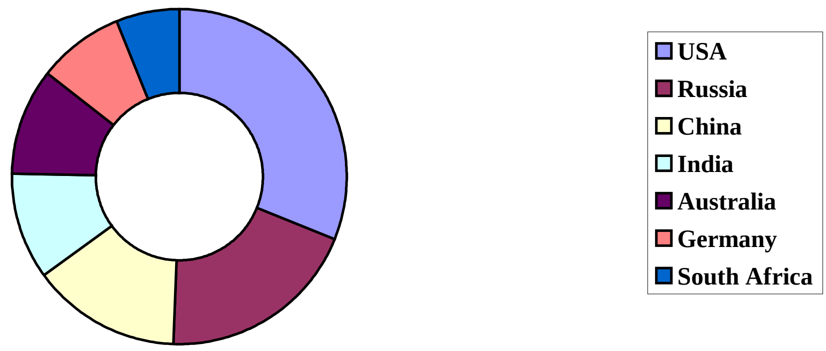
Significant changes between these results and those of the previous Survey are recorded by nine countries: Australia, Canada, Hungary, India, Poland, Romania, South Africa, Turkey, and the USA.

Poland recorded the largest increase in bituminous reserves over the previous Survey (68%), followed by India (13%), while US bituminous reserves increased by 4%.

South Africa's and Australia's bituminous reserves have both been reduced by 10%, whilst Canada's considerably smaller proved reserves have fallen 23%.

Hungary's reported reserves have been seriously downgraded to almost non-existent under the bituminous and sub-bituminous categories – and halved under the lignite category. In global terms, this adjustment by Hungary is not significant (previously accounting for less than 0.5% of total proved recoverable reserves of coal); however, at the national level, Hungary has now no reported bituminous reserves, with only small sub-bituminous reserves (80 million tonnes) and just over a billion tonnes of lignite.

Figure 1.2: Proved coal reserves at end-1999 - leading countries



Romania has also reported a very significant downgrading of its coal reserves which were concentrated in the sub-bituminous and lignite categories. This revision removes almost all reported reserves of sub-bituminous coal (from 810 Mt down to 35 Mt) and a halving of lignite reserves (2 800 Mt down to 1 421 Mt).

Turkey's reported proved recoverable reserves – mostly in the form of sub-bituminous coal and lignite – are now well over three times the level advised for the 1998 Survey.

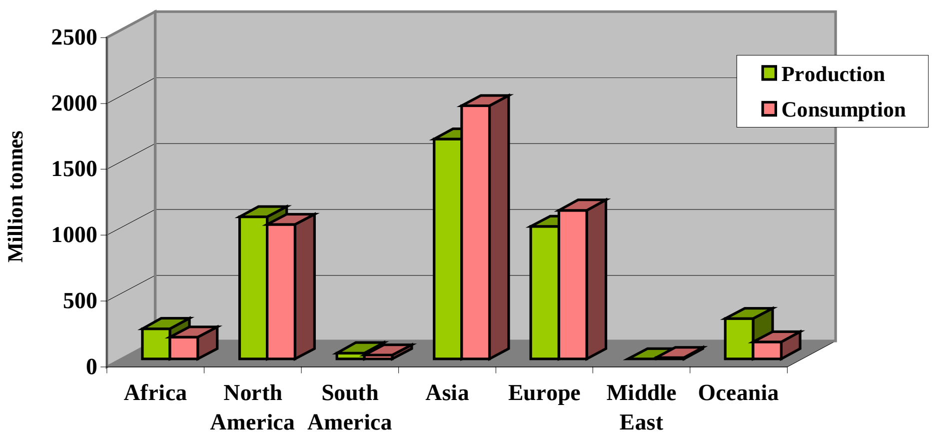
Looking beyond the issue of coal reserves, a number of the key indicators within the coal industry have shown significant change over the past three years.

Ownership of coal-producing enterprises has changed significantly. On one level, the trend which had just commenced in the second half of the last decade – the withdrawal of the oil majors from the strategic coal production investments undertaken in the wake of the oil shocks of the 1970's – turned into a flood of disposals. Very limited coal-producing assets remained in the hands of oil companies by the end of 2000. Of those assets remaining, most have been on the market, with the special circumstances of the individual assets being the primary reason for the failure to conclude this chapter in the history of coal in the hands of oil companies.

In addition to the departure of the oil majors from coal production, industry concentration has been pursued by a number of the major coal-producing companies. A number of global mining houses and global coal specialists increased their coal portfolio, taking advantage of the lower asset values reflecting the poor market returns for coal over the last decade, and encouraging many smaller operations to exit from the sector. Further industry concentration is expected to continue within the industry.

In the period since the 18th Survey, the most significant production adjustment has occurred in China. In 1997 Chinese hard coal production was 1 268 Mt; however, the 1999 Chinese output of hard coal was less than a billion tonnes. This reduction in production reflects the very significant restructuring being undertaken within the Chinese coal industry. This has resulted in a large number of small local pits being closed (estimated to be in excess of 40 000 over the last two years) – but at the same time, China has developed new high-volume open-cast coal operations to underpin both domestic and export supplies for the future.

Figure 1.3: Coal production and consumption, 1999 - regional distribution



The USA continues to expand production – now over 975 Mt per annum – but with less tonnage being made available to the export market. While tonnage traded bilaterally between USA and Canada remains a function of logistical advantage, USA seaborne coal exports have halved between 1996 and 2000, down to a new level of around 36 Mt. This is a reminder that the1 USA remains a ‘swing’ supplier with the export tonnage made available when favourable global market conditions prevail. In the later part of 2000, demand for energy in the USA domestic market had strengthened to such a level that coal spot prices were significantly above long-term contract price trends. This situation now raises questions over the future USA market conditions for coal, given the USA capacity to expand production if contract prices stimulate such a response.

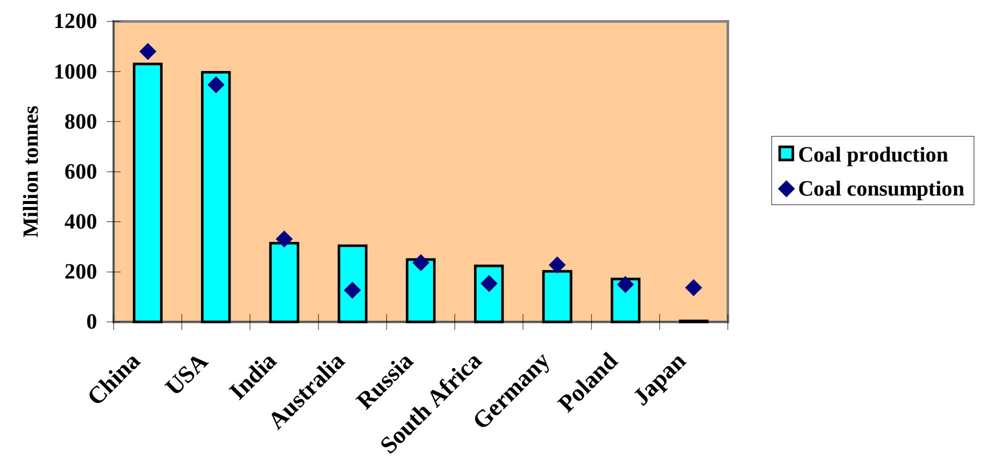
Traded coal on a global level continues to expand. While the long-term importers remain in the trade – and continue to increase demand – other countries have emerged as significant markets as their domestic coal industry is further exposed to a competitive coal market. Germany and the UK are notable in this group, along with Spain. But will this be a short- or long-term market opportunity with the environmental policies being sponsored by a number of the EU Member States?

Imports into the USA market are also growing, reflecting the availability of coal from Colombia to access some of the USA coastal regions.

This is a powerful reminder of the role of transport in the cost-competitive delivery of coal into most global markets and as a key factor in determining the export source of the coal.

The second half of the 1990's has seen the consolidation of China and Indonesia as two of the top five exporters, with around 10% of the global export market each.

Figure 1.4: Coal production and consumption, 1999 - leading countries



Specific attributes of some coals have also aided the development of coal production and heightened interest in reserves located in countries such as Indonesia. Low sulphur levels make many of the Indonesian coals commercially attractive to a global customer base required to meet ever-tightening SO_x emission levels.

This highlights the importance of a qualitative assessment of reserves that takes into account environmental issues which are still evolving on a global level. Different standards across different countries (from low to high) suggest reported reserves would also reflect these differences, to the degree that externalities have been and will be incorporated into the reserves assessment.

Allied to this is the work of the US Geological Survey (USGS) to create a reliable worldwide coal-quality and related information database. The goal for the World Coal Quality Inventory (WoCQI) is to generate reliable, internally consistent coal quality analyses for all major coal-producing countries.

Accurate information on coal, particularly information on coal properties and characteristics, is required to make informed decisions regarding the best use of indigenous resources, international import needs and export opportunities, domestic and foreign policy objectives, technology transfer opportunities, foreign investment prospects, environmental and health assessments, and by-product use and disposal issues. Further information is available at: http://pubs.usgs.gov/factsheet/fs155-00/

The two major uses for coal – steel production and electricity generation – continue to be at the heart of development for most countries seeking economic growth. Coal supplies around 23% of the total global primary energy demand, around 38% of total world electricity production and is an essential input for steel production via the BOF process, which accounts for almost 70% of total world steel production.

But will this remain … what are the risks and constraints facing coal in continuing a ‘business-as-usual’ outlook?

The year 2000 took energy – and the users of this resource – on the next phase of the combined political and economic roller coaster. At the mid-point of 2000, North Sea Brent crude oil was quoted at US$ 30.18 (27 June), an 80% increase over the price one year earlier.

Coal prices, particularly in the spot and short-term market, have moved strongly upwards as the oil price has remained in the US$ mid-twenties band, encouraging fuel switching away from oil and gas where the energy market has the capacity to substitute fuel inputs or energy sources. The skyrocketing of natural gas prices stimulated demand for coal in a market with considerable coal-burning capacity.

The good news is that coal has been available to respond to the market situation …flexibility still remains in the “system” to switch fuels in many countries. Coal-fired generating capacity was available to enable fuel substitution to occur to alleviate the market pressure. However, this option is being slowly closed off in a number of important European markets as coal-fired electricity capacity is taken out of service.

Will the coal option continue to be available to respond in the future under similar circumstances?

For the coal production side of the debate, the answer is simple: medium- and long-term availability of coal for the international market is assured, with a diverse range of sources and suppliers.

But the delivery and use of coal will rely on other elements of the overall electricity production chain – and, importantly, the policy conditions under which markets will be required to operate at the regional and national levels.

What are the factors – political, economic, environmental and social – that will affect coal’s future involvement in the energy market?

Deregulation of markets and the establishment of new, higher hurdles of environmental performance have been found to be fun and rewarding in the playground of energy surplus, which is the circumstance of most developed countries. It is not a luxury available to, or shared by, many countries seeking to enhance living conditions and standards to a basic level for all citizens.

Where deregulation of the electricity markets has been undertaken or commenced in developed countries, the market has always featured adequate or excess generating capacity (including reserve capacity). This makes life simple in the short- and medium-term and creates unrealistic expectations for the future. Future capacity investments are not certain and will rely on major firms being created out of market concentration to be able to absorb/cover the financial/commercial risks of such developments, guaranteeing oligopolistic behaviour at best within the ‘deregulated’ market in the future.

Can governments ‘pick and choose’ the energy mix they want based on their goal for achieving certain environmental outcomes? The political issue of climate change and the desire of some governments to reduce greenhouse gas (GHG) emissions is an area of great potential change for energy, and for coal in particular.

The coal industry – production and consumption – will change because of the emerging political circumstances and new market conditions. Coal will need to reduce its *environmental footprint*.

Some countries have introduced (or indicated their intention to introduce in the near future) support policies for alternative energy sources and mandated energy market shares for coal’s competitors.

Coal is the most carbon-intensive of the fossil fuels at the point of combustion. Improved coal technology and efficiency are consistent with the GHG objectives of the United Nations Framework Convention on Climate Change (UNFCCC) (and the Kyoto Protocol) and can provide significant benefits, in both developed and developing countries. Deployment of these technologies will support the continuation of coal in the global energy mix.

Technology can deliver solutions to the GHG emissions for coal – significant research is now focussed on the challenges of tomorrow. Advanced technologies are being pursued for the conversion of coal into energy - and to enhance the capture and sequestering of carbon by-products.

The US Department of Energy (DOE) has a major research programme to develop new carbon sequestration technologies, which capture and store gases that enhance the natural "greenhouse effect." The DOE programme objective is to reduce the expense of carbon sequestration to US$ 10 or less per ton by 2015, equivalent to about one US cent per kilowatt hour on the average electricity bill.

Technology advances will ensure coal remains a critical part of the energy equation. Other policy and market responses will underwrite low-cost measures to address the environmental issues of climate change and GHG emissions to the atmosphere.

Coal will remain part of the energy resource endowment, possibly with a greater role in energy delivery as a key element of the ‘energy bridge’ to the future under the conditions of sustainable development. The World Energy Assessment[*] recently highlighted the global energy challenge to provide greater access to clean and affordable fuels and electricity to the two billion people still dependent on traditional fuels with serious health consequences. Coal can assist in meeting this challenge – with cleaner technologies ensuring both that energy needs can be satisfied and improved environmental outcomes attained.

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[*] World Energy Assessment – an initiative of the UN Development Programme (UNDP), the UN Department of Economic and Social Affairs (UNDESA) and the World Energy Council (WEC)

DEFINITIONS

Proved amount in place is the tonnage that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology.

Maximum depth of deposits and **minimum seam thickness** relate to proved amount in place.

Proved recoverable reserves are the tonnage within the proved amount in place that can be recovered (extracted from the earth in raw form) under present and expected local economic conditions with existing available technology.

Estimated additional amount in place is the indicated and inferred tonnage *additional* to the proved amount in place. It includes estimates of amounts which could exist in unexplored extensions of known deposits or in undiscovered deposits in known coal-bearing areas, as well as amounts inferred through knowledge of favourable geological conditions. Speculative amounts are not included.

Estimated additional reserves recoverable is the tonnage within the estimated additional amount in place which geological and engineering information indicates with reasonable certainty might be recovered in the future.

TABLE NOTES

The tables cover bituminous coal (including anthracite), sub-bituminous coal and lignite. Data for peat are given in Chapter 8. There is no universally accepted system of demarcation between coals of different rank and what is regarded as sub-bituminous coal tends to vary from one country to another. Moreover, if it is not isolated as such, sub-bituminous is sometimes included with bituminous and sometimes with lignite.

There are no internationally agreed standards for estimating coal reserves and, although the WEC attempts to establish precisely worded definitions, it is a matter of judgement for each country to determine the quantities that, in its opinion, meet these definitions.

Table 1.1 Coal: proved recoverable reserves at end-1999

Excel files

	million tonnes			
	Bituminous including anthracite	**Sub-bituminous**	**Lignite**	**TOTAL**
Algeria	40			40
Botswana	4 300			4 300
Central African Republic			3	3
Congo (Democratic Rep.)	88			88
Egypt (Arab Rep.)		22		22
Malawi		2		2
Morocco	N			N
Mozambique	212			212
Niger	70			70
Nigeria	21	169		190
South Africa	49 520			49 520
Swaziland	208			208
Tanzania	200			200
Zambia	10			10
Zimbabwe	502			502
Total Africa	**55 171**	**193**	**3**	**55 367**
Canada	3 471	871	2 236	6 578
Greenland		183		183
Mexico	860	300	51	1 211
United States of America	115 891	101 021	33 082	249 994
Total North America	**120 222**	**102 375**	**35 369**	**257 966**
Argentina		430		430
Bolivia	1			1
Brazil		11 929		11 929
Chile	31	1 150		1 181
Colombia	6 267	381		6 648
Ecuador			24	24
Peru	960		100	1 060
Venezuela	479			479
Total South America	**7 738**	**13 890**	**124**	**21 752**
Afghanistan	66			66
China	62 200	33 700	18 600	114 500
India	82 396		2 000	84 396
Indonesia	790	1 430	3 150	5 370
Japan	773			773
Kazakhstan	31 000		3 000	34 000
Korea (Democratic People's Rep.)	300	300		600
Korea (Republic)	78			78
Kyrgyzstan			812	812
Malaysia	4			4
Mongolia				
Myanmar (Burma)	2			2
Nepal	2			2
Pakistan		2 265		2 265
Philippines		232	100	332
Taiwan, China	1			1
Thailand			1 268	1 268
Turkey	278	761	2 650	3 689
Uzbekistan	1 000		3 000	4 000
Vietnam	150			150
Total Asia	**179 040**	**38 688**	**34 580**	**252 308**

Table 1.1 Coal: proved recoverable reserves at end-1999 contd.

	million tonnes			
	Bituminous including anthracite	**Sub-bituminous**	**Lignite**	**TOTAL**
Albania				
Austria			25	25
Bulgaria	13	233	2 465	2 711
Croatia	6		33	39
Czech Republic	2 114	3 414	150	5 678
France	22		14	36
Germany	23 000		43 000	66 000
Greece			2 874	2 874
Hungary		80	1 017	1 097
Ireland	14			14
Italy		27	7	34
Netherlands	497			497
Norway		1		1
Poland	20 300		1 860	22 160
Portugal	3		33	36
Romania	1	35	1 421	1 457
Russian Federation	49 088	97 472	10 450	157 010
Serbia, Montenegro	64	1 460	14 732	16 256
Slovakia			172	172
Slovenia		40	235	275
Spain	200	400	60	660
Sweden		1		1
Ukraine	16 274	15 946	1 933	34 153
United Kingdom	1 000		500	1 500
Total Europe	**112 596**	**119 109**	**80 981**	**312 686**
Iran (Islamic Rep.)	1 710			1 710
Total Middle East	**1 710**			**1 710**
Australia	42 550	1 840	37 700	82 090
New Caledonia	2			2
New Zealand	33	206	333	572
Total Oceania	**42 585**	**2 046**	**38 033**	**82 664**
TOTAL WORLD	**519 062**	**276 301**	**189 090**	**984 453**

Notes:
1. A quantification of proved recoverable reserves for Mongolia and Albania is not available
2. The data shown against Serbia, Montenegro include reserves in Bosnia-Herzogovina and the Former Yugoslav Republic of Macedonia
3. Sources: WEC Member Committees, 2000/2001; data reported for previous WEC Surveys of Energy Resources; national and international published sources

Table 1.2i Bituminous coal (including anthracite): resources at end-1999

Excel files	Proved amount in place			Estimated additional	
	Tonnage	Maximum depth of deposits	Minimum seam thickness	Amount in place	Reserves recoverable
	million tonnes	metres	metres	million tonnes	million tonnes
Africa					
South Africa	115 515	350	1.0		
Swaziland	567	550	1.0	450	
North America					
Canada	4 609	1 200	0.6	92 224	62 445
United States of America	250 482	671	0.3	445 346	
South America					
Argentina	4				
Chile	64			1	
Venezuela	1 308			6 955	
Asia					
Japan	8 265				
Korea (Republic)	132	1 000	0.6	393	126
Taiwan, China	100	800	0.4		
Turkey	428	1 200	0.8	698	209
Europe					
Austria	1				
Croatia	4				
Czech Republic	7 231	1 600	0.6		6 961
France	160	1 300	1.0		
Germany	44 000	1 500	1.0	186 000	
Hungary	13	900	0.4	1 582	1 965
Netherlands	1 406	1 500	0.8	2 750	1 375
Poland	50 900	1 000	1.0		
Romania	1			N	
Spain	1 300	1 200	0.5	3 000	200
Ukraine	21 699	1 800	0.5	5 423	
Oceania					
Australia	62 240	600	0.3	125 000	75 000
New Zealand	45			942	313

Notes:
1. The data on resources are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Sources: WEC Member Committees, 2000/2001

Table 1.2ii Sub-bituminous coal: resources at end-1999

Excel files	Proved amount in place			Estimated additional	
	Tonnage	Maximum depth of deposits	Minimum seam thickness	Amount in place	Reserves recoverable
	million tonnes	metres	metres	million tonnes	million tonnes
North America					
Canada	1 153	300	1.5	48 764	15 165
Greenland	183	550		200	100
United States of America	167 087	305	1.5	273 593	
South America					
Argentina	700	800	0.5		
Brazil	17 051	870	0.5	15 319	7 660
Chile	91				
Asia					
Pakistan	3 775		0.3	99 490	
Philippines	305	300	0.6		
Turkey	1 526	828	0.1	202	
Europe					
Czech Republic	1 957	500	2.0		4 267
Hungary	622	600	0.8	2 578	1 766
Italy	60	500	1.4	280	
Norway	55	450	0.6		
Romania	991			174	
Slovenia	57	190	10.0		
Spain	800	200	0.8	1 600	500
Sweden	4	15	0.5	20	
Ukraine	21 261	1 800	0.6	5 502	
Oceania					
Australia	2 620	200	1.5	27 800	21 200
New Zealand	376			2 085	682

Notes:
1. The data on resources are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Sources: WEC Member Committees, 2000/2001

Table 1.2iii Lignite: resources at end-1999

Excel files	Proved amount in place			Estimated additional	
	Tonnage	Maximum depth of deposits	Minimum seam thickness	Amount in place	Reserves recoverable
	million tonnes	metres	metres	million tonnes	million tonnes
North America					
Canada	2 961	50	1.5	51 034	42 115
United States of America	39 934	61	0.8	393 822	
South America					
Argentina	7 350				
Asia					
Philippines	118	100	0.6		
Thailand	1 391	500	3.0	760	
Turkey	4 535	492	0.1	80	
Europe					
Austria	340				
Croatia	41				
Czech Republic	623	130	1.5		240
France	114	1 000	1.0		
Germany	78 000	600	2.0		
Hungary	1 361	80	1.0	3 245	1 041
Italy	15	150	3.0	22	20
Poland	13 600	350	3.0		
Romania	2 500			4 641	
Slovakia					389
Slovenia	602	547	8.0		
Spain	60	50	0.5		
Ukraine	2 578	400	2.7	320	
Oceania					
Australia	41 900	300	3.0	175 300	157 800
New Zealand	2 297			9 817	7 078

Notes:
1. The data on resources are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Sources: WEC Member Committees, 2000/2001

Table 1.3 Coal: 1999 production

Excel files

	thousand tonnes			
	Bituminous	**Sub-bituminous**	**Lignite**	**Total**
Algeria	25			25
Botswana	945			945
Congo (Democratic Rep.)	50			50
Egypt	200			200
Malawi		44		44
Morocco	129			129
Mozambique	18			18
Niger	168			168
Nigeria		20		20
South Africa	223 510			223 510
Swaziland	426			426
Tanzania	5			5
Zambia	128			128
Zimbabwe	4 977			4 977
Total Africa	**230 581**	**64**		**230 645**
Canada	36 538	24 300	11 659	72 497
Mexico	2 366	7 678		10 044
United States of America	568 260	352 260	76 570	997 090
Total North America	**607 164**	**384 238**	**88 229**	**1 079 631**
Argentina	337			337
Brazil	5 602			5 602
Chile	170	470		640
Colombia	32 754			32 754
Peru	20			20
Venezuela	6 500			6 500
Total South America	**45 383**	**470**		**45 853**
Afghanistan	2			2
Bhutan	50			50
China	985 000		45 000	1 030 000
Georgia	12			12
India	292 203		22 212	314 415
Indonesia	70 703			70 703
Japan	3 906			3 906
Kazakhstan	56 436		1 763	58 199
Korea (Democratic People's Rep.)	60 000	21 500		81 500
Korea (Republic)		4 197		4 197
Kyrgyzstan	135		280	415
Laos	202			202
Malaysia		309		309
Mongolia	1 423		3 529	4 952
Myanmar (Burma)	13		27	40
Nepal			9	9
Pakistan		3 307		3 307
Philippines		1 028		1 028
Taiwan, China	90			90
Tajikistan		19		19
Thailand			18 270	18 270
Turkey	1 990		65 050	67 040
Uzbekistan	89		2 864	2 953
Vietnam	8 830			8 830
Total Asia	**1 481 084**	**30 360**	**159 004**	**1 670 448**

Table 1.3 Coal: 1999 production contd.

	thousand tonnes			
	Bituminous	**Sub-bituminous**	**Lignite**	**Total**
Albania			33	33
Austria			1 137	1 137
Bosnia-Herzogovina			1 850	1 850
Bulgaria	90		25 940	26 030
Croatia	15			15
Czech Republic	14 419	44 278	512	59 209
FYR Macedonia			8 400	8 400
France	4 533		558	5 091
Germany	40 500		161 282	201 782
Greece			61 900	61 900
Hungary	700	6 500	7 700	14 900
Italy			19	19
Norway		400		400
Poland	110 200		60 800	171 000
Romania	N	2 751	20 131	22 882
Russian Federation	166 000		83 400	249 400
Serbia, Montenegro	49		30 451	30 500
Slovakia			3 748	3 748
Slovenia		758	3 804	4 562
Spain	13 200	3 700	8 500	25 400
Ukraine	34 871	46 176	1 182	82 229
United Kingdom	37 077			37 077
Total Europe	**421 654**	**104 563**	**481 347**	**1 007 564**
Iran (Islamic Rep.)	1 500			1 500
Total Middle East	**1 500**			**1 500**
Australia	222 000	16 200	65 800	304 000
New Zealand	1 630	1 670	210	3 510
Total Oceania	**223 630**	**17 870**	**66 010**	**307 510**
TOTAL WORLD	**3 010 996**	**537 565**	**794 590**	**4 343 151**

Notes:
1. Sources: WEC Member Committees, 2000/2001; BP Statistical Review of World Energy 2001; Energy - Monthly Statistics, Eurostat; World Mineral Statistics 1995-1999, British Geological Survey; national sources; estimates by the editors

Table 1.4 Coal: 1999 consumption

Excel files

	thousand tonnes			
	Bituminous	Sub-bituminous	Lignite	Total
Algeria	490			490
Botswana	945			945
Congo (Democratic Rep.)	100			100
Egypt (Arab Rep.)	2 000			2 000
Ghana	3			3
Kenya	100			100
Libya /GSPLAJ	5			5
Madagascar	14			14
Malawi	17			17
Mauritania	6			6
Mauritius	75			75
Morocco	3 200			3 200
Niger	168			168
Nigeria		20		20
South Africa	153 460			153 460
Swaziland	180			180
Tanzania	5			5
Tunisia	1			1
Zambia	121			121
Zimbabwe	4 750			4 750
Total Africa	**165 640**	**20**		**165 660**
Canada	23 700	26 600	10 200	60 500
Cuba	20			20
Dominican Republic	160			160
Jamaica	25			25
Mexico	2 716	9 469		12 185
Panama	65			65
Puerto Rico	185			185
United States of America	520 800	350 000	76 600	947 400
US Virgin Islands	260			260
Total North America	**547 931**	**386 069**	**86 800**	**1 020 800**
Argentina	1 300			1 300
Brazil	12 286	6 690		18 976
Chile	4 130	870		5 000
Colombia	4 200			4 200
Peru	500			500
Venezuela	164			164
Total South America	**22 580**	**7 560**		**30 140**
Afghanistan	2			2
Armenia	5			5
Azerbaijan	1			1
Bangladesh	300			300
Bhutan	75			75
China	1 035 000		45 000	1 080 000
Cyprus	20			20
Georgia	25			25
Hong Kong, China	6 393			6 393
India	308 160		22 200	330 360
Indonesia	17 000			17 000
Japan	137 000			137 000
Kazakhstan	41 650		1 600	43 250
Korea (Democratic People's Rep.)	61 680	21 500		83 180
Korea (Republic)	54 137	4 992		59 129

Table 1.4 Coal: 1999 consumption contd.

	thousand tonnes			
	Bituminous	**Sub-bituminous**	**Lignite**	**Total**
Kyrgyzstan	350		350	700
Malaysia	1 150	1 500		2 650
Mongolia	1 500		3 200	4 700
Myanmar (Burma)	16		27	43
Nepal	300			300
Pakistan		4 370		4 370
Philippines		6 416		6 416
Sri Lanka	1			1
Taiwan, China	40 023			40 023
Tajikistan	100	19		119
Thailand	3 230		18 840	22 070
Turkey	11 200		64 080	75 280
Uzbekistan	1 150		2 850	4 000
Vietnam	5 500			5 500
Total Asia	**1 725 968**	**38 797**	**158 147**	**1 922 912**
Albania			33	33
Austria	3 440		1 640	5 080
Belarus	200			200
Belgium	9 710	310		10 020
Bosnia-Herzogovina			1 850	1 850
Bulgaria	3 400		25 940	29 340
Croatia	284		81	365
Czech Republic	10 402	41 454	512	52 368
Denmark	7 804			7 804
Estonia	80			80
Finland	5 368			5 368
FYR Macedonia	250		8 400	8 650
France	22 416		612	23 028
Germany	64 500		163 335	227 835
Greece	1 382		61 000	62 382
Hungary	1 400	6 500	7 700	15 600
Iceland	100			100
Ireland	1 839		40	1 879
Italy	17 100	N	N	17 100
Latvia	126			126
Lithuania	200			200
Luxembourg	151			151
Moldova	500			500
Netherlands	11 800			11 800
Norway		2 100		2 100
Poland	89 000		60 800	149 800
Portugal	5 000			5 000
Romania	2 411	2 752	20 131	25 294
Russian Federation	154 000		83 000	237 000
Serbia, Montenegro	100		30 400	30 500
Slovakia	12 282		5 042	17 324
Slovenia	80	1 237	3 770	5 087
Spain	28 200	17 400	8 500	54 100
Sweden	3 000			3 000
Switzerland	140			140
Ukraine	61 785		1 240	63 025
United Kingdom	55 529			55 529
Total Europe	**573 979**	**71 753**	**484 026**	**1 129 758**

Table 1.4 Coal: 1999 consumption contd.

	thousand tonnes			
	Bituminous	Sub-bituminous	Lignite	Total
Iran (Islamic Rep.)	1 900			1 900
Israel	9 200			9 200
Lebanon	200			200
Total Middle East	**11 300**			**11 300**
Australia	44 900	16 200	65 800	126 900
Fiji	24			24
New Caledonia	170			170
New Zealand	230	1 660	260	2 150
Papua New Guinea	1			1
Total Oceania	**45 325**	**17 860**	**66 060**	**129 245**
TOTAL WORLD	**3 092 723**	**522 059**	**795 033**	**4 409 815**

Notes:
1. Sources: WEC Member Committees, 2000/2001; BP Statistical Review of World Energy 2001; Energy - Monthly Statistics, Eurostat; national sources; estimates by the editors

COUNTRY NOTES

The following Country Notes on coal have been compiled by the editors, drawing upon a wide variety of material, including information received from WEC Member Committees, national and international publications.

Major international published sources consulted included:

- *Energy Balances of OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Energy Balances of Non-OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Major coalfields of the world*; June 2000; IEA Coal Research.

AUSTRALIA

Proved amount in place (total coal, million tonnes)	106 760
Proved recoverable reserves (total coal, million tonnes)	82 090
Production (total coal, million tonnes, 1999)	304.0

Australia is endowed with substantial coal resources, with its proved recoverable reserves ranking fifth in the world. The major deposits of black coal (bituminous and sub-bituminous) are located in New South Wales and Queensland; smaller but locally important resources occur in Western Australia, South Australia and Tasmania. The main deposits of brown coal are in Victoria, the only State producing this rank. Other brown coal resources are present in Western Australia, South Australia and Tasmania.

The proved amount of coal in place, reported for the present Survey by the Australian Geological Survey Organisation (AGSO), comprises 62.2 billion tonnes of bituminous coal, 2.6 billion tonnes of sub-bituminous and 41.9 billion tonnes of brown coal/lignite. Within these tonnages, the proportion deemed to be recoverable ranges from 68% of the bituminous coal (with 48% of its reserves surface-mineable) to 90% of the lignite, all of which is suitable for open-cast mining. About one-third of Australia's massive reserves of bituminous coal are of coking quality.

Indicated and inferred tonnages, additional to the proved amount in place, are vast: AGSO's current assessment puts bituminous coal at 125 billion tonnes, sub-bituminous at nearly 28 billion tonnes and lignite at around 175 billion tonnes. In total, more than 250 billion tonnes of this additional coal is considered to be eventually recoverable.

In 1999 Australia produced 238 million tonnes of saleable black coal and 66 million tonnes of brown coal. The major domestic market for black coal is electricity generation: in 1998, power stations accounted for 81% of total black coal consumption, with the other large consumers being the iron and steel industry and cement manufacture. Brown coal is used almost entirely for power generation.

Australia has been the world's largest exporter of hard coal since 1984: in 1999, it exported 172 million tonnes. About 54% of 1999 exports were of metallurgical grade (coking coal), destined largely for Japan, the Republic of Korea and Europe.

BOTSWANA

Proved recoverable reserves (total coal, million tonnes)	4 300
Production (total coal, million tonnes, 1999)	0.9

Vast deposits of bituminous coal have been located in Botswana, principally in the eastern part of the country. Coalfields in Greater Morupule and Mmamabula have been studied in detail, their proven in-situ resources being established as some 2.9 billion tonnes and 4.3 billion tonnes, respectively. These assessments were based upon deposits to a maximum depth of 200-250 metres and a minimum seam thickness of 0.25 metres.

The only mine to have been developed so far is at Morupule, near the town of Palapye, where Morupule Colliery Limited (controlled by Anglo American Corporation) commenced coal extraction in 1973.

With cumulative output to the end of 1999 amounting to nearly 15 million tonnes, Botswana's remaining proved amount of coal in place is nearly 7 200 million tonnes; on an assumed average recovery factor of 60%, the theoretical proved recoverable reserves are some 4 300 million tonnes. The Morupule deposit accounts for about 40% of Botswana's measured coal resource, the balance being attributable to Mmamabula.

Over and above the proved amount in place, there is an estimated additional in-situ amount of some 205 billion tonnes, comprising 29 billion tonnes of "indicated" resources and 176 billion tonnes of "inferred" resources, covering all the major coalfields that have been explored in Botswana. It is not at present possible to provide an estimate of the recoverable portion of these indicated and inferred amounts.

The Morupule mine's chief customers are the Botswana Power Corporation, the copper/nickel mine at Selibe-Phikwe and the soda ash plant at Sua Pan. The BPC power station at Morupule (net capacity 118 MW) generates about half of Botswana's electricity supplies, the balance being provided by imports from South Africa.

BRAZIL

Proved amount in place (total coal, million tonnes)	17 051
Proved recoverable reserves (total coal, million tonnes)	11 929
Production (total coal, million tonnes, 1999)	5.6

Brazil has considerable reserves of sub-bituminous coal, mostly located in the southern states of Rio Grande do Sul, Santa Catarina and Paraná.

For the present Survey, the Brazilian WEC Member Committee has reported a proved amount in place (defined as covering measured, indicated and inferred reserves) of just over 17 billion tonnes, of which 70% is categorised as proved recoverable reserves. There is estimated to be some 15.3 billion tonnes of additional coal in place, of which 50% is considered to recoverable.

With respect to the stated level of proved recoverable reserves, it is estimated that 21% could be exploited through surface mining, and that 7% is considered to be of coking quality. In 1999, 50% of Brazilian coal production was obtained by surface mining.

Almost all of Brazil's current coal output is classified as steam coal, of which about 90% is used as power-station fuel and the remainder in industrial plants. Virtually all of Brazil's metallurgical coal is imported: about three-quarters is used as input for coke production.

CANADA

Proved amount in place (total coal, million tonnes)	8 723
Proved recoverable reserves (total coal, million tonnes)	6 578
Production (total coal, million tonnes, 1999)	72.5

Canada has considerable coal resources, with proved reserves of more than 6.5 billion tonnes. The first reassessment of resources that has been reported since the data provided for the 1992 *Survey of Energy Resources* results in substantially lower levels for the proved amount in place. Bituminous coals (including anthracite) are evaluated as 4.6 billion tonnes, based on deposits to a maximum depth of 1 200 metres and a minimum seam thickness of 0.6 metres; sub-bituminous grades are put at approximately 1.1 billion tonnes (maximum depth 300 metres, minimum thickness 1.5 metres); and lignite at 3.0 billion tonnes (maximum depth 50 metres, minimum thickness 1.5 metres). The proved recoverable reserves for each rank have been assessed as approximately 75% of the respective proved amount in place.

Estimates of the tonnages of coal (in-place and recoverable) that are considered to be additional to the "proved" amounts of each rank have been considerably increased: all six quantities now run into tens of billions of tonnes. Such numbers can never possess any high degree of accuracy, but they do serve to underline Canada's undoubtedly massive coal endowment.

Canada's coal resources are mainly located in the mid-to-western provinces of Saskatchewan, Alberta and British Columbia, with smaller deposits in the eastern provinces of Nova Scotia and New Brunswick. The first four named provinces are responsible for more than 98% of Canadian coal production. Bituminous deposits are found in the two eastern provinces, together with Alberta and British Columbia; Alberta also possesses sub-bituminous grades, while lignite deposits are found mainly in Saskatchewan.

Alberta is both the largest coal-producing and coal-consuming province; as in the other producing provinces, coal is mainly used for electricity generation. In total, more than 89% of Canadian coal production is used for electricity generation, about 8% for steel production and 3% for other industries, mainly cement.

Ontario, as the second largest coal consumer, conforms to the national pattern of usage. Consumption has increased in Ontario as a number of nuclear generating units have been shut down.

British Columbia produces mostly metallurgical coal, which is all exported (over 28 million tonnes in 1998).

The Canadian coal industry is almost entirely in private ownership; output is currently from large surface mines. Virtually all underground operations have now ceased.

CHINA

Proved recoverable reserves (total coal, million tonnes)	114 500
Production (total coal, million tonnes, 1999)	1 030.0

China is a major force in world coal, standing in the front rank in terms of reserves, production and consumption, and is rapidly increasing its significance as a coal exporter.

The levels of proved recoverable reserves originally provided by the Chinese WEC Member Committee for the 1992 Survey have been retained for each successive edition; in billions of tonnes, they amount to: bituminous coal and anthracite 62.2; sub-bituminous coal 33.7 and lignite 18.6.

Coal deposits have been located in most of China's regions but three-quarters of proved recoverable reserves are in the north and north-west, particularly in the provinces of Shanxi, Shaanxi and Inner Mongolia.

After more than twenty years of almost uninterrupted growth, China's coal production peaked at nearly 1.4 billion tonnes in 1996, since when output has fallen year-by-year, largely as a result of the closure of large numbers of small local mining operations. By far the greater part of output is of bituminous coal: lignite constitutes only about 4%.

The major coal-consuming sectors are power stations (including CHP), which accounted for nearly 50% of total consumption (excluding the coal industry's own use/loss) in 1998, the iron and steel industry with a 15% share, and other industrial users with about 25%.

Coal exports more than doubled between 1994 and 2000, when they exceeded 55 million tonnes; China is now the world's fifth largest coal exporter.

COLOMBIA

Proved recoverable reserves (total coal, million tonnes)	6 648
Production (total coal, million tonnes, 1999)	32.8

Colombia's vast coal resources are located in the north and west of the country. Published data on measured reserves (sourced from the state coal entity Ecocarbón, March 1998) indicated a total of 6 648 million tonnes, of which Cerrejón North and Central Zones account for 55% and the fields in the department of Cesar for 29%. Virtually all Colombia's coal resources fall into the bituminous category: the reserves in the San Jorge field in Córdoba, with an average calorific value in the sub-bituminous/lignite bracket, are shown under sub-bituminous in Table 1.1.

Development of Colombian coal for export has centred on the Cerrejón deposits which are located in the Guajira Peninsula in the far north, about 100 km inland from the Caribbean coast. The coal is found in the northern portion of a basin formed by the Cesar and Rancheria rivers; the deposit has been divided by the Government into the North, Central and South Zones. In October 1975 the Government opened international bidding for the development of El Cerrejón-North Zone reserves and in December 1976 Carbocol (then 100% owned by the Colombian State) and Intercor (an Exxon affiliate) entered into an Association Contract for the development and mining of the North Zone. The contract has three phases and covers a 33-year period with the production phase scheduled to end early in 2009.

Carbocol was privatised in October 2000, the purchasers being a consortium of Anglo-American, Billiton and Glencore.

Coal exports from Colombia totalled 29.9 million tonnes in 1999, equivalent to 91% of its coal production. Cerrejón North remains one of the world's largest export mines.

CZECH REPUBLIC

Proved amount in place (total coal, million tonnes)	9 811
Proved recoverable reserves (total coal, million tonnes)	5 678
Production (total coal, million tonnes, 1999)	59.2

The Czech Republic possesses sizeable coal resources, with a proved amount in place of nearly 10 billion tonnes, of which about 58% is reported to be economically recoverable. In terms of rank, 37% of the proved reserves are classified as bituminous, 60% as sub-bituminous and 3% as lignite.

Bituminous coal deposits are mainly in the Ostrava-Karviná basin in the east of the country, and lie within the Czech section of the Upper Silesian coalfield. The principal sub-bituminous/lignite basins are located in the regions of North and West Bohemia, close to the Krusne Hory (Ore Mountains) which constitute the republic's north-western border with Germany.

Since 1990, Czech output of bituminous coal has fallen by about 35%, to 14.4 million tonnes in 1999, whilst sub-bituminous/lignite has nearly halved, declining from 79 million tonnes in 1990 to less than 45 million tonnes in 1999. A substantial proportion (nearly 60%) of the republic's bituminous coal production consists of coking coal. In 1998, exports of bituminous and sub-bituminous coal amounted to 10.5 million tonnes, equivalent to just over 15% of production.

Apart from its coking coal, which is consumed by the iron and steel industry, most of the republic's bituminous coal is used for electricity and heat generation, with industrial and private consumers accounting for only modest proportions. This pattern of utilisation also applies to sub-bituminous coal, which is still the main power station fuel.

GERMANY

Proved amount in place (total coal, million tonnes)	122 000
Proved recoverable reserves (total coal, million tonnes)	66 000
Production (total coal, million tonnes, 1999)	201.8

Notwithstanding a reduction of 1 billion tonnes in the assessment of proved recoverable coal reserves by comparison with that reported for the previous (1998) Survey, Germany remains in the front rank for coal resources, reserves and production. The proved amount in place is stated to be 122 billion tonnes, including 44 billion tonnes of bituminous coals based on deposits to a maximum depth of 1 500 metres and a minimum seam thickness of 1 metre. Geological resources of lignite amount to 78 billion tonnes, with a maximum deposit depth of 600 metres and a minimum seam thickness of 2 metres. Mineable reserves, equated to the category of proved recoverable reserves, are reported as 23 billion tonnes of bituminous coal and 43 billion tonnes of lignite. Reserves within the reach of operating or planned mines would be considerably smaller – at some 8 billion tonnes in the case of the lignite deposits.

Germany’s output of hard coal has fallen from 76.6 million tonnes in 1990 to 40.5 million tonnes in 1999, whilst lignite production has declined even more rapidly, from 357.5 to 161.3 million tonnes over the same period.

The Ruhr coalfield produces over three-quarters of German hard coal. The coal qualities range from anthracite to high-volatile, strongly-caking bituminous coal. The Saar is the second largest coalfield, with substantial deposits of weakly-caking bituminous coal. All German hard coal is deep-mined from seams at depths exceeding 900 metres.

The lignite deposit in the Rhine region is the largest such formation in Europe. In the former East Germany there are major deposits of lignite at Halle Leipzig and Lower Lausitz; these have considerable domestic importance.

The principal markets for bituminous coal are electricity generation, iron and steel, and cement manufacture: other industrial and household uses are relatively modest. Almost all German lignite is consumed in power stations, apart from a considerable tonnage (12.4 million tonnes in 1998) which is converted into brown coal briquettes for the industrial, residential and commercial markets.

GREECE

Proved recoverable reserves (total coal, million tonnes)	2874
Production (total coal, million tonnes, 1999)	61.9

Coal resources are all in the form of lignite. Apart from a very small amount of private mining, all production is carried out by the mining division of the Public Power Corporation (DEI). There are two lignite centres, Ptolemais-Amynteo (LCPA) in the northern region of West Macedonia, and Megalopolis (LCM) in the southern region of Peloponnese. These two centres control the operations of seven open-cast mines; LCPA mines account for about 75% of DEI’s output of lignite.

In the lignite-mining areas, six dedicated power stations (total generating capacity: 4 850 MW) produce more than two-thirds of Greece’s electricity supply. In 1999, DEI mines produced 61 million tonnes of lignite, which was used to generate about 29 TWh of electricity. Two 330 MW lignite-fired power stations are planned for construction at Florina in the northern region of Western Macedonia.

Greece is the second largest producer of lignite in the European Union and amongst the six largest in the world.

INDIA

Proved recoverable reserves (total coal, million tonnes)	84 396
Production (total coal, million tonnes, 1999)	314.4

Coal is the most abundant fossil fuel resource in India and places the country in the top rank of world coal producers. The principal deposits of hard coal are in the eastern half of the country, ranging from Andhra Pradesh, bordering the Indian Ocean, to Arunachal Pradesh in the extreme north-east: the States of Bihar, Orissa, Madhya Pradesh and West Bengal together account for about 85% of reserves. In addition to 82.4 billion tonnes of proved reserves of bituminous coal, the Geological Survey of India states that there are 89.5 billion tonnes of indicated reserves and 39.7 billion tonnes of inferred reserves. Coking coals constitute 20% of the tonnage of proved reserves.

Lignite deposits mostly occur in the southern State of Tamil Nadu. India's geological resources of lignite are estimated to be around 30 billion tonnes, of which about 2 billion tonnes in the Neyveli area are regarded as "mineable under the presently adopted mining parameters", and taken as proved recoverable reserves in the present Survey. Annual production of lignite is currently in the region of 22 million tonnes, almost all of which is used for electricity generation.

Although India's coal reserves cover all ranks from lignite to bituminous, they tend to have a high ash content and a low calorific value. The low quality of much of its coal prevents India from being anything but a small exporter of coal (traditionally to the neighbouring countries of Bangladesh, Nepal and Bhutan) and conversely, is responsible for sizeable imports (around 10 million tonnes/year of coking coal and 6 million tonnes/year of steam coal) from Australia, China, Indonesia and South Africa.

Within the Ministry of Mines & Minerals, the Department of Coal has the overall responsibility for determining policies and strategies in respect of exploration and development of coal and lignite reserves. Under the administrative control of the Department, key functions are exercised through the public sector undertakings, namely Coal India and its subsidiaries and the Neyveli Lignite Corporation (essentially entrusted with the task of lignite production and associated power generation), and also through the Singareni Collieries Company (a joint sector undertaking of the Government of India and the Government of Andhra Pradesh).

Coal is the most important source of energy for electricity generation in India: about three-quarters of electricity is generated by coal-fired power stations. In addition, the steel, cement, fertiliser, chemical, paper and many other medium and small-scale industries are also major coal users. In the course of phasing out steam traction the direct demand for coal for rail transport has virtually disappeared.

INDONESIA

Proved recoverable reserves (total coal, million tonnes)	5 370
Production (total coal, million tonnes, 1999)	70.7

Indonesia possesses very substantial coal resources: according to recent data from the Directorate of Mineral and Coal Enterprises, measured resources total 11 569 million tonnes and indicated resources amount to a further 27 306 million tonnes. Within these huge tonnages, mineable reserves (taken as corresponding with proved recoverable reserves for the purposes of the present Survey) are given as 5 368 million tonnes, of which about 53% is located in Sumatra and 47% in Kalimantan.

A breakdown of mineable reserves by rank is not currently available from the Directorate of Mineral and Coal Enterprises; the allocation shown in Table 1.1 should be regarded as strictly provisional – it is based upon a breakdown of total coal resources issued by the Directorate of Coal in 1995, which showed lignite as accounting for 59% of coal deposits, sub-bituminous coal 27% and bituminous 14%, with anthracite representing less than 0.4% of the total.

Indonesian coals in production generally have medium calorific values (5 000-7 000 kcal/kg or 21-29 MJ/kg), with relatively high percentages of volatile matter; they benefit from low ash and sulphur contents, making them some of the cleanest coals in the world.

Competitive quality characteristics have secured substantial export markets for Indonesian coal: in 2000 over 58 million tonnes were shipped overseas, representing just over 75% of total coal output.

Within Indonesia, coal's main market is power generation, which accounted for 69% of internal consumption in 1998.

PAKISTAN

Proved recoverable reserves (total coal, million tonnes)	2 265
Production (total coal, million tonnes, 1999)	3.3

The republic's coal resources appear to be substantial: The Geological Survey of Pakistan (GSP) gives measured resources as 3 775 million tonnes, with indicated resources of a further 12 124 million tonnes, inferred resources of 87 366 and hypothetical resources as 81 391 million tonnes, as at June 30, 1999. The Pakistan WEC Member Committee considers that 60% of the measured resources should be regarded as proved recoverable reserves.

The discovery of a huge coalfield in the Thar Desert of eastern Sindh province transformed the country's coal resources and Thar now contributes 84% of the measured reserves. Under the auspices of an USAID programme which began in 1985, the field was located in the 1980's; in the early 1990's a drilling programme largely confirmed its extent.

Since issuing the end-June 1997 data quoted in the 1998 WEC Survey, the GSP has re-assessed the allocation of the Thar coal field's resource base, increasing its measured resources by 36%, indicated resources by 61% and inferred resources by 30%; overall some 24 billion tonnes have been transferred out of the "hypothetical" category, whilst maintaining the level of total resources.

Notwithstanding its massive potential, Pakistan's coal production in recent years has been only about 3-3.5 million tonnes per annum. About half is currently produced in the western province of Balochistan; no Thar coal is produced at present.

Small tonnages of indigenous coal are used for electricity generation and by households, but by far the largest portion is used to fire brick-kilns. Just over 1 million tonnes of Australian coking coal is imported each year for use in the iron and steel industry.

POLAND

Proved amount in place (total coal, million tonnes)	64 500
Proved recoverable reserves (total coal, million tonnes)	22 160
Production (total coal, million tonnes, 1999)	171.0

Most of Poland's substantial tonnage of coal resources is in the form of hard coal, which comprises 79% of the reported proved amount in place and nearly 92% of proved recoverable reserves. The WEC Member Committee has reported revised resource assessments by comparison with those advised for the 1998 *Survey of Energy Resources* with (in particular) a 15% reduction in the proved amount of bituminous coal in place and a 68% increase in the corresponding tonnage recoverable.

The latest figures show the proved amount of hard coal in place as almost 51 billion tonnes, on the basis of a maximum deposit depth of 1 000 metres and a minimum seam thickness of 1 metre; the corresponding level for lignite is 13.6 billion tonnes, at a maximum deposit depth of 350 metres and minimum seam thickness of 3 metres.

Poland's hard coal resources are mainly in the Upper Silesian Basin, which lies in the south-west of the country, straddling the border with the Czech Republic: about 80% of the basin is in Polish territory. Other hard-coal fields are located in the Lower Silesia and Lublin basins. There are a number of lignite deposits in central and western Poland, with four of the larger basins currently being exploited for production.

The quality of the Upper Silesian hard coals is generally quite high, with relatively low levels of sulphur and ash content. One-third of Poland's proved reserves of hard coal are regarded as of coking quality.

Although output of hard coal (and, to a lesser extent, of lignite) has declined during the past ten years, and especially since 1997, Poland is still among the world's eight largest coal producers (see Table 1.3). Its 1999 output was 110 million tonnes of hard coal and 61 million tonnes of lignite. Apart from Russia, Poland is the only world-class coal exporter in Europe: its total exports in 1999 were some 24 million tonnes, of which steam coal accounted for 72% and coking for 28%. Germany, Denmark and the UK are currently Poland's largest export markets for coal.

About 57% of inland consumption of hard coal goes to the production of electricity and bulk heat, manufacturing industry accounts for 30% and residential/commercial/agricultural uses 13%. Almost all lignite production is used for base-load electricity generation.

The decline in hard coal production reflects a deep reform of the industry, of which the key objectives have been:

- a reduction in excess production potential;
- substantially reduced employment levels;
- an increase in the quality of coal produced;
- gradual privatisation of the mines.

Lignite is produced from open-cast sites and constitutes the cheapest energy source in Poland. It is expected that lignite output will remain at the present level up to 2020.

RUSSIAN FEDERATION

Proved recoverable reserves (total coal, million tonnes)	157 010
Production (total coal, million tonnes, 1999)	249.4

The levels quoted for Russian coal resources and reserves are unchanged from those given in the 1998 *Survey of Energy Resources*, as the WEC Member Committee was unable to obtain any more recent coal data for the present Survey.

The proved amount of coal in place at end-1996 comprised 75.8 billion tonnes of bituminous coal, based on a maximum deposit depth of 1 200 metres and a minimum seam thickness of 0.6-0.7 metres; 113.3 billion tonnes of sub-bituminous grades (at depths of up to 600 metres and minimum thickness 1-2 metres); and 11.5 billion tonnes of lignite (at 300 metres and 1.5-2 metres, respectively).

Proved recoverable reserves were reported as just over 49 billion tonnes of bituminous coal, of which 23% was considered to be surface-mineable and 55% was suitable for coking. Of the 97.5 billion tonnes of proved recoverable reserves of sub-bituminous coal, 74% was suitable for surface mining, while all of the 10.5 billion tonnes of recoverable lignite reserves fell into this category. Overall, about 94 billion tonnes of Russia’s proved reserves were deemed to be recoverable by opencast or strip mining. Further enormous tonnages of coal, of the order of over 30 times the quoted proved reserves, were reported to be recoverable in the future.

Russian coal reserves are widely dispersed and occur in a number of major basins. These range from the Moscow basin in the far west to the eastern end of the Donetsk basin (most of which is within the Ukraine) in the south, the Pechora basin in the far northeast of European Russia, and the Irkutsk, Kuznetsk, Kansk-Achinsk, Lena, South Yakutia and Tunguska basins extending across Siberia to the Far East.

The principal economic hard coal deposits of Russia are found in the Pechora and Kuznetsk basins. The former, which covers an area of some 90 000 km^2, has been extensively developed for underground operations, despite the severe climate and the fact that 85% of the basin is under permafrost. The deposits are in relatively close proximity to markets and much of the coal is of good rank, including coking grades. The Kuznetsk basin, an area of some 26 700 km^2, lies to the east of the city of Novosibirsk and contains a wide range of coals; the ash content is variable and the sulphur is generally low. Coal is produced from both surface and underground mines.

Lying east of the Kuznetsk and astride the trans-Siberian railway, the Kansk-Achinsk basin contains huge deposits of brown (sub-bituminous) coal with medium (in some cases, low) ash content and generally low sulphur; large strip-mines are linked to dedicated power stations and carbo-chemical plants. The vast Siberian coal-bearing areas of the Lena and Tunguska basins constitute largely unexplored resources, the commercial exploitation of which would probably be difficult to establish.

The transportation of coal from mining to consuming areas is often problematical in a country of Russia’s proportions. As the reserves in the western areas have been increasingly depleted the focus of production has moved further east and the burden on the rail system has increased.

From a peak of around 425 million tonnes in 1988, Russia’s total coal production declined dramatically following the disintegration of the USSR, and now stands at about 250-260 million tonnes per annum. In 1998 about 70% of Russian consumption was accounted for by power stations and district heating plants. In recent years Russia has been a net exporter of coal, but on a declining scale.

SOUTH AFRICA

Proved amount in place (total coal, million tonnes)	115 515
Proved recoverable reserves (total coal, million tonnes)	49 520
Production (total coal, million tonnes, 1999)	223.5

From the first discovery of coal in South Africa in 1699, the country has grown to become one of the leading coal nations of the world. Coal's prominence in the national energy scene is largely attributable to a very large resource base and historically a ready supply of low-cost labour. In the past South Africa's political isolation led the country to restrict its dependence on oil imports to a greater degree than any other non-centrally planned economy, and to emphasise the development of its coal resources.

The coal resources reported for the present Survey are based on an assessment published by the Geological Survey of South Africa (now the Council for Geoscience) in 1987, adjusted for cumulative production of coal over the period since its preparation.

The Council for Geoscience, on behalf of the Department of Minerals and Energy, is currently carrying out a major review of South Africa's coal resources; its report is not expected to be released until 2002, at the earliest.

Coal occurs principally in three regions:

- the shaly Volksrust Formation, which covers most of central and northern Mpumalanga province (formerly the Transvaal). The coal is found in isolated basins and troughs which results in the fields being disconnected and widely separated;
- the sandy Vryheid Formation of the northern part of the main Karoo basin (northern Free State, northern Kwazulu-Natal and southern Mpumalanga): this generally continuous area is probably the most important economically;
- the Motleno Formation, which is confined to the north-eastern Cape. It is of minor economic importance compared to other coalfields in South Africa.

Some lignite deposits are known along the Kwazulu-Natal and Cape coasts, but are considered to be of scant economic importance.

Coal occurrences have been divided into 19 separate coalfields, 18 of which are located in an area extending some 600 km from north to south by 500 km from east to west. The Molteno field lies some 300 km south of the main coal-bearing region.

Eskom, the South African electric utility, accounts for well over half of coal consumption. A further large slice is consumed by the Sasol plants in making synthetic fuels and chemicals from coal. The third main user is the industrial sector, including the iron and steel industry. Coal use in residential and commercial premises is relatively small, while demand by the railways has virtually disappeared.

Coal exports are equivalent to about 30% of South African output and are mainly destined for Europe and Asia/Pacific. The main route for exports is via Richards Bay, Kwazulu-Natal, where there is one of the largest coal-export terminals in the world.

THAILAND

Proved amount in place (total coal, million tonnes)	1 391
Proved recoverable reserves (total coal, million tonnes)	1 268
Production (total coal, million tonnes, 1999)	18.3

Thailand has sizeable resources of lignite, notably at Mae Moh in the north of the country. Annual output of lignite increased by almost 90% between 1990 and 1997, but has since been in gradual decline.

All of Mae Moh's production is consumed by the Mae Moh power plant (2 625 MW). On the other hand, most of the lignite produced by other Thai mines is used by industry, chiefly in cement manufacture. Imports of bituminous coal are almost all consumed in the iron and steel sector.

UNITED KINGDOM

Proved recoverable reserves (total coal, million tonnes)	1 500
Production (total coal, million tonnes, 1999)	37.1

Coal deposits are widely distributed and for many years the UK was one of the world's largest coal producers, and by far its largest exporter. Production rose to a peak of nearly 300 million tonnes/year during World War I and thereafter did not fall below 200 million tonnes/year until 1960. Output began a long-term decline in the mid-1960's, falling to less than 100 million tonnes/year by 1990. Reflecting continued competition from natural gas and imported coal, UK coal production sank to 37 million tonnes in 1999.

The UK coal industry was privatised at the end of 1994, with the principal purchaser being RJB Mining, which acquired 16 deep mines from British Coal. At the end of June 2000 there were 19 major deep mines, 14 smaller deep mines and 48 open-cast sites in production. Deep-mined coal output in 1999 was 20.9 million tonnes and open-cast sites produced 15.3 million tonnes; production from slurry etc. amounted to 0.9 million tonnes. Most deep-mined coal has a significantly higher content of sulphur and chlorine than that of internationally-traded coal. There is now virtually no UK production of coking coal.

The decline of the British coal industry makes it exceptionally difficult to quantify resources and reserves in compliance with the definitions specified for this Survey. In British Coal's annual report for 1991/1992, coal in place (in seams over 0.6 metres thick and less than 1 200 metres deep) was estimated as 190 billion tonnes, of which some 45 billion tonnes could be extracted with current technology. The report qualified these estimates by stating that "the working of these resources will depend on economic circumstances, together with any other strategic considerations".

For the purpose of the present Survey, the problem lies in quantifying the proportion of the coal in place which should be regarded as "exploitable under present and expected local economic conditions" (see Definitions), and the proportion of the technologically recoverable reserves which would satisfy the same economic criterion.

By far the greater part of the 190 billion tonnes of coal in place quoted above is not within the take of currently operating mines. The UK Department of Trade and Industry's 1997 *Energy Report* states that "there were estimated to be approximately 1 billion tonnes of economically viable coal reserves at existing mines at the end of 1994". Parker (1997)* estimated proven UK coal reserves accessible to existing deep mines and identified open-cast sites as "of the order of 800 million tonnes". In this Survey, UK proved recoverable reserves of bituminous coal are quoted at the 1997 *Energy Report* level of 1 billion tonnes, although a recent assessment (Parker (2000)**), which allows for the effects of subsequent production and for the closure of certain mines, points to an even lower figure.

Estimates of lignite reserves and resources relate only to the Crumlin deposit in County Antrim, Northern Ireland.

* Parker, M.J., (1997); *UK Coal Reserves in Perspective*; Energy Exploration & Exploitation, vol. 15 no 1.

** Parker, M.J., (2000); *Thatcherism and the Fall of Coal*; Oxford University Press for the Oxford Institute of Energy Studies.

UNITED STATES OF AMERICA

Proved amount in place (total coal, million tonnes)	457 503
Proved recoverable reserves (total coal, million tonnes)	249 994
Production (total coal, million tonnes, 1999)	997.1

The US coal resource base is the largest in the world. Proved recoverable reserves of 250 billion tonnes are equivalent to about 25% of the global total. The US Department of Energy/Energy Information Administration's (EIA) demonstrated reserve base (DRB), (corresponding to the WEC category of "proved amount in place") is 457 billion tonnes (504 billion short tons), of which bituminous coal (including anthracite) constitutes about 55%, sub-bituminous 36% and lignite 9%. Coal deposits are widely distributed, being found in 38 states and underlying about 13% of the total land area. The Western Region (notably Montana and Wyoming) accounts for about 47% of the DRB, the Interior Region (in particular, Illinois and Kentucky) for 31% and the Appalachian Region (chiefly West Virginia, Pennsylvania and Ohio) for 21%. Bituminous coal reserves are recorded for 27 states, whereas only 8 states have sub-bituminous reserves, of which 90% are located in Montana and Wyoming.

Total proved recoverable reserves represent about 55% of the proved amount of coal in place. Overall, almost 27% of the recoverable reserves of bituminous coal (including anthracite) is surface-mineable, compared with 44% of sub-bituminous reserves and 100% of those of lignite.

US coal output is the second highest in the world, after China, and accounted for about 23% of global production in 1999. Coal is the USA's largest single source of indigenous primary energy; power stations and CHP plants accounted for over 92% of domestic coal consumption in 1998. Coal exports amounted to 53 million tonnes in 1999: the USA remains one of the world's leading suppliers of coking coal and other bituminous grades.

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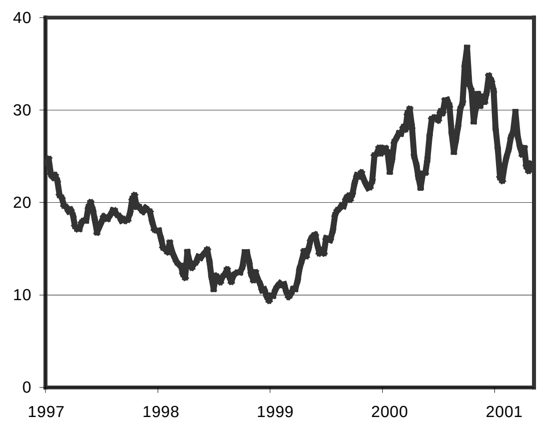
Chapter 2

CRUDE OIL AND NATURAL GAS LIQUIDS

The period 1996-1999 was marked by large variations in the price of crude oil. The price per barrel started to slide in late 1997 and finally bottomed out at $10/bbl at the end of 1998. Two factors can be held responsible for this decline: a slowdown in the growth of oil demand and a supply surplus. In 1997, the economic crisis in Asia sharply reduced oil demand growth even as the non-observance of production quotas by OPEC countries led to excess supply. To help counteract this price collapse, OPEC decided to cut production by 1.5 million b/d in March 1999. This drop in production, combined with the recovery of oil demand growth and a tight situation on the reformulated gasoline market in the United States, caused prices to rebound to over $35/bbl (in July 2000). Confronting this price escalation, OPEC boosted production four more times during 2000 for a total increase of 3.7 million b/d, enabling the price to stabilise in the vicinity of $25/bbl.

Figure 2.1: Evolution of Oil Price ($/bbl) (Dated Brent) 1997/2001



Source: IEA

- **The debate over reserves**

During the 1990’s, the debate over oil reserves/resources generated controversy between the "pessimists" and the "optimists".

The "pessimists" advocate the position that the world is finite and so are its recoverable oil resources. To make their argument, they rely on descriptive statistics and base their conclusions on the statistical study of past discoveries, considering all oil and gas fields to be static objects (with no evolution in the size of initially recoverable reserves). The pessimists believe that all of the oil-bearing regions worth exploring have already been explored and that the big fields have already been discovered, ergo future discoveries will be small. They claim that the official figures for proven reserves have been overestimated for some regions and that world oil production is currently at its optimum - or can be expected to reach its optimum in the medium term - and will decrease steadily thereafter.

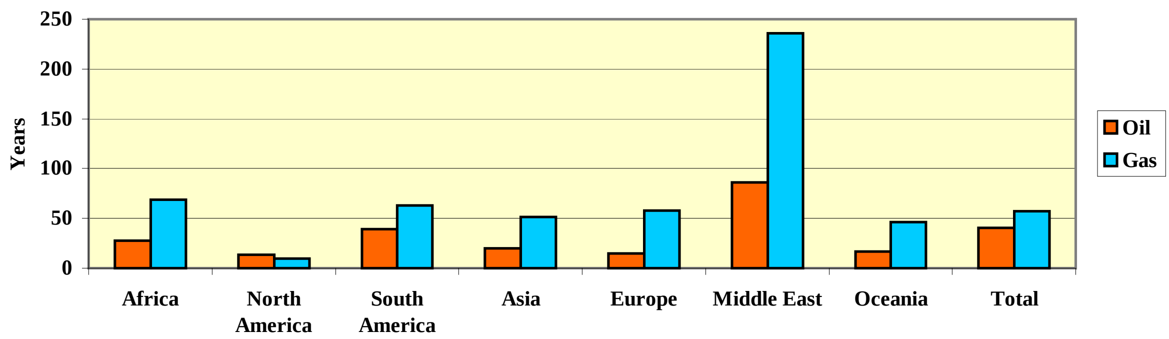
The "optimists" hold a dynamic concept of reserves and believe that a method based solely on applying descriptive statistics to past discoveries will only yield a partial image of actual potential. The volumes of exploitable oil and gas are closely correlated to technological advances, technical costs and the price of the barrel of crude or the cubic metre of gas. For example, it is estimated that today only 35% to 40% of the oil present in discovered fields is recovered. According to an optimist, any improvement in this recovery rate - even if by only one point - allows the industry to tap substantial additional reserves. Similarly, the boundary between conventional and non-conventional hydrocarbons is not fixed, but has continued to shift regularly over time. For instance, optimists note that it is now both feasible and profitable to exploit fields at water depths exceeding 1 000 metres, which was still thought to be impossible 15 years ago.

- **The evolution of hydrocarbon resources from 1996 to 1999**

Between the 1998 WEC Survey of Energy Resources and the present Survey, proved recoverable reserves of hydrocarbons (as reported by WEC Member Committees and other sources) remained fairly stable overall: oil reserves fell by 2.7% while gas reserves went up by 2.8%

In the case of oil, Africa and South America were the major regions to experience growth (of around 4% in each case) whereas Africa (+13%) and Oceania (+11%) witnessed the largest percentage additions to gas reserves. At the current rate of production, the industry could continue to produce oil for 40 more years, gas for over 55 years. The geographic breakdown of hydrocarbon resources remains basically unchanged, with a high concentration in the Middle East (65%) and in the OPEC countries for oil, and a more equitable distribution between the FSU (37%) and the Middle East (35%) for gas.

Figure 2.2: Hydrocarbon reserves/production ratios



Some of the arguments advanced by pessimists are supported by the fact that fewer "giant" fields (with ultimate recoverable reserves exceeding 500 million bbls for oil and 3 tcf for gas) are being discovered. In the 1960's, about one hundred such fields were found, but only about thirty came to light in the 1980's.

- **What happened to giant hydrocarbon discoveries in the 1990's?**

To consider oil first, 29 giant fields were discovered, including 7 at water depths greater than 1 000 metres. In Africa, 15 accumulations representing over 500 million boe were found, including 6 at water depths in excess of 1 000 m. In Latin America, there were 4 discoveries of this type.

As for gas, 29 giant gas fields were located, including 8 in the Middle East (Pars and Azadegan in Iran) and 5 in Australia. Of this total, 5 were at water depths of over 1 000 m.

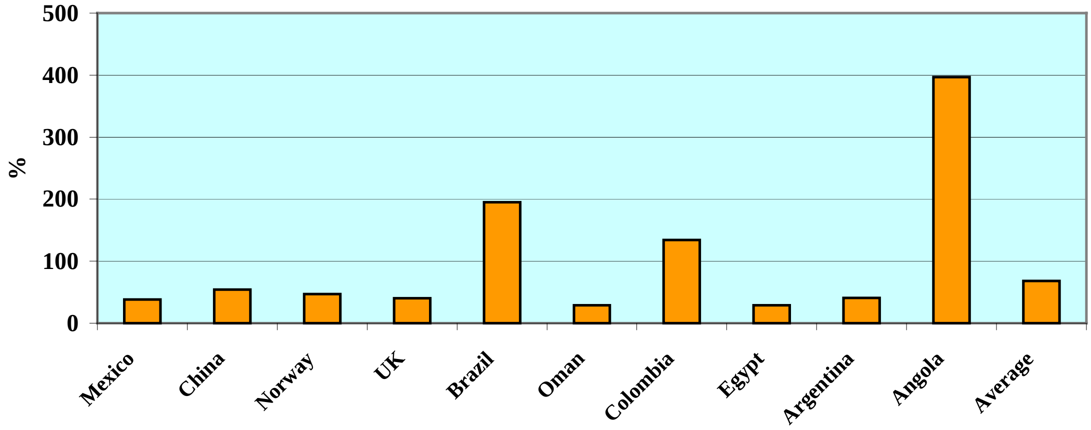
All in all, the 1990's matched the 1980's for giant discoveries, with the very deep offshore sector making a powerful contribution to this stability.

- **The 1990's, or the advent of deep offshore activity**

During the 1990's, even more than in the 1980's, the discoveries of new oil fields were concentrated in a small number of countries. In point of fact, during the period 1990-1999, 50% of new fields were concentrated in 10 of the 95 countries where discoveries were made. These new fields were primarily located in regions long known or recently found to be oil-rich: Iran and Saudi Arabia, on the one hand, and Brazil and Angola (deep offshore) on the other.

Brazil and Angola reported a high reserve renewal rate, thanks to deep offshore finds (Figure 2.3).

Figure 2.3: rate of oil reserve renewal, 1990-1999



Source: IHS Energy

The Roncador field in the Campos Basin allowed Brazil to set a new offshore production record (1 800 m) while Angola saw a series of giant offshore discoveries, including Dalia, Girassol, and Kuito. However, such major discoveries tend to obscure the fact that, elsewhere in the world, the oil industry has obtained more contrasting results. Since the early 1990's, discovered volumes have generally been inferior to produced volumes. Between 1990 and 1994, 62% of the oil produced was replaced by new discoveries, but the renewal rate then fell to 52% for 1995-1999.

- **Deep offshore: an ongoing technological challenge**

In 1978, the greatest production depth was 300 m. By 1998, deepwater production was under way at 1 800 m, a record set by Petrobras in the Campos Basin in Brazil. During this twenty-year period, the deep offshore sector continued to push back its technological limits.

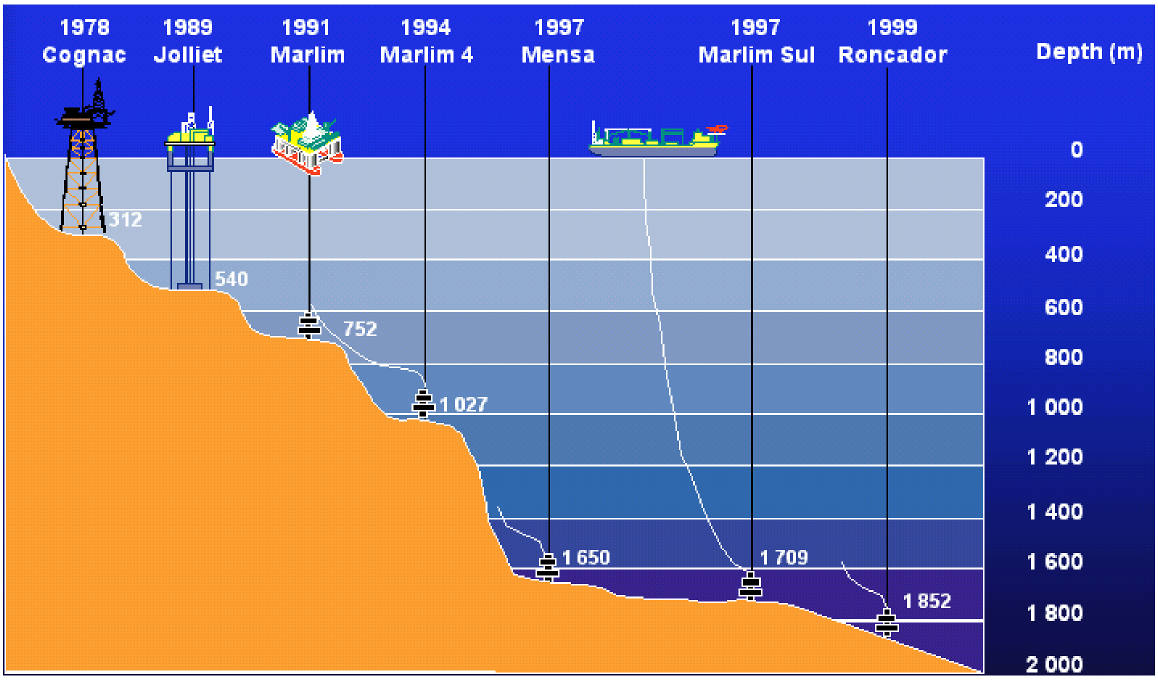


Figure 2.4: Deep Offshore Production Records (source: IFP)

Today, the potential represented by deep offshore resources has not yet been clearly determined. Sedimentary areas lying in over 200 m of water represent nearly 55 million km² of sedimentary basins, or four times the conventional offshore surface area. The permits that have already been delivered only cover 5% of this area.

Deep-offshore conditions present certain characteristics (high pressures, low temperatures, large water-depth range, the constant presence of ocean currents, etc.) that are radically different from those typifying conventional offshore operations.
It did not take long for the industry to realize that conventional offshore solutions could not be applied at greater water depths, and that new concepts would have to be developed in order to tap the 10 billion toe of proven deep offshore reserves.

The entire exploration-to-production chain was reviewed and adapted to greater water depths:

- The development and use of (3D) seismic was intensified.
- Innovative drilling and production structures were designed. Because these structures could not be installed on the seabed at such great depths, FPSO (Floating Production Storage and Offloading) and TLP (Tension Leg Platform) systems were developed.
- Efforts were made to come up with new materials for the flexibles (able to withstand high pressures at great water depths, etc.).

- Horizontal and multibranch wells came into general use, reducing the number of wells.

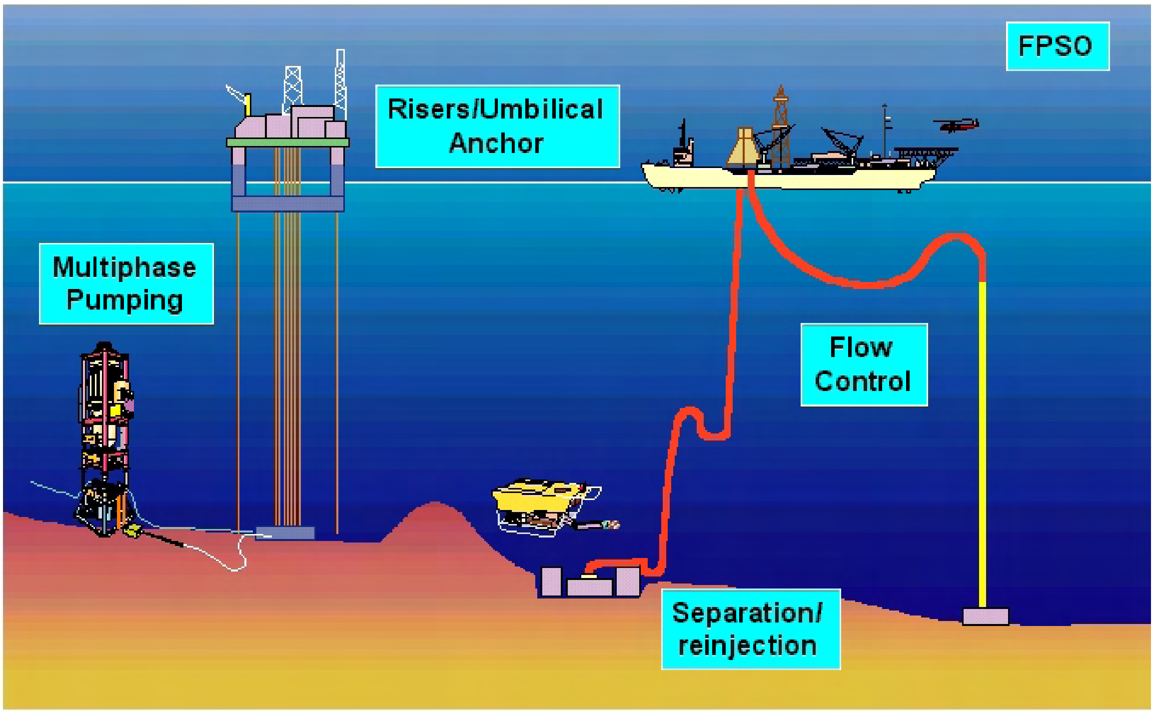


Figure 2.5: Key deep offshore technologies (source: IFP)

For oil companies, the next target depth is 3 000 m. Meeting this objective constitutes a major industry challenge for the next 5 to 10 years.

The transition from deep offshore to ultra-deep offshore will require higher allocations of R&D resources. Beyond a certain limit, it will not be possible to extrapolate from existing solutions, so new ones will have to be found and proven appropriate and reliable.

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DEFINITIONS

Crude oil is a naturally occurring mixture consisting predominantly of hydrocarbons that exists in liquid phase in natural underground reservoirs and is recoverable as liquids at typical atmospheric conditions of pressure and temperature. Crude oil has a viscosity no greater than 10 000 mPa.s (centipoises) at original reservoir conditions; oils of greater viscosity are included in Chapter 4 - Natural Bitumen and Extra-Heavy Oil.

Natural gas liquids (NGL's) are hydrocarbons that exist in the reservoir as constituents of natural gas but which are recovered as liquids in separators, field facilities or gas-processing plants. Natural gas liquids include (but are not limited to) ethane, propane, butanes, pentanes, natural gasoline and condensate; they may include small quantities of non-hydrocarbons.

If reserves/resources/production/consumption of NGL's exist but cannot be separately quantified, they are included (as far as possible) under crude oil.

In the tables the following definitions apply to both crude oil and natural gas liquids:

Proved amount in place is the tonnage originally occurring in known natural reservoirs which has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology.

Proved recoverable reserves is the tonnage within the proved amount in place that can be recovered in the future under present and expected economic conditions with existing available technology.

Estimated additional amount in place is the tonnage additional to the proved amount in place that is of foreseeable economic interest. Speculative amounts are not included.

Estimated additional reserves recoverable is the tonnage within the estimated additional amount in place which geological and engineering information indicates with reasonable certainty might be recovered in the future.

R/P (reserves/production) ratio is calculated by dividing proved recoverable reserves at the end of 1999 by production in that year. The resulting figure is the time in years that the proved recoverable reserves would last if production were to continue at the 1999 level.

Table 2.1 Crude oil and natural gas liquids: proved recoverable reserves at end-1999

Excel Files	million tonnes			million barrels		
	Crude oil	NGL's	TOTAL	Crude oil	NGL's	TOTAL
Algeria			**1 235**			**10 040**
Angola			**730**			**5 412**
Benin			**1**			**8**
Cameroon			**55**			**400**
Congo (Brazzaville)			**212**			**1 506**
Congo (Democratic Rep.)			**26**			**187**
Côte d'Ivoire			**14**			**100**
Egypt (Arab Rep.)	412	117	**529**	2 991	1 159	**4 150**
Equatorial Guinea			**1**			**12**
Ethiopia			**N**			**N**
Gabon			**342**			**2 499**
Ghana			**2**			**17**
Libya/GSPLAJ			**3 892**			**29 500**
Morocco			**N**			**2**
Nigeria			**3 000**			**22 500**
Senegal						
South Africa	5	2	**7**	46	18	**64**
Sudan			**36**			**262**
Tunisia			**40**			**308**
Total Africa			**10 122**			**76 967**
Barbados			**N**			**3**
Canada	636	143	**779**	4 704	1 698	**6 402**
Cuba			**44**			**283**
Guatemala			**79**			**526**
Mexico	3 536	321	**3 858**	24 631	3 629	**28 260**
Trinidad & Tobago			**85**			**605**
United States of America	2 968	760	**3 728**	21 765	7 906	**29 671**
Total North America			**8 573**			**65 750**
Argentina			**429**			**3 054**
Bolivia			**17**			**132**
Brazil			**1 172**			**8 415**
Chile			**20**			**150**
Colombia			**323**			**2 289**
Ecuador			**302**			**2 115**
Peru			**48**			**355**
Surinam			**11**			**74**
Venezuela			**11 048**			**76 785**
Total South America			**13 370**			**93 369**
Azerbaijan			**161**			**1 178**
Bangladesh			**6**			**57**
Brunei			**184**			**1 350**
China			**4 793**			**35 085**
Georgia			**5**			**35**
India			**645**			**4 799**
Indonesia			**707**			**5 203**
Japan	8		**8**	58		**58**

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Table 2.1 Crude oil and natural gas liquids: proved recoverable reserves at end-1999 contd.

	million tonnes			million barrels		
	Crude oil	NGL's	TOTAL	Crude oil	NGL's	TOTAL
Kazakhstan			**742**			**5 417**
Kyrgyzstan			**5**			**40**
Malaysia			**513**			**3 900**
Myanmar (Burma)			**7**			**50**
Pakistan	33		**33**	246		**246**
Philippines	35	8	**43**	258	78	**336**
Taiwan, China			**1**			**4**
Tajikistan			**2**			**12**
Thailand	20	27	**47**	145	271	**416**
Turkey	43		**43**	310		**310**
Turkmenistan			**75**			**546**
Uzbekistan			**81**			**594**
Vietnam			**82**			**600**
Total Asia			**8 183**			**60 236**
Albania			**25**			**165**
Austria			**12**			**86**
Belarus			**27**			**198**
Bulgaria			**2**			**15**
Croatia	8	3	**11**	57	32	**89**
Czech Republic	11		**11**	74		**74**
Denmark			**122**			**906**
France	20	1	**21**	145	9	**154**
Germany			**42**			**308**
Greece			**1**			**10**
Hungary	8		**8**	55		**55**
Italy	61		**61**	448		**448**
Lithuania			**2**			**12**
Netherlands			**13**			**94**
Norway	1 440	70	**1 510**	11 007	662	**11 669**
Poland			**14**			**94**
Romania			**108**			**811**
Russian Federation			**6 654**			**48 573**
Serbia, Montenegro			**10**			**77**
Slovakia			**1**			**9**
Slovenia			**N**			**N**
Spain	2	N	**2**	12	5	**17**
Ukraine	116	57	**173**	847	589	**1 436**
United Kingdom			**665**			**5 003**
Total Europe			**9 495**			**70 303**
Bahrain			**20**			**148**
Iran (Islamic Rep.)			**12 667**			**93 100**
Iraq			**15 141**			**112 500**
Israel			**1**			**4**
Jordan			**N**			**1**
Kuwait			**13 310**			**96 500**
Oman			**737**			**5 400**
Qatar			**600**			**4 500**

Table 2.1 Crude oil and natural gas liquids: proved recoverable reserves at end-1999 contd.

	million tonnes			million barrels		
	Crude oil	**NGL's**	**TOTAL**	**Crude oil**	**NGL's**	**TOTAL**
Saudi Arabia			**35 983**			**263 500**
Syria (Arab Rep.)			**343**			**2 500**
United Arab Emirates			**12 915**			**98 100**
Yemen			**525**			**4 000**
Total Middle East			**92 242**			**680 253**
Australia	212	233	**445**	1 671	2 177	**3 848**
New Zealand			**14**			**106**
Papua New Guinea			**43**			**333**
Total Oceania			**502**			**4 287**
TOTAL WORLD			**142 487**			**1 051 165**

Notes:
1. The data on the split of total oil reserves between crude and NGL's are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Data in barrels have been converted at average specific factors for crude oil and NGL's respectively, for each country
3. Sources: WEC Member Committees, 2000/2001; *Oil & Gas Journal*, December 18, 2000; *Annual Statistical Report 2000*, OAPEC; *Annual Statistical Bulletin 1999*, OPEC; various national sources

Table 2.2i Crude oil and natural gas liquids: resources at end-1999

Excel Files	Crude oil million tonnes			Natural gas liquids million tonnes		
	Proved amount in place	Estimated additional		Proved amount in place	Estimated additional	
		Amount in place	Reserves recoverable		Amount in place	Reserves recoverable
Africa						
Ghana	14					
Morocco	N		N	N		N
North America						
Canada	3 147	22 440	6 732	399	1 027	713
Mexico	4 834	1 124		416	118	
United States of America	83 000	26 000	8 728	9 615	3 846	1 288
South America						
Argentina			164			
Brazil	10 137		790			
Venezuela	117 087					
Asia						
Indonesia	8 127	745	628			
Thailand	132	31	10	45	42	21
Turkey	153					
Europe						
Austria	12					
Croatia	8			3		
Czech Republic	14		13			
Denmark	1 267	341	80			
France	419			34		
Germany			10			
Hungary	110	108	15			
Italy			28			
Netherlands	128		15			
Norway	2 595	1 200		135		
Poland	14					
Romania	196	1 694				
Slovenia	N	N	N			
Spain	67	7	4	2		N
Ukraine	138	52	33	79	21	1
United Kingdom		1 000	455			
Oceania						
Australia			17			139
New Zealand	46					

Notes:
1. The data on resources are predominantly those reported by WEC Member Committees. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Sources: WEC Member Committees, 2000/2001; national sources for Mexico and Australia

Table 2.2ii Crude oil and natural gas liquids: resources at end-1999

Excel Files

	Crude oil (million barrels)			Natural gas liquids (million barrels)		
	Proved amount in place	Estimated additional		Proved amount in place	Estimated additional	
		Amount in place	Reserves recoverable		Amount in place	Reserves recoverable
Africa						
Ghana	102					
Morocco	N		N	N		N
North America						
Canada	23 287	166 051	49 815	4 737	12 191	8 457
Mexico	33 666	7 829		4 702	1 334	
United States of America	610 000	190 000	64 000	100 000	40 000	13 400
South America						
Argentina			1 168			
Brazil	72 784		5 672			
Venezuela	813 758					
Asia						
Indonesia	59 814	5 481	4 623			
Thailand	967	223	74	452	418	208
Turkey	1 099					
Europe						
Austria	86					
Croatia	57			32		
Czech Republic	95		88			
Denmark	9 384	2 522	591			
France	3 072			357		
Germany			73			
Hungary	796	787	110			
Italy			203			
Netherlands	927		109			
Norway	19 836	9 173		1 276		
Poland	97					
Romania	1 471	12 713				
Slovenia	N	N	N			
Spain	505	55	27	24		N
Ukraine	1 010	377	244	826	217	5
United Kingdom		7 523	3 423			
Oceania						
Australia			132			1 356
New Zealand	340					

Notes:

1. The data on resources are predominantly those reported by WEC Member Committees. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Data in this table should be considered as merely indicative of the volumes implied by the tonnage data: they have been converted at the same specific factors as used in Table 2.1 and left unrounded, although their apparent precision should of course be disregarded
3. Sources: WEC Member Committees, 2000/2001; national sources for Mexico and Australia

Table 2.3 Crude oil and natural gas liquids: 1999 production

Excel Files	million tonnes			thousand barrels per day			
	Crude oil	NGL's	Total	Crude oil	NGL's	Total	R/P ratio
Algeria	39.9	24.1	64.0	888	648	1 536	17.9
Angola	36.8		36.8	746		746	19.9
Benin	0.1		0.1	1		1	23.2
Cameroon	4.8		4.8	95		95	11.5
Congo (Brazzaville)	14.5		14.5	282		282	14.6
Congo (Democratic Rep.)	1.2		1.2	24		24	21.3
Côte d'Ivoire	0.5		0.5	10		10	27.4
Egypt (Arab Rep.)	38.4	3.0	41.4	763	81	844	13.5
Equatorial Guinea	4.5		4.5	100		100	0.3
Gabon	17.0		17.0	340		340	20.1
Ghana	0.3		0.3	6		6	7.5
Libya/GSPLAJ	64.9	2.1	67.0	1 347	60	1 407	57.4
Morocco	N	N	N	N	N	N	25.1
Nigeria	95.6	2.5	98.1	1 964	62	2 026	30.4
Senegal	N	N	N	N	N	N	
South Africa	1.1	0.4	1.5	25	10	35	5.0
Sudan	3.2		3.2	63		63	11.4
Tunisia	3.9	0.1	4.0	83	1	84	10.0
Total Africa	**326.7**	**32.2**	**358.9**	**6 737**	**862**	**7 599**	**27.7**
Barbados	0.1	N	0.1	2	N	2	4.3
Canada	68.6	21.2	89.8	1 345	675	2 020	8.7
Cuba	2.1		2.1	38		38	20.4
Guatemala	1.3		1.3	23		23	62.7
Mexico	152.0	14.1	166.1	2 906	437	3 343	23.2
Trinidad & Tobago	5.0	1.7	6.7	98	43	141	11.8
United States of America	294.0	59.8	353.8	5 881	1 850	7 731	10.5
Total North America	**523.1**	**96.8**	**619.9**	**10 293**	**3 005**	**13 298**	**13.5**
Argentina	41.0	1.3	42.3	800	41	841	9.9
Bolivia	1.5	0.3	1.8	33	8	41	8.8
Brazil	55.3	0.5	55.8	1 102	15	1 117	20.6
Chile	0.4	0.2	0.6	8	5	13	31.6
Colombia	42.1	0.7	42.8	816	22	838	7.5
Ecuador	19.4	0.3	19.7	373	9	382	15.2
Peru	5.2	0.1	5.3	106	4	110	8.8
Surinam	0.7		0.7	12		12	16.9
Venezuela	155.9	6.2	162.1	2 985	190	3 175	66.3
Total South America	**321.5**	**9.6**	**331.1**	**6 235**	**294**	**6 529**	**39.2**
Azerbaijan	13.6	0.2	13.8	272	6	278	11.6
Bangladesh	N	0.1	0.1	N	3	3	52.1
Brunei	8.3	0.6	8.9	167	15	182	20.3
China	160.2		160.2	3 213		3 213	29.9
Georgia	0.1	N	0.1	2	N	2	48.7
India	32.6	4.1	36.7	665	122	787	16.7
Indonesia	59.9	7.5	67.4	1 208	196	1 404	10.2
Japan	0.6		0.6	13		13	12.2
Kazakhstan	26.7	3.4	30.1	535	97	632	23.5
Kyrgyzstan	0.1	N	0.1	1	N	1	77.8
Malaysia	28.8	6.9	35.7	601	191	792	13.5
Myanmar (Burma)	0.4	N	0.4	9	N	9	14.9
Pakistan	2.7	0.1	2.8	55	4	59	11.4
Philippines	N		N	1		1	> 100
Taiwan, China	0.1	N	0.1	1	1	2	6.0
Tajikistan	N	N	N	N	N	N	92.1

Table 2.3 Crude oil and natural gas liquids: 1999 production contd.

	million tonnes			thousand barrels per day			
	Crude oil	**NGL's**	**Total**	**Crude oil**	**NGL's**	**Total**	**R/P ratio**
Thailand	1.7	3.6	5.3	34	98	132	8.6
Turkey	2.9		2.9	58		58	14.6
Turkmenistan	6.9	0.2	7.1	138	5	143	10.5
Uzbekistan	4.7	3.4	8.1	94	97	191	8.5
Vietnam	14.6		14.6	292		292	5.6
Total Asia	**364.9**	**30.1**	**395.0**	**7 359**	**835**	**8 194**	**20.1**
Albania	0.3		0.3	6		6	75.3
Austria	1.0	0.1	1.1	19	3	22	10.7
Belarus	1.8		1.8	37		37	14.7
Bulgaria	N		N	1		1	82.2
Croatia	1.3	0.2	1.5	26	6	32	7.6
Czech Republic	0.2		0.2	3		3	62.2
Denmark	14.7		14.7	299		299	8.3
France	1.5	0.2	1.7	31	5	36	11.7
Germany	2.7		2.7	54		54	15.6
Greece	0.3	N	0.3	5	1	6	4.3
Hungary	1.3	0.5	1.8	26	15	41	3.7
Italy	5.0	N	5.0	100	1	101	12.2
Lithuania	0.2		0.2	5		5	7.1
Netherlands	1.6	1.0	2.6	30	25	55	4.7
Norway	142.5	6.2	148.7	2 984	161	3 145	10.2
Poland	0.4		0.4	8		8	32.2
Romania	6.2	0.2	6.4	127	6	133	16.7
Russian Federation	295.1	9.7	304.8	5 901	277	6 178	21.5
Serbia, Montenegro	0.7		0.7	14		14	14.7
Slovakia	0.1		0.1	1		1	20.1
Slovenia	N		N	N		N	3.0
Spain	0.4	0.4	0.8	8	14	22	2.1
Ukraine	2.6	1.1	3.7	52	33	85	46.3
United Kingdom	128.3	8.8	137.1	2 644	267	2 911	4.7
Total Europe	**608.2**	**28.4**	**636.6**	**12 381**	**814**	**13 195**	**14.6**
Bahrain	1.8	0.4	2.2	37	12	49	8.3
Iran (Islamic Rep.)	171.5	3.7	175.2	3 439	111	3 550	71.9
Iraq	124.0	1.8	125.8	2 525	56	2 581	> 100
Israel	N		N	N		N	> 100
Jordan	N		N	N		N	68.5
Kuwait	94.3	4.8	99.1	1 873	150	2 023	> 100
Oman	45.1	0.2	45.3	905	6	911	16.2
Qatar	30.8	3.1	33.9	632	92	724	17.0
Saudi Arabia	383.6	26.0	409.6	7 696	853	8 549	84.4
Syria (Arab Rep.)	28.7	0.4	29.1	574	11	585	11.7
United Arab Emirates	96.8	10.7	107.5	2 015	312	2 327	> 100
Yemen	18.5	0.3	18.8	386	10	396	27.7
Total Middle East	**995.1**	**51.4**	**1 046.5**	**20 082**	**1 613**	**21 695**	**85.9**
Australia	16.0	8.5	24.5	345	232	577	18.3
New Zealand	1.8	0.2	2.0	36	7	43	6.8
Papua New Guinea	4.1		4.1	88		88	10.4
Total Oceania	**21.9**	**8.7**	**30.6**	**469**	**239**	**708**	**16.6**
TOTAL WORLD	**3 161.4**	**257.2**	**3 418.6**	**63 556**	**7 662**	**71 218**	**40.4**

Notes:
1. Sources: WEC Member Committees, 2000/2001; *BP Statistical Review of World Energy*, June 2001; *Oil & Gas Journal*, December 18, 2000; other international and national sources

Table 2.4 Crude oil and natural gas liquids: 1999 consumption

Excel Files	million tonnes			thousand barrels per day		
	Crude oil	**NGL's**	**Total**	**Crude oil**	**NGL's**	**Total**
Algeria			21.9			456
Angola			1.8			37
Cameroon			1.7			36
Congo (Democratic Rep.)			0.3			6
Côte d'Ivoire			4.2			87
Egypt (Arab Rep.)			28.6			595
Eritrea			0.2			4
Gabon			0.8			17
Ghana			0.8			17
Kenya			1.7			35
Libya/GSPLAJ			16.0			333
Madagascar			0.2			4
Mauritania			0.9			20
Morocco	6.7		6.7	135		135
Nigeria			7.5			150
Senegal			0.9			19
South Africa			16.0			320
Sudan			1.0			21
Tanzania			0.4			8
Tunisia			1.9			40
Zambia			0.2			5
Total Africa			**113.7**			**2 345**
Aruba			9.5			195
Canada	82.0	8.8	90.8	1 647	260	1 907
Cuba			2.5			52
Dominican Republic			2.4			50
El Salvador			0.9			19
Guatemala			0.8			17
Jamaica			1.2			25
Martinique			0.8			17
Mexico	66.5		66.5	1 339		1 339
Netherlands Antilles			13.5			280
Nicaragua			0.9			19
Panama			2.5			50
Puerto Rico			8.4			175
Trinidad & Tobago			7.5			150
United States of America	737.2	62.5	799.7	14 804	1 850	16 654
US Virgin Islands			16.5			345
Total North America			**1 024.4**			**21 294**
Argentina	28.0	1.3	29.3	562	39	601
Bolivia			1.9			39
Brazil	82.1	1.1	83.2	1 590	33	1 623
Chile	9.5		9.5	190		190
Colombia			13.5			280
Ecuador			7.6			158
Paraguay	0.1		0.1	2		2
Peru			7.5			155
Surinam			0.2			4
Uruguay	1.6		1.6	32		32
Venezuela			55.0			1 050
Total South America			**209.4**			**4 134**

Table 2.4 Crude oil and natural gas liquids: 1999 consumption contd.

	million tonnes			thousand barrels per day		
	Crude oil	**NGL's**	**Total**	**Crude oil**	**NGL's**	**Total**
Azerbaijan			9.5			193
Bangladesh			1.0			21
Brunei			0.6			13
China			188.0			3 915
Cyprus			1.2			24
Georgia			0.1			2
India	79.5	0.1	79.6	1 597	3	1 600
Indonesia			46.6			970
Japan			216.0			4 522
Kazakhstan			10.5			235
Korea (Democratic People's Rep.)			2.4			50
Korea (Republic)	120.3		120.3	2 391		2 391
Kyrgyzstan			0.2			4
Malaysia			18.0			375
Myanmar (Burma)			1.0			21
Pakistan			6.6			135
Philippines			17.4			350
Singapore			45.0			935
Sri Lanka			1.8			37
Taiwan, China			35.3			708
Tajikistan			N			N
Thailand	36.5	1.4	37.9	733	41	774
Turkey			26.0			523
Turkmenistan			6.0			123
Uzbekistan			7.3			166
Vietnam			N			1
Total Asia			**878.3**			**18 088**
Albania			0.4			8
Austria	8.6	0.1	8.7	172	3	175
Belarus			12.0			240
Belgium			32.1			645
Bulgaria			5.5			110
Croatia			5.2			105
Czech Republic	6.2		6.2	125		125
Denmark			7.9			160
Finland	11.1	0.5	11.6	223	15	238
FYR Macedonia			0.5			10
France	83.8	0.2	84.0	1 682	7	1 689
Germany			106.6			2 140
Greece			16.1			325
Hungary	7.4		7.4	149		149
Ireland	2.8		2.8	57		57
Italy	92.4		92.4	1 855		1 855
Latvia		N	N		1	1
Lithuania	4.3	0.2	4.5	87	5	92
Netherlands			61.1			1 287
Norway	16.4	1.5	17.9	329	45	374
Poland	16.7		16.7	335		335
Portugal	14.0		14.0	281		281
Romania	10.4		10.4	210		210
Russian Federation			172.5			3 464
Serbia, Montenegro			1.4			28
Slovakia	5.4		5.4	109		109

Table 2.4 Crude oil and natural gas liquids: 1999 consumption contd.

	million tonnes			thousand barrels per day		
	Crude oil	**NGL's**	**Total**	**Crude oil**	**NGL's**	**Total**
Slovenia	0.3		0.3	6		6
Spain			58.8			1 181
Sweden	22.9		22.9	460		460
Switzerland	5.6		5.6	112		112
Ukraine			13.3			277
United Kingdom	81.6	1.6	83.2	1 638	48	1 686
Total Europe			**887.4**			**17 934**
Bahrain			13.0			265
Iran (Islamic Rep.)	67.0	2.0	69.0	1 345	60	1 405
Iraq			26.0			540
Israel	10.5		10.5	210		210
Jordan	3.5		3.5	70		70
Kuwait			53.0			1 065
Oman			4.2			84
Qatar			3.2			64
Saudi Arabia			105.0			2 190
Syria (Arab Rep.)			12.7			255
United Arab Emirates			12.0			241
Yemen			4.5			90
Total Middle East			**316.6**			**6 479**
Australia			37.0			765
New Zealand	4.7	0.1	4.8	94	3	97
Total Oceania			**41.8**			**862**
TOTAL WORLD			**3 471.6**			**71 136**

Notes:
1. The data refer to consumption of indigenous and imported crude oil and NGL's, comprising refinery throughput plus direct use of crude oil/ngl's as fuel.
2. It is often not possible to isolate consumption of NGL's; if details are unavailable they are included with crude oil. This situation makes it impossible to calculate accurate conversions of oil consumption from tonnes to barrels in all cases.
3. Sources: WEC Member Committees 2000/2001; *Oil, Gas, Coal and Electricity Quarterly Statistics*, fourth quarter, 2000, IEA/OECD; other international and national sources; estimates by the editors

COUNTRY NOTES

The following Country Notes on crude oil and natural gas liquids provide a brief account of each country currently producing oil. They have been compiled by the editors, drawing upon a wide variety of material, including information received from WEC Member Committees, national and international publications.

The principal international published sources consulted were:

- *Annual Statistical Bulletin 1999*; OPEC;
- *Annual Statistical Report 2000*; OAPEC;
- *BP Statistical Review of World Energy 2001*;
- *Country Profiles* 1999-2000; 2000-2001; The Economist Intelligence Unit;
- *Energy Balances of OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Energy Balances of Non-OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Energy Statistics of OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Energy Statistics of Non-OECD Countries 1997-1998*; 2000; International Energy Agency;
- *International Petroleum Encyclopedia 1999*; PennWell Publishing Co.;
- *Oil & Gas Journal*, various issues; PennWell Publishing Co.;
- *Our Industry Petroleum*; 1977; The British Petroleum Company Ltd.;
- *Petroleum Economist*, various isses;
- *Petroleum Exploration Opportunities in the Former Soviet Union*; Joseph P. Riva, Jr.; 1994; PennWell Publishing Co.;
- *World Oil*, August 2000; Gulf Publishing Company.

Brief salient data are shown for each country, including the proved amount in place (as reported by WEC Member Committees) and the year of first commercial production (where ascertained).

ALBANIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	25
Production (crude oil and NGL's, million tonnes, 1999)	0.3
R/P ratio (years)	75.3
Year of first commercial production	1933

A minor producer for many years, Albania possesses a number of small oil fields, all on land. More than half of its output comes from the Marinza-Patos field, discovered in 1957. Most Albanian crudes are exceptionally heavy: Marinza-Patos, for example, averages 13º API; the sulphur content is generally high.

ALGERIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1 235
Production (crude oil and NGL's, million tonnes, 1999)	64.0
R/P ratio (years)	17.9
Year of first commercial production	1950

Indigenous oil reserves are the third largest in the African region, after Libya and Nigeria. The principal oil provinces are located in the central and south-eastern parts of the country, with the largest oil field being Hassi Messaoud, which was discovered in 1956. Substantial volumes of natural gas liquids (condensate and LPG) are produced at Hassi R'mel and other gas fields. Algerian crudes are of high quality, with a low sulphur content.

A variety of levels have been published for Algeria's proved oil reserves as at end-1999, ranging (in billions of barrels) from OGJ's 9.2 to World Oil's 13.0; intermediate levels are quoted by OPEC (11.314) and OAPEC (10.040). For the present Survey, the OAPEC level has been utilised.

Algeria has been a member of OPEC since 1969, and is also a member of OAPEC. It exported more than half of its crude oil output in 1999, mainly to Western Europe and North America.

ANGOLA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	730
Production (crude oil and NGL's, million tonnes, 1999)	36.8
R/P ratio (years)	19.9
Year of first commercial production	1956

Proved reserves of oil (as quoted by OGJ) are the second largest in sub-Saharan Africa. The early discoveries (from 1955 onwards) were made on land, but the greater part of Angola's oil resources lie in the coastal waters of its enclave of Cabinda and off the north-western mainland. Major discoveries have been made in recent times in deep-water locations. Offshore exploration and production activities largely escaped disruption during the long civil war, and output has risen steadily since the early 1980's. By far the greater part of the crude produced is exported.

ARGENTINA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	429
Production (crude oil and NGL's, million tonnes, 1999)	42.3
R/P ratio (years)	9.9
Year of first commercial production	1907

In terms of oil resources, Argentina is well in the middle ranks of South American countries, with a rising level of reserves which now exceeds those of Colombia and Ecuador. The main oil-producing areas are the west-central areas of Neuquén and Cuyo-Mendoza, the Noroeste area near Bolivia in the north, the southern province of Chubut and the Austral area in the far south (including Argentina's portion of Tierra del Fuego). Offshore fields have been discovered in the San Jorge basin off Chubut province and near Tierra del Fuego.

Proved recoverable oil reserves at end-1999 are reported by the WEC Member Committee for Argentina as 429 million tonnes, of which 4 million tonnes are located offshore. The estimated level of additional recoverable reserves is given as 164 million tonnes.

Oil output rose strongly during most of the 1990's, but a decline set in at the end of the decade: a considerable proportion is exported (39% in 1998). Production of NGL's amounts to 1.3 million tonnes/year.

AUSTRALIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	445
Production (crude oil and NGL's, million tonnes, 1999)	24.5
R/P ratio (years)	18.3
Year of first commercial production	1964

Although drilling for oil took place as long ago as 1892, it was not until well after World War II that Australia achieved oil-producer status. Since then, numerous oil fields have been discovered, notably in the following areas: Gippsland Basin (Bass Strait), off Victoria; Cooper Basin, South Australia; Eromanga and Surat Basins, Queensland; Carnarvon Basin (North-west Shelf) off Western Australia; Bonaparte Basin in the Timor Sea.

The Australian Geological Survey Organisation (AGSO) quotes *Economic Demonstrated Resources* at end-1997 as follows (in gigalitres): crude oil 266; condensate 176; naturally occurring LPG 171. The resulting total of 613 gigalitres (equivalent to 3 848 million barrels) has been adopted for the present Survey, as the nearest available equivalent to proved recoverable oil reserves.

Production of oil (including condensate and other NGL's) has fluctuated in recent years: in 1999 it averaged 577 000 b/d, of which crude oil accounted for 60%, condensate 22% and LPG/ethane for 18%. Over 40% of Australia's total oil output in 1999 was exported, mostly to Japan and other Asian destinations, the USA and New Zealand.

AUSTRIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	12
Production (crude oil and NGL's, million tonnes, 1999)	1.1
R/P ratio (years)	10.7
Year of first commercial production	1935

Several fields discovered prior to World War II are still in production. OMV's Matzen field, discovered in 1949, accounted for about half of Austrian crude output in 1999. Total production, all of which is processed in domestic refineries, has been practically constant for more than 15 years.

AZERBAIJAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	161
Production (crude oil and NGL's, million tonnes, 1999)	13.8
R/P ratio (years)	11.6
Year of first commercial production	1873

This is one of the world's oldest oil-producing areas, large-scale commercial production having started in the 1870's. During World War II the republic was the USSR's major source of crude, but then decreased in importance as the emphasis moved to Siberia. Recoverable reserves are still of considerable size: Riva (1994) quotes proven reserves as 1.3 billion barrels (broadly in line with *Oil & Gas Journal's* figure of 1 178 million barrels used above), with additional "inferred reserves" from known resources as 1.7 billion barrels and recoverable undiscovered resources at a "most likely" level of 3.6 billion barrels.

The development of Azerbaijan's offshore oil resources in the Caspian Sea, currently under way, would re-establish the republic as a major oil producer and exporter. With new Caspian fields coming into production, oil output rose substantially in 1998 and 1999. In the latter year, 89% of Azerbaijan’s production was obtained offshore.

BAHRAIN

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	20
Production (crude oil and NGL’s, million tonnes, 1999)	2.2
R/P ratio (years)	8.3
Year of first commercial production	1933

This was the first of the states on the western side of the Gulf to develop crude oil production. The Awali field came into commercial operation in 1933 - it remains the sole producing field. Proven reserves now stand at 148 million barrels, with output of crude about 38 000 b/d and NGL's a further 12 000 b/d. The crude is refined in the Bapco refinery at Sitra, while most of the NGL's are exported. Bahrain is a member of OAPEC.

BANGLADESH

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	5.7
Production (crude oil and NGL’s, million tonnes, 1999)	0.1
R/P ratio (years)	52.1
Year of first commercial production	1973

There are a number of gas/condensate fields, some of which were discovered prior to the establishment of Bangladesh in 1972. Current oil output (almost all of which can be classed as condensate) is in the order of 3 000 b/d.

BARBADOS

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	0.4
Production (crude oil and NGL’s, million tonnes, 1999)	0.1
R/P ratio (years)	4.3
Year of first commercial production	1973

With the smallest national oil production sector in the Western Hemisphere, the country's slender resources had appeared to be approaching exhaustion. However, an intensive drilling programme boosted production in 1998 and 1999 to about twice the level achieved in the previous two years. The crude produced is exported to Trinidad for processing.

BELARUS

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	27
Production (crude oil and NGL’s, million tonnes, 1999)	1.8
R/P ratio (years)	14.7

There are modest oil resources, with a number of small fields all located in the Pripyat region in the south-east of the country. Total output has been in gradual decline since 1990.

BENIN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1.1
Production (crude oil and NGL's, million tonnes, 1999)	0.05
R/P ratio (years)	23.2
Year of first commercial production	1981

The Seme offshore field, discovered in 1968, has been producing crude on a very moderate scale for the past 20 years. Proved reserves, originally assessed as 100 million barrels, have been sharply reduced more than once and now stand at about 8 million barrels. The small amount of crude produced is all exported.

BOLIVIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	17
Production (crude oil and NGL's, million tonnes, 1999)	1.8
R/P ratio (years)	8.8
Year of first commercial production	1930

The oil fields which have been discovered so far are all located in the eastern foothills of the Andes, in the sub-Andean and Pie de Monte basins. Almost all current output is of very light oils, more akin to condensate than to crude oil. The level of proved recoverable reserves used in this Survey is based upon OGJ's assessment of approximately 132 million barrels.

During the 1990's oil output followed an upward trend. Although Bolivia was formerly a fairly substantial crude exporter, during the last two decades virtually all output has been processed locally.

BRAZIL

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1 172
Production (crude oil and NGL's, million tonnes, 1999)	55.8
R/P ratio (years)	20.6
Year of first commercial production	1940

Brazil's proved reserves feature significantly within the Western Hemisphere - not in the same league as the three largest producers (USA, Venezuela and Mexico), but exceeding those of Canada and greater than those of Argentina, Colombia and Ecuador combined. Most of the reserves located up till the mid-1970's were in the north-east and central regions, remote from the main centres of oil demand in the south and south-east. Discoveries in offshore areas, in particular the Campos Basin, transformed the reserves picture.

The proved amount of oil in place reported by the Brazilian WEC Member Committee is substantially higher than that for the 1998 survey (10 137 million tonnes versus 5 455 million tonnes) but the proved recoverable reserves reported are only marginally higher (1 172 against 1 111 million tonnes). Of the current proved reserves, 90% are located offshore.

Oil production followed a strongly upward trend during the 1990's: virtually all output is processed in domestic refineries.

BRUNEI

Proved recoverable reserves (crude oil and NGL's, million tonnes)	184
Production (crude oil and NGL's, million tonnes, 1999)	8.9
R/P ratio (years)	20.3
Year of first commercial production	1929

Although the earliest discoveries (Seria and Rasau fields) were made on land, virtually all subsequent oil fields have been found in offshore waters. With proved reserves of 1 350 million barrels (according to OGJ), Brunei has the third highest level in south-east Asia. There were eight offshore fields in production in 1999, together with three onshore fields: total output (including about 15 000 b/d of natural gasoline) was 182 000 b/d, somewhat higher than in recent years. About 95% of Brunei's oil output is exported, mostly to Japan, Thailand, South Korea and Singapore.

BULGARIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	2.0
Production (crude oil and NGL's, million tonnes, 1999)	0.03
R/P ratio (years)	82.2
Year of first commercial production	1954

Oil resources discovered so far have been very limited in extent. There are a few small fields in the north of the country near the Romanian border and one offshore field (Tjulenovo) in the Black Sea. Total output has been in gradual decline since around 1980.

CAMEROON

Proved recoverable reserves (crude oil and NGL's, million tonnes)	55
Production (crude oil and NGL's, million tonnes, 1999)	4.8
R/P ratio (years)	11.5
Year of first commercial production	1978

Virtually all the oil fields that have been located are in western offshore waters, contiguous with those of Nigeria. Almost all were discovered in the 1970's, mostly by Elf and Pecten (a Shell subsidiary). Exploration activity accelerated following the establishment of a new petroleum code in 1990, but proved reserves have stagnated at 400 million barrels since the end of 1988. Crude production has been on a declining trend since 1985. About 75% of output is exported, mostly to Europe and the USA.

CANADA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	779
Production (crude oil and NGL's, million tonnes, 1999)	89.8
R/P ratio (years)	8.7
Year of first commercial production	1862

There is a very substantial oil resource base, albeit not on the scale of the USA and Mexico. Resources and reserves have been reported by the Energy Council of Canada in terms of the *Initial Established Reserves* and *Remaining Established Reserves*, as defined by the Canadian Association of Petroleum Producers (CAPP). Within proved amounts in place of 3 147 million tonnes of crude oil and 399 million tonnes of NGL's, the reported levels of proved recoverable reserves (reflecting *Remaining Established Reserves*) are 636 million tonnes (748 million m^3) of crude and 143 million tonnes (270 million m^3) of NGL's (ethane, propane, butanes and pentanes plus). Offshore recoverable reserves account for nearly 26% of the crude oil and 4% of the NGL's.

Further huge quantities of crude oil and NGL's (totalling some 23.5 billion tonnes) have been reported as additional amounts in place, of which approximately 6.7 billion tonnes of crude and 0.7 billion tonnes of NGL's are considered to be potentially recoverable.

After many years as a comparatively minor producer, Canada's oil output became of real significance only after major discoveries such as the Leduc field in 1947. Output advanced rapidly from around 1950; crude oil production passed the million b/d mark in 1968. In 1999 output of crude was 1.35 million b/d and that of NGL's (including pentanes) 675 000 b/d.

Canada is the world leader in the production of oil from deposits of oil sands - see the chapter on natural bitumen.

CHILE

Proved recoverable reserves (crude oil and NGL's, million tonnes)	20
Production (crude oil and NGL's, million tonnes, 1999)	0.6
R/P ratio (years)	31.6
Year of first commercial production	1950

Oil resources are on a fairly modest scale, and are located in the Magallanes Basin in the far south of the country, on or near the island of Tierra del Fuego; several oil and gas fields straddle the border with Argentina. Chile's portion of Magallanes has reached maturity, after producing some 400 million barrels: oil output has fallen every year since 1982. Proved recoverable reserves, as published by *Oil & Gas Journal*, were reduced by 50% in 1997, from 300 to 150 million barrels, at which level they have remained.

CHINA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	4 793
Production (crude oil and NGL's, million tonnes, 1999)	160.2
R/P ratio (years)	29.9
Year of first commercial production	1939

The first significant oil find was the Lachunmia field in the north-central province of Gansu, which was discovered in 1939. An extensive exploration programme, aimed at self-sufficiency in oil, was launched in the 1950's; two major field complexes were discovered: Daqing (1959) in the north-eastern province of Heilongjiang and Shengli (1961) near the Bo Hai gulf. The most recent advice from the China National Committee of the World Energy Council gave proved recoverable oil reserves as 5 272 million tonnes as at the end of 1996. Allowing for cumulative production in 1997-1999 of 479 million tonnes, the remaining recoverable reserves stand at about 4.8 billion tonnes (no information has been received regarding additions or revisions to reserves).

China's oil reserves are by far the largest of any country in Asia: oil output is on a commensurate scale, with the 1999 level accounting for about 40% of the regional total. China exported more than 7 million tonnes of crude oil in 1999.

COLOMBIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	323
Production (crude oil and NGL's, million tonnes, 1999)	42.8
R/P ratio (years)	7.5
Year of first commercial production	1921

Initially, oil discoveries were made principally in the valley of the Magdalena. Subsequently, other fields were discovered in the north of the country (from the early 1930's) and in 1959 oil was found in the Putamayo area in southern Colombia, near the border with Ecuador. More recently, major discoveries have included the Caño Limón field near the Venezuelan frontier, and the Cusiana and Cupiagua fields in the Llanos Basin to the east of the Andes. However, the remaining proved reserves have been shrinking since 1992, and are now at a very low level in relation to production (R/P ratio of only 7.5), on the basis of data published by the state oil company, Ecopetrol.

Colombia's production grew strongly between 1994 and 1999, increasing by about 80% over the period: 2000, however, displayed a sharp contraction in crude oil output, from 816 000 b/d in 1999 to 687 000 b/d (a 15.8% decrease).

CONGO (BRAZZAVILLE)

Proved recoverable reserves (crude oil and NGL's, million tonnes)	212
Production (crude oil and NGL's, million tonnes, 1999)	14.5
R/P ratio (years)	14.6
Year of first commercial production	1957

After becoming a significant oil producer in the mid-1970's, the country is now the fourth largest in sub-Saharan Africa. Most of the fields in current production were discovered by Elf or Agip between 1969 and 1983, in shallow coastal waters. The average quality of oil output has improved over the years, aided by the coming on-stream of Elf's deep-water Nkossa field. The bulk of oil production is exported.

CONGO (DEMOCRATIC REP.)

Proved recoverable reserves (crude oil and NGL's, million tonnes)	26
Production (crude oil and NGL's, million tonnes, 1999)	1.2
R/P ratio (years)	21.3
Year of first commercial production	1975

Oil reserves are confined to a small area in the estuary of the river Congo and the adjoining offshore zone. The greater part of the country's modest production comes from Chevron's offshore fields, with the balance emanating from onshore fields operated by Zairep (Fina). Most of the republic's output is exported.

CÔTE D'IVOIRE

Proved recoverable reserves (crude oil and NGL's, million tonnes)	14
Production (crude oil and NGL's, million tonnes, 1999)	0.5
R/P ratio (years)	27.4
Year of first commercial production	1980

A small number of oil fields were discovered offshore and modest levels of output (around 1 million tonnes/year) were achieved during the 1980's. Production ceased in 1992, but was restarted in 1995 by a joint venture between the state company Petroci and a number of foreign oil concerns.

CROATIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	11
Production (crude oil and NGL's, million tonnes, 1999)	1.5
R/P ratio (years)	7.6

There are widespread, albeit fairly modest, oil resources, with the majority of the fields located in Slavonia, in the north and north-east of the country. Proved recoverable reserves at end-1999 have been reported as 7.7 million tonnes of crude oil and 3.1 million tonnes of NGL's. Crude oil output, which has been tending to decline in recent years, is refined locally.

CUBA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	44
Production (crude oil and NGL's, million tonnes, 1999)	2.1
R/P ratio (years)	20.4
Year of first commercial production	1933

Known oil resources are on a small scale: proved reserves (as given by OGJ) remained static at 100 million barrels from 1990 to 1997, but were then raised (in two stages) to the current level of 283.5 million barrels. Over a million tonnes per annum of Cuban crude is used directly as fuel; the balance is refined locally.

CZECH REPUBLIC

Proved recoverable reserves (crude oil and NGL's, million tonnes)	11
Production (crude oil and NGL's, million tonnes, 1999)	0.2
R/P ratio (years)	62.2

Indigenous oil resources are on a limited scale. There are a few oil fields in the south-east of the country, with a total output of only about 175 000 tonnes in 1999. Reported proved recoverable reserves were 11 million tonnes at end-1999, within a proved amount in place of 14 million tonnes. In addition to these quantities, there is estimated to be some 13 million tonnes of recoverable oil.

DENMARK

Proved recoverable reserves (crude oil and NGL's, million tonnes)	122
Production (crude oil and NGL's, million tonnes, 1999)	14.7
R/P ratio (years)	8.3
Year of first commercial production	1972

All the oil fields so far discovered are located in the North Sea. Proved recoverable reserves (as reported by the Danish WEC Member Committee) are the fourth largest in Europe (excluding the Russian Federation). Within a proved amount in place of 1 492 million m^3 (approximately 9.4 billion barrels), 144 million m^3 (906 million barrels) is reported to be recoverable. Beyond these quantities are an estimated additional amount in place of 401 million m^3 (over 2.5 billion barrels), of which 94 million m^3 (591 million barrels) is deemed to be recoverable in the future.

The principal fields in production in 1999 were Dan, Gorm, Skjold, Siri and Harold, which together accounted for 80% of Danish oil output. About 75% of the crude was exported, chiefly to other countries in Western Europe.

ECUADOR

Proved recoverable reserves (crude oil and NGL's, million tonnes)	302
Production (crude oil and NGL's, million tonnes, 1999)	19.7
R/P ratio (years)	15.2
Year of first commercial production	1917

The early discoveries of oil (1913-1921) were made in the Santa Elena peninsula on the south-west coast. From 1967 onwards, numerous oil fields were discovered in the Amazon Basin to the north-east of the country, adjacent to the Putamayo fields in Colombia: these eastern (Oriente) fields are now the major source of Ecuador's oil production.

The level of proved reserves was raised by over 25% in 1993 and again (marginally) in 1995. Nearly two-thirds of oil production is exported, the rest being refined locally.

EGYPT (ARAB REP.)

Proved recoverable reserves (crude oil and NGL's, million tonnes)	529
Production (crude oil and NGL's, million tonnes, 1999)	41.4
R/P ratio (years)	13.5
Year of first commercial production	1911

Egypt has the fifth largest proved oil reserves in Africa, with about two-thirds located in its offshore waters. According to the Egyptian General Petroleum Corporation's 1999 Annual Report, Egypt's crude oil reserves were 412 million tonnes at the end of 1999. Reserves of NGL's (condensates and LPG) are not quoted separately in the Report, but the Egyptian WEC Member Committee reported a level of 117 million tonnes as at end-1996, which has been retained for this Survey. The main producing regions are in or alongside the Gulf of Suez and in the Western Desert. In 1999 some 69% of crude oil production came from fields in the Gulf of Suez region, 17% from the Western Desert, over 7% from Sinai and nearly 7% from the Eastern Desert.

Egypt is a member of OAPEC: crude oil exports account for about a quarter of its production. Total oil output (including condensate and gas-plant LPG's) has been declining in recent years. In 1999 crude oil production was 38.4 million tonnes (763 000 b/d), condensate production was 1.94 million tonnes (48 000 b/d), and LPG's from gas-processing plants amounted to just over 1 million tonnes (33 000 b/d).

EQUATORIAL GUINEA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1.5
Production (crude oil and NGL's, million tonnes, 1999)	4.5
R/P ratio (years)	-
Year of first commercial production	1992

The Alba offshore condensate field was discovered in 1984 near the island of Bioko, a province of Equatorial Guinea, by the American company Walter International. In 1996, four years after Alba was brought into production, Mobil and its US partner United Meridian began producing from Zafiro, another offshore field. Output was built up rapidly during the next two years; total oil production in Equatorial Guinea averaged 100 000 b/d in 1999.

The proved reserves quoted above (based on *Oil & Gas Journal* data) exclude the Zafiro field: consequently a realistic reserves/production ratio cannot be quoted.

FRANCE

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	21
Production (crude oil and NGL’s, million tonnes, 1999)	1.7
R/P ratio (years)	11.7
Year of first commercial production	1918

Prior to 1918 oil resources in Alsace/Lorraine were included in the total for Germany.

Current reserves are very largely in the Aquitaine Basin in the south-west and in the Paris Basin. The reported level of the proved amount in place is substantial (at some 450 million tonnes), but the proved recoverable portion is relatively small. Oil output has been in gradual decline for more than 10 years.

GABON

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	342
Production (crude oil and NGL’s, million tonnes, 1999)	17.0
R/P ratio (years)	20.1
Year of first commercial production	1961

Extensive oil resources have been located, both on land and offshore. In terms of proved recoverable reserves (as reported in OGJ), Gabon ranks third largest in sub-Saharan Africa. The published volume of proved reserves was raised from 1 340 to 2 499 million barrels in 1997, at which level it has remained. The onshore Rabi-Kounga field, discovered by Shell Gabon in 1985, accounts for over 50% of national output.

Gabon was a member of OPEC from 1975 to 1995, when it withdrew on the grounds that it was unfair for it to be charged the same membership fee as the larger producers but not to have equivalent voting rights.

In recent years over 95% of Gabon's oil output has been exported, mainly to the USA.

GEORGIA

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	4.8
Production (crude oil and NGL’s, million tonnes, 1999)	0.10
R/P ratio (years)	48.7
Year of first commercial production	1930

Oil resources are on a minor scale: *Oil & Gas Journal* gives proved reserves as 35 million barrels, while Riva (1994) estimates proved and inferred reserves as 100 million barrels, and projects as much again as recoverable from undiscovered resources. The oil fields so far discovered are in the eastern part of the country, plus some in the coastal strip along the Black Sea. Oil output during the past 10 years has not exceeded 200 000 tonnes/year (4 000 b/d).

GERMANY

Proved recoverable reserves (crude oil and NGL's, million tonnes)	42
Production (crude oil and NGL's, million tonnes, 1999)	2.7
R/P ratio (years)	15.6
Year of first commercial production	1880

In the course of a long history of oil production, Germany was for a time (circa 1955-1975) the largest producer of crude in Western Europe. The reported level of proved recoverable reserves has risen by 50% since the 1998 Survey, but the total is still relatively modest. There are a considerable number of small onshore fields, mostly located in the north and north-east of the country, and two offshore fields (Mittelplate and Schwedeneck-See) situated not far south of the border with Denmark. Total oil output has been gradually declining for many years.

GHANA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	2.3
Production (crude oil and NGL's, million tonnes, 1999)	0.3
R/P ratio (years)	7.5
Year of first commercial production	1978

Oil reserves discovered in two offshore basins (Saltpond and Tano) in the late 1970's provide a moderate resource base, assessed at some 37 million tonnes in 1992. Proved recoverable reserves have fluctuated over past years but now stand at about 2.3 million tonnes, based on the level reported in OGJ. Output, initially from the Saltpond field and more recently also from the North and South Tano fields, has been at a low level throughout.

GREECE

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1.4
Production (crude oil and NGL's, million tonnes, 1999)	0.3
R/P ratio (years)	4.3
Year of first commercial production	1981

The country's slender oil resources are confined to the Prinos and Prinos North fields, located off the island of Thasos in the northern Aegean Sea. Output of crude has been on a downward trend since around 1985.

GUATEMALA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	79
Production (crude oil and NGL's, million tonnes, 1999)	1.3
R/P ratio (years)	62.7
Year of first commercial production	1976

A number of oil fields have been discovered since 1970, the most important field in current production being Xan (1985). Proved reserves remain on a fairly modest scale despite OGJ's 1998 revision from 200 to 526 million barrels. The crude produced is exported, mostly to the USA.

HUNGARY

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	8
Production (crude oil and NGL’s, million tonnes, 1999)	1.8
R/P ratio (years)	3.7
Year of first commercial production	1937

The reported amount of oil in place is fairly considerable (nearly 110 million tonnes) but the proved recoverable reserves are quite small. Within an estimated additional amount of around 108 million tonnes, about 15 million tonnes is considered to be recoverable at some time.

Most of the known oil fields are in the eastern part of the country; by far the largest producer is the Algyo field in south-east Hungary, which accounted for 52% of national output of crude in 1999. Overall production of oil (including NGL's) has been in gradual decline during the 1990's.

INDIA

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	645
Production (crude oil and NGL’s, million tonnes, 1999)	36.7
R/P ratio (years)	16.7
Year of first commercial production	1890

The amount of proved recoverable reserves reported for this Survey is 645 million tonnes, of which 335 million tonnes is located offshore.

For more than 60 years after its discovery in 1890, the Digboi oil field in Assam, in the north-east of the country, provided India with its only commercial oil production: this field was still producing in 1999, albeit at only about 300 b/d. Since 1960 numerous onshore discoveries have been made in the western, eastern and southern parts of India; the outstanding find was, however, made in offshore waters in 1974, when the Bombay High oil and gas field was discovered. In 1999 this one field provided 36% of national oil output. Total production of oil (including gas-plant liquids) has fluctuated in recent years around a mean level of about 37 million tonnes per annum.

INDONESIA

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	707
Production (crude oil and NGL’s, million tonnes, 1999)	67.4
R/P ratio (years)	10.2
Year of first commercial production	1893

The first commercial discovery of oil was made in north Sumatra in 1885; subsequent exploration led to the finding of many more fields, especially in southern Sumatra, Java and Kalimantan. The Indonesian WEC Member Committee has reported that proved recoverable oil reserves were 5 203 million barrels at the end of 1999, of which 1 114 million barrels (21.4%) were located in offshore deposits. Additional (non-proved) oil that is considered to be recoverable in the future amounts to 4 623 million barrels.

In 1999 Indonesia exported about 60% of its output of crude oil and condensate, as well as a large part of its production of gas-plant LPG's. It has been a member of OPEC since 1962.

IRAN (ISLAMIC REP.)

Proved recoverable reserves (crude oil and NGL's, million tonnes)	12 667
Production (crude oil and NGL's, million tonnes, 1999)	175.2
R/P ratio (years)	71.9
Year of first commercial production	1913

The first commercial crude oil discovered in Iran was at Masjid-i-Sulaiman in 1908. Further exploration in the next two decades resulted in the discovery of a number of major oil fields, including Agha Jari and Gach Saran. Fields such as these confirmed Iran in its role as a global player in the oil industry. After many years as a major oil producer, the country's oil resources are still enormous: proved reserves, as published by OPEC (and also quoted by *World Oil*) were
93 100 million barrels at the end of 1999, the level which has been adopted for the present Survey. OAPEC and OGJ quote the somewhat lower figure of 89 700 million barrels, but the reserves/production ratio is high (at around 70 years) in either case.

In 1999, 74% of Iran's crude oil output of 3.4 million b/d was exported, mostly to Europe and Asia. Iran was a founder member of OPEC in 1960.

IRAQ

Proved recoverable reserves (crude oil and NGL's, million tonnes)	15 141
Production (crude oil and NGL's, million tonnes, 1999)	125.8
R/P ratio (years)	>100
Year of first commercial production	1927

Crude oil deposits were discovered near Kirkuk in northern Iraq in 1927, with large-scale production getting under way in 1934-1935 following the construction of export pipelines to the Mediterranean. After World War II more oil fields were discovered and further export lines built. Proved reserves, as quoted by OAPEC, OPEC and OGJ, now stand at some 112 billion barrels, second only to Saudi Arabia in the whole of the Middle East, and indeed in the world.

Iraq was a founder member of OPEC in 1960 and it is also a member of OAPEC.

The Iraqi oil industry was severely disrupted by the 1990-1991 Gulf War and its aftermath. Prior to the conflict the republic was producing some 2.8 million b/d and exporting nearly 2.3 million b/d, mainly to Europe, North America and Asia. Output and exports in 1999 approached their pre-1990 levels.

ISRAEL

Proved recoverable reserves (crude oil and NGL's, million tonnes)	0.5
Production (crude oil and NGL's, million tonnes, 1999)	0.004
R/P ratio (years)	>100
Year of first commercial production	1956

Despite hydrocarbons exploration both on land and offshore (in the Mediterranean and the Dead Sea) the known oil resources are at best marginal. Proved reserves are assessed at just under 4 million barrels; annual crude oil output in recent years has been about 4 000 tonnes.

ITALY

Proved recoverable reserves (crude oil and NGL's, million tonnes)	61
Production (crude oil and NGL's, million tonnes, 1999)	5.0
R/P ratio (years)	12.2
Year of first commercial production	1861

Like France and Germany, Italy has a long history of oil production, albeit on a very small scale until the discovery of the Ragusa and Gela fields in Sicily in the mid-1950's. Subsequent exploration led to the discovery of a number of fields offshore Sicily, several in Adriatic waters and others onshore in the Po Valley Basin. The reported level of proved recoverable reserves is considerably higher than that for the 1998 Survey. Total oil output (including minor quantities of NGL's) has been falling in recent years.

JAPAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	8
Production (crude oil and NGL's, million tonnes, 1999)	0.6
R/P ratio (years)	12.2
Year of first commercial production	1875

Indigenous oil resources are modest: a number of small fields have been discovered on the islands of Honshu and Hokkaido, including two in Honshu's offshore waters. More than one-third of Japan's 1999 crude output of 12 000 b/d was produced offshore. Total oil output (including small amounts of NGL's) has drifted downwards in recent years.

JORDAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	0.12
Production (crude oil and NGL's, million tonnes, 1999)	0.002
R/P ratio (years)	68.5
Year of first commercial production	1985

Hydrocarbons exploration work has been undertaken at intervals since 1938 by successive foreign operators but the only commercial discovery has been the Hamza field, located by a Yugoslav company in 1982. Small-scale production got under way in 1984 but after a brief life the field was reported to have been formally closed in the middle of 1993. Hamza's lifetime production had been some 800 000 barrels: its reserves remaining were in the region of 300 000 barrels.

OGJ's reported level of total proved reserves was raised to 900 000 barrels at end-1999. It reports that the Hamza field is in fact still producing oil, albeit at a miniscule rate (less than 40 b/d).

See also the chapter on oil shale, for information regarding Jordan's large unexploited reserves of shale.

KAZAKHSTAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	742
Production (crude oil and NGL's, million tonnes, 1999)	30.1
R/P ratio (years)	23.5
Year of first commercial production	1911

Kazakhstan's oil resources are easily the largest of all the former Soviet republics (apart from the Russian Federation): *Oil & Gas Journal* puts proved reserves (as adopted above) at 5 417 million barrels, whilst other published assessments quote higher levels (e.g. *World Oil*: 6.42 billion barrels; BP: 8 billion barrels). These volumes are all considerably higher than Riva (1994), who estimated proved reserves as 3.3 billion barrels, with inferred reserves of 13.7 and undiscovered resources of 26 billion barrels. Kazakstan's total remaining oil endowment is thus put at some 43 billion barrels (say, 6 billion tonnes).

Most of the republic's oil fields are in the north and west of the country. Output of oil rose by 46% between 1995 and 1999 to just over 30 million tonnes (632 000 b/d), including 3.4 million tonnes (97 000 b/d) of NGL's. In 1998, exports accounted for 70% of the republic's oil production.

KUWAIT

Proved recoverable reserves (crude oil and NGL's, million tonnes)	13 310
Production (crude oil and NGL's, million tonnes, 1999)	99.1
R/P ratio (years)	>100
Year of first commercial production	1946

Note: Kuwait data include its share of Neutral Zone.

The State of Kuwait is one of the most oil-rich countries in the world: it ranks fourth in terms of the volume of proved reserves. Oil was discovered at Burgan in 1938 and commercial production commenced after World War II. Seven other oil fields were discovered during the next 15 years and output rose rapidly. Kuwait was one of the founder-members of OPEC in 1960 and is also a member of OAPEC. The level of proved recoverable reserves adopted for the present Survey is 96.5 billion barrels, (as quoted by OAPEC, OGJ and OPEC) - a figure unchanged since 1991.

Kuwait's oil industry and economic infrastructure were severely damaged during the Gulf War in 1990-1991 but crude oil output was restored by 1993. In compliance with its OPEC quota, Kuwait's crude production in 1999 averaged 1.87 million b/d; at 948 000 b/d, exports accounted for just over 50% of the crude oil produced. The main markets for Kuwaiti crude were Asia, North America and Western Europe.

KYRGYZSTAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	5.5
Production (crude oil and NGL's, million tonnes, 1999)	0.07
R/P ratio (years)	77.8

Kyrgyzstan's proved reserves of some 40 million barrels are relatively modest, although large parts of the republic have not been explored. Riva (1994) quoted prospective undiscovered reserves as 0.4-1.6 billion barrels, with a "most likely" level of 0.6. The oil fields so far discovered are all in the west of the country, near its borders with Tajikistan and Uzbekistan. Production of crude has declined in recent times to well under 100 000 tonnes/year.

LIBYA/GSPLAJ

Proved recoverable reserves (crude oil and NGL's, million tonnes)	3 892
Production (crude oil and NGL's, million tonnes, 1999)	67.0
R/P ratio (years)	57.4
Year of first commercial production	1961

With proved oil reserves of 29.5 billion barrels, Libya accounts for 38% of the total for Africa. The majority of the known oil reservoirs lie in the northern part of the country; there are a few offshore fields in western waters near the Tunisian border. The crudes produced are generally light (over 35^o API) and very low in sulphur. Libya joined OPEC in 1962 and is also a member of OAPEC.

Libya exported 85% of its crude oil output in 1999, almost all to Western Europe.

The level of proved reserves adopted for the present Survey is based upon data published by *Oil & Gas Journal*, and is line with the levels quoted by *World Oil* and OPEC in their latest published compilations of reserve data. The OAPEC *Annual Statistical Report 2000* gives a substantially higher figure (45 billion barrels), as it has for all years since 1990.

LITHUANIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1.6
Production (crude oil and NGL's, million tonnes, 1999)	0.2
R/P ratio (years)	7.1
Year of first commercial production	1990

Although oil fields have been discovered in at least 16 locations, recoverable reserves are considered to be very modest. Oil production began in 1990 and, although gradually rising, is still of very slender proportions.

MALAYSIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	513
Production (crude oil and NGL's, million tonnes, 1999)	35.7
R/P ratio (years)	13.5
Year of first commercial production	1913

Oil was discovered at Miri in northern Sarawak in 1910, thus ushering in Malaysia's long history as an oil producer. However, it was not until after successful exploration in offshore areas of Sarawak, Sabah and peninsular Malaysia in the 1960's and 1970's that the republic really emerged as a major producer. Proved reserves have remained in the vicinity of 4 billion barrels since the early 1990's. After following a rising trend for many years, oil production has levelled off since 1995, in line with the Government's National Depletion Policy. In 1998, over 50% of Malaysian crude oil production was exported, chiefly to Thailand, the Republic of Korea, Indonesia, Japan and India.

MEXICO

Proved recoverable reserves (crude oil and NGL's, million tonnes)	3 858
Production (crude oil and NGL's, million tonnes, 1999)	166.1
R/P ratio (years)	23.2
Year of first commercial production	1901

Mexico's massive oil resource base has given rise to one of the world's largest oil industries, centred on the state enterprise Petróleos Mexicanos (Pemex), founded in 1938.

In its *Memoria de Labores 1999*, Pemex quotes its proved reserves (in millions of barrels) as: crude oil 24 631, condensate 752 and gas-plant liquids 2 876. In addition to these *Proved* oil reserves (totalling 28 260 million barrels), *Probable* reserves are given as 10 108 million barrels and *Possible* reserves as 9 164 million barrels: a total of over 47.5 billion barrels.

Commercial oil production began in 1901 and by 1918 the republic was the second largest producer in the world. The discovery and development of oil fields along the eastern side of the country - in particular, offshore fields in the Gulf of Campeche - have brought annual production up to its present level. Output of crude oil, condensate and NGL's in 1999 was 3 343 000 b/d; exports of crude totalled 1 553 000 b/d, of which some 75% were consigned to the USA.

MOROCCO

Proved recoverable reserves (crude oil and NGL's, million tonnes)	0.25
Production (crude oil and NGL's, million tonnes, 1999)	0.01
R/P ratio (years)	25.1
Year of first commercial production	1932

With nearly 70 years of oil production history, Morocco is Africa's longest-established minor producer, although annual output peaked at just over 3 000 b/d in 1963. Two oil fields and two gas/condensate fields were in production in 1999: all are located in the western coastal strip. National output has fluctuated in recent years but remains of negligible proportions.

MYANMAR (BURMA)

Proved recoverable reserves (crude oil and NGL's, million tonnes)	6.8
Production (crude oil and NGL's, million tonnes, 1999)	0.4
R/P ratio (years)	14.9
Year of first commercial production	1889

Having been an oil producer on a moderate scale for well over a hundred years, the republic's remaining proved reserves are fairly slender, at an estimated 50 million barrels. Many small oil deposits have, over the years, been discovered in the valley of the Irrawaddy: by 1999, five fields remained in production, of which two (Chauk-Lanywa and Yenangyaung) had been discovered as long ago as 1902. In recent years the bulk of oil production has come from the Mann field. Total output has been gradually declining and is now less than 500 000 tonnes/year (10 000 b/d). All of the crude produced is processed locally.

NETHERLANDS

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	13
Production (crude oil and NGL’s, million tonnes, 1999)	2.6
R/P ratio (years)	4.7
Year of first commercial production	1943

Oil has been produced for well over 50 years, but there is estimated to be about 128 million tonnes still in place, of which about 10% is considered to be economically recoverable. Around 75% of the proved reserves are located offshore. The Netherlands oil fields are mostly in the west of the country, in the vicinity of Rotterdam and The Hague, plus a number of offshore locations in nearby waters. One onshore field (Schoonebeek) is close to the German border, not far from the Groningen gas-producing area. The largest onshore producer in 1999 was Rijswijk, just east of The Hague. Total output (including NGL's) has been declining in recent years.

NEW ZEALAND

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	14
Production (crude oil and NGL’s, million tonnes, 1999)	2.0
R/P ratio (years)	6.8
Year of first commercial production	1935

New Zealand’s known oil resources are quite modest, with relatively more strength in natural gas liquids than in crude oil. There are seven sedimentary basins; oil and gas discoveries have been concentrated in the Taranaki region on the west side of North Island. Minor quantities of oil were produced from the Motorua field in Taranaki from 1935 to 1972. Other fields subsequently brought into production include the (onshore) Kapuni and (offshore) Maui gas/condensate fields and the onshore McKee oil field. Estimates of resources and reserves reported by the Ministry of Economic Development are in terms of "proven plus possible" values. Within a proved amount in place of 46.43 million tonnes of crude oil and NGL’s, the recoverable reserves are put at 14.48 million tonnes, of which 12.21 million tonnes are located offshore.

Oil output in 1999 comprised 1.8 million tonnes of crude/condensate and 0.2 million tonnes of gas-plant NGL's. About 75% of the crude/condensate was exported, very largely to Australia and the USA.

NIGERIA

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	3 000
Production (crude oil and NGL’s, million tonnes, 1999)	98.1
R/P ratio (years)	30.4
Year of first commercial production	1957

Nigeria's proved oil reserves are the second largest in Africa, after those of Libya. The country's oil fields are located in the south, mainly in the Niger delta and offshore in the Gulf of Guinea. Nigeria has been a member of OPEC since 1971.

Published assessments of proved recoverable reserves are closer to consensus than hitherto: for the purposes of the present Survey, the level of 22.5 billion barrels reported by OPEC (*Annual Statistical Bulletin*, 1999) has been adopted (OAPEC and OGJ quote the same figure).

Just over 75% of Nigeria's crude oil output was exported in 1999, mostly to North America and Western Europe.

NORWAY

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1 510
Production (crude oil and NGL's, million tonnes, 1999)	148.7
R/P ratio (years)	10.2
Year of first commercial production	1971

Starting with the discovery of the Ekofisk oil field in 1970, successful exploration in Norway's North Sea waters has brought the country into No. 1 position in Europe (excluding the Russian Federation), in terms of oil in place, proved reserves and production. For the present Survey, the Norwegian WEC Member Committee has reported proved amounts in place of 2 595 million tonnes of crude oil and 135 million tonnes of NGL's, within which the recoverable element is given as 1 440 and 70 million tonnes, respectively. In addition to the quoted proved amount, there is estimated to be a further 1 200 million tonnes of crude oil in place: the proportion that might be ultimately recoverable cannot be specified.

Norway's recoverable reserves are over twice those of the UK; oil output in 1999 was however only about 8% higher than that of the UK. Norwegian oil production contracted slightly in 1998-1999, after 16 years of unremitting growth. The groups of fields with the largest output in 1999 were Oseberg, Statfjord, Gulfaks, Ekofisk and Troll. Over 90% of Norwegian oil production was exported in 1999, mostly to Western European countries, the USA and Canada.

OMAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	737
Production (crude oil and NGL's, million tonnes, 1999)	45.3
R/P ratio (years)	16.2
Year of first commercial production	1967

In a regional context, this is one of the less well-endowed Middle East countries but its proved reserves are, nevertheless, quite substantial (5.4 billion barrels at end-1999, according to OAPEC). Three oil fields were discovered in the north-west central part of Oman in the early 1960's; commercial production began after the construction of an export pipeline. Many other fields have subsequently been located and brought into production, making the country a significant oil producer and exporter; it has, however, never joined OPEC or OAPEC. Production levels have steadily increased over the years and averaged 911 000 b/d in 1999: a high proportion of crude oil output is exported, mainly to Japan, South-east Asia and China.

PAKISTAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	33
Production (crude oil and NGL's, million tonnes, 1999)	2.8
R/P ratio (years)	11.4
Year of first commercial production	1922

Oil has been produced in what is now the republic of Pakistan from the early 1920's: the remaining proved reserves amount to just over 33 million tonnes (equivalent to 246 million barrels). A number of fields were discovered in the upper Indus basin in the 1930's and 1940's. Since around 1980 a large number of hydrocarbon discoveries have been made in the central and southern parts of the country. In 1999 there were at least 70 oil and condensate fields in production, although none of them was of any great size. Total output has fluctuated within a range of about 55 000-65 000 b/d since 1989. About 15% of oil production was exported in 1999.

PAPUA NEW GUINEA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	43
Production (crude oil and NGL's, million tonnes, 1999)	4.1
R/P ratio (years)	10.4
Year of first commercial production	1992

Five sedimentary basins are known to exist in PNG. Most exploration activity, and all hydrocarbon discoveries to date, have been made in the Papuan Basin in the southern part of the mainland. After many campaigns of exploration (starting in 1911), the first commercial discoveries were eventually made during the second half of the 1980's. Commercial production began in 1992 after an export pipeline had been built. The oil exported is a blend called Kutubu Light (45º API). Output in 1999 averaged just under 90 000 b/d.

PERU

Proved recoverable reserves (crude oil and NGL's, million tonnes)	48
Production (crude oil and NGL's, million tonnes, 1999)	5.3
R/P ratio (years)	8.8
Year of first commercial production	1883

Peru is probably the oldest commercial producer of oil in South America, but its remaining recoverable reserves are comparatively slender, at less than 50 million tonnes (based on OGJ's figure of 355 million barrels). For many years oil production was centred on the fields in the Costa (coastal) area in the north-west; from about 1960 onwards the Zocalo (continental shelf) off the north-west coast and the Oriente area east of the Andes came into the picture. In 1998 the Oriente fields accounted for about 68% of total oil output, the Costa fields for 18% and the Zocalo 14%. Production overall has followed a gently downward slope in recent years.

PHILIPPINES

Proved recoverable reserves (crude oil and NGL's, million tonnes)	43
Production (crude oil and NGL's, million tonnes, 1999)	0.04
R/P ratio (years)	>100
Year of first commercial production	1979

This is one of the more recent arrivals on the Asian oil scene, the first discoveries being made in 1976-1977. Except for a few fields on the islands of Cebu and Leyte, all oil finds have been made offshore, in the South China Sea west of the islands of Mindoro and Palawan. Mean proved reserves of crude oil and NGL's at end-1999 were some 336 million barrels, within a reported range of 231-285 million barrels for crude and one of 59-98 million barrels for condensate.

Output from the offshore Nido field began in 1979, reaching a peak of 42 000 b/d by the end of the year; a rapid decline soon set in, and national production has never regained its 1979 level.

POLAND

Proved recoverable reserves (crude oil and NGL's, million tonnes)	14
Production (crude oil and NGL's, million tonnes, 1999)	0.4
R/P ratio (years)	32.2
Year of first commercial production	1874

One of Europe's oldest producers of crude oil, Poland now possesses a low level of reported recoverable reserves, and a commensurately low level of output. There are three groups of oil fields: one in Pomerania near the Baltic coast, a second near the western border with Germany and the third in the Carpathians, in the far south of Poland. Several fields have been discovered offshore, one of which (B-3) has been brought into production.

QATAR

Proved recoverable reserves (crude oil and NGL's, million tonnes)	600
Production (crude oil and NGL's, million tonnes, 1999)	33.9
R/P ratio (years)	17.0
Year of first commercial production	1949

In regional terms, oil resources are relatively small, Qatar's strength being much more in natural gas. In the 1930's interest in its prospects was aroused by the discovery of oil in neighbouring Bahrain. The Dukhan field was discovered in 1939 but commercialisation was deferred until after World War II. During the period 1960-1970, several offshore fields were found, and Qatar's oil output grew steadily. It joined OPEC in 1961 and also became a member of OAPEC.

The level of proved recoverable oil reserves (4 500 million barrels) retained for the present Survey is that quoted by OAPEC in its *Annual Statistical Report 2000*, and is one that OAPEC has kept unchanged since 1994. However, it should be noted that OGJ, which had retained a level of 3 700 million barrels for Qatar's oil reserves over the same period, has recently published a significantly higher figure for proved reserves at end-2000: 13 157 million barrels.

Crude oil production has risen sharply since 1995 and now exceeds 700 000 b/d. Qatar is a major producer of NGL's: its output was over 80 000 b/d in 1998, almost all of which was exported, very largely to Japan, the Republic of Korea and other Asia/Pacific countries. Crude oil exports follow a similar pattern of destinations.

ROMANIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	108
Production (crude oil and NGL's, million tonnes, 1999)	6.4
R/P ratio (years)	16.7
Year of first commercial production	1857

Besides being one of Europe's oldest oil producers, Romania still possesses substantial reserves of recoverable oil. Within a proved amount of oil in place of 196 million tonnes, recoverable reserves are reported as 108 million tonnes. A very large quantity (around 1.7 billion tonnes) is given as the estimated additional amount in place, but no indication is available as to how much of this might be recoverable.

The principal region of production has long been the Ploesti area in the Carpathian Basin to the north-west of Bucharest, but a new oil province has come on the scene in recent years with the start-up of production from two offshore fields (West and East Lebada) in the Black Sea. In national terms, oil output (including NGL's) has been slowly contracting during the past five or six years.

RUSSIAN FEDERATION

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	6 654
Production (crude oil and NGL’s, million tonnes, 1999)	304.8
R/P ratio (years)	21.5

The Russian oil industry has been developing for well over a century, much of that time under the Soviet centrally-planned and state-owned system, in which the achievement of physical production targets was of prime importance. After World War II, hydrocarbons exploration and production development shifted to the east, with the opening-up of the Volga-Urals and West Siberia regions. The level of proved recoverable reserves adopted for the present Survey is based on the figure of 48 573 million barrels quoted by OGJ, and is unchanged since the 1998 Survey.

Production levels in Russia advanced strongly from the mid-1950's to around 1980 when output levelled off for a decade. After a sharp decline in the first half of the 1990’s, oil production levelled off at around 305 million tonnes/year, until an upturn in 2000 brought the total up to just over 323 million tonnes. Russia exports over 40% of its oil production.

SAUDI ARABIA

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	35 983
Production (crude oil and NGL’s, million tonnes, 1999)	409.6
R/P ratio (years)	84.4
Year of first commercial production	1936

Note: Saudi Arabia data include its share of Neutral Zone.

The Kingdom has been a leading oil producer for more that 40 years and currently has by far the world's largest proven reserves of oil: at end-1999 these represented about 25% of the global total. The first major commercial discovery of oil in Saudi Arabia was the Dammam field, located by Aramco in 1938; in subsequent years the company discovered many giant fields, including Ghawar (1948), generally regarded as the world's largest oil field, and Safaniyah (1951), the world's largest offshore field.

Whilst not displaying an exact consensus, current published assessments of Saudi Arabia’s proved oil reserves fall within a narrow bracket: namely (in billions of barrels), *World Oil* 261.4, OPEC 262.8, OAPEC and OGJ (as used in this Survey) 263.5.

Saudi Arabia was a founder-member of OPEC and also of OAPEC. In 1999 its output of crude oil averaged 7.7 million b/d (including its share of Neutral Zone production): of this total, some 5.7 million b/d was exported. Major destination regions were Asia, North America and Western Europe.

SENEGAL

Proved recoverable reserves (crude oil and NGL's, million tonnes)	N
Production (crude oil and NGL's, million tonnes, 1999)	N
R/P ratio (years)	-
Year of first commercial production	1995

During the 1970's, offshore exploration located a deposit of nearly a billion barrels of heavy oil (10º API) and traces of lighter crudes, but no commercially viable resources were established until the discovery of the Diam Niadio East field by the Irish independent company Tullow Oil in 1993. Diam Niadio East was succeeded by another field (Wayambam) in 1999. Both fields are primarily producers of natural gas, which has been supplied to the Senegalese utility Senelec for electricity generation. Small quantities of condensate have been processed by the SAR refinery at Dakar.

Tullow withdrew from Senegal in January 2001 on the expiry of its licence period.

Senegal's presently known oil reserves can be regarded as minimal.

SERBIA, MONTENEGRO

Proved recoverable reserves (crude oil and NGL's, million tonnes)	10
Production (crude oil and NGL's, million tonnes, 1999)	0.7
R/P ratio (years)	14.7

A number of oil fields have been discovered in a variety of locations within the Federal Republic of Yugoslavia, but the overall level of proved reserves is quite low. Production of crude oil has tended to decline in recent years, with a particularly sharp drop in 1999, the year in which NATO carried out air strikes against Yugoslavia. Normally, the bulk of oil output comes from the northern province of Vojvodina, with the balance of production provided by newer fields in central Serbia.

SLOVAKIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1.3
Production (crude oil and NGL's, million tonnes, 1999)	0.07
R/P ratio (years)	20.1

There are three oil fields at the eastern end of the country, together with one on its western border with the Czech Republic, but the overall levels of oil resources and reserves are deemed to be very low. Oil output is correspondingly small, and is moreover gradually declining.

SLOVENIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	0.003
Production (crude oil and NGL's, million tonnes, 1999)	0.001
R/P ratio (years)	3.0

A small number of oil fields have been discovered in the eastern part of the republic but resources, reserves and production are all reported to be of extremely small proportions.

SOUTH AFRICA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	7.4
Production (crude oil and NGL's, million tonnes, 1999)	1.5
R/P ratio (years)	5.0
Year of first commercial production	1993

In May 1997 the South African state oil exploration company Soekor began oil production at the offshore Oribi field, located 140 km south-west of Mossel Bay. Natural gas and condensate produced from the Mossel Bay field off the southern coast provide the feedstock for the Mossgas synthesis plant, which produces a range of liquid fuels (mostly for automotive purposes).

South Africa's oil production in 1999 (excluding synthesis from coal by Sasol) comprised 25 000 b/d of Oribi crude and 10 000 b/d of Mossel Bay condensate. On the basis of advice from the South African WEC Member Committee, recoverable reserves have been estimated as five times the 1999 production levels.

SPAIN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	2.0
Production (crude oil and NGL's, million tonnes, 1999)	0.8
R/P ratio (years)	2.1
Year of first commercial production	1966

The only commercial discovery of oil onshore has been the Ayoluengo field in north-central Spain, which was found in 1964. Beginning in the 1970's a number of offshore fields were discovered off the port of Tarragona on the Mediterranean coast. While the reported amount in place is over 67 million tonnes of crude plus 2 million tonnes of NGL's, the recoverable reserves are put at a very low level: they are effectively all offshore. Over and above the proved quantities, some 7 million tonnes is estimated to be in place, of which about half is deemed to be recoverable.

National output of crude oil (plus some NGL's) peaked in 1983 at just over 3 million tonnes and has generally followed a declining trend in subsequent years.

SUDAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	36
Production (crude oil and NGL's, million tonnes, 1999)	3.2
R/P ratio (years)	11.4
Year of first commercial production	1992

Several oil fields, including Heglig and Unity, were discovered in south-central Sudan in the early 1980's but terrorist action forced the companies concerned to withdraw. Other foreign companies started to undertake exploration and development activities some ten years later. Commercial production from the Heglig field began in 1996; since then Sudan has developed into an oil producer and exporter of some significance, a key factor being the construction of a 250 000 b/d export pipeline to the Red Sea. By the end of 1999, Sudan's oil production was around 130 000 b/d, and rapidly increasing.

SURINAM

Proved recoverable reserves (crude oil and NGL's, million tonnes)	11
Production (crude oil and NGL's, million tonnes, 1999)	0.7
R/P ratio (years)	16.9
Year of first commercial production	1982

The proved level of oil reserves is, at 74 million barrels, the lowest in South America. Three oil fields have been identified in the vicinity of the capital, Paramaribo, but only one (Tambaredjo, discovered in 1981) was reported to be in production in 1999.

SYRIA (ARAB REP.)

Proved recoverable reserves (crude oil and NGL's, million tonnes)	343
Production (crude oil and NGL's, million tonnes, 1999)	29.1
R/P ratio (years)	11.7
Year of first commercial production	1968

After many years (1930-1951) of unsuccessful exploration, oil was eventually found in 1956 at Karachuk. This and other early discoveries mostly consisted of heavy, high-sulphur crudes. Subsequent finds, in particular in the Deir al-Zor area in the valley of the Euphrates, have tended to be of much lighter oil.

Proved recoverable reserves are taken as 2.5 billion barrels, the level quoted by OPEC, OAPEC and OGJ.

National oil output has plateaued at just under 600 000 b/d in recent years, with nearly 60% being exported. Syria's principal customers for its crude oil are Italy, France and Spain: it is a member of OAPEC.

TAIWAN, CHINA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	0.6
Production (crude oil and NGL's, million tonnes, 1999)	0.1
R/P ratio (years)	6.0
Year of first commercial production	1904

The first commercial oil field in what is now Taiwan, China was discovered in 1904. Other small fields have been located over the years, but the island's overall oil resources are insignificant. Proved reserves are only 4 million barrels and oil output has been static at 1 000 b/d of crude (plus even smaller amounts of NGL's) for the past five years.

TAJIKISTAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	1.6
Production (crude oil and NGL's, million tonnes, 1999)	0.02
R/P ratio (years)	92.1

The republic has a relatively modest oil endowment, with cumulative production only about 50 million barrels, and remaining proved reserves estimated at only 12 million barrels (according to *Oil & Gas Journal*). Riva (1994) quotes a higher figure (100 million barrels) as proved, plus inferred reserves of 200 million and undiscovered resources of around 300 million - a total remaining resource of some 600 million barrels or say 80 million tonnes. The oil fields discovered up to the present time are mostly located in the south-western part of the country, plus a few in the north-east. Oil production has fallen sharply from around 300 000 tonnes/year in the mid-1980's to less than 20 000 tonnes in 1999.

THAILAND

Proved recoverable reserves (crude oil and NGL's, million tonnes)	47
Production (crude oil and NGL's, million tonnes, 1999)	5.3
R/P ratio (years)	8.6
Year of first commercial production	1959

Resources of crude oil and condensate are not very large in comparison with other countries in the region. The data reported by the Thai WEC Member Committee for the present Survey show proved reserves of oil as 19.85 million tonnes of crude oil and 27 million tonnes of NGL's. The estimated additional amounts in place are reported as 30.5 million tonnes of crude and 41.6 million tonnes of NGL's, of which the recoverable portions are 10.2 and 20.7 million tonnes, respectively.

Total output of oil (crude oil, condensate and other NGL's) has been on a gradually rising trend throughout the 1990's. Exports of condensate and natural gasoline amounted to nearly 16 000 b/d in 1999.

TRINIDAD & TOBAGO

Proved recoverable reserves (crude oil and NGL's, million tonnes)	85
Production (crude oil and NGL's, million tonnes, 1999)	6.7
R/P ratio (years)	11.8
Year of first commercial production	1908

The petroleum industry of Trinidad is approaching its centenary, several oil fields that are still in production having been discovered in the first decade of the 20^{th} century. The remaining recoverable reserves are small in regional terms, at just over 600 million barrels. The oil fields that have been discovered are virtually all in the southern part of the island, or in the corresponding offshore areas (in the Gulf of Paria to the west and off Galeota Point at the south-east tip of the island).

Output of crude oil and condensate has remained on a plateau of about 140 000 b/d for the past few years; production of gas-plant NGL's began in 1991 and averaged about 11 000 b/d in 1999. Approximately one-third of Trinidad's crude output is exported.

TUNISIA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	40
Production (crude oil and NGL's, million tonnes, 1999)	4.0
R/P ratio (years)	10.0
Year of first commercial production	1966

Notwithstanding early promise of becoming a major oil producer, Tunisia has not established a substantial oil resource base. Proved reserves are now quite moderate in regional terms and amount to little more than a tenth of the corresponding assessment in the mid-1970's. There are several oil-producing regions: on land in the west-central, east-central and far southern parts of the country, and offshore in the Gulfs of Hammamet and Gabès. The principal producers in 1999 were the onshore El Borma and Sidi El Kilani fields and the offshore Ashtart field in the Gulf of Gabès.

Tunisia is a member of OAPEC: it exports around 75% of its crude output, principally to Europe and the USA. Production gradually declined after 1992, but appears to have levelled-out at about 4 million tonnes/year.

TURKEY

Proved recoverable reserves (crude oil and NGL's, million tonnes)	43
Production (crude oil and NGL's, million tonnes, 1999)	2.9
R/P ratio (years)	14.6
Year of first commercial production	1948

After more than 50 years as an oil producer, Turkey still has a considerable oil resource base (proved amount in place reported as about 153 million tonnes), and recoverable reserves have been raised from 34 to 43 million tonnes since the 1998 Survey. The great majority of the oil fields discovered so far are located in the south-eastern part of the country, and are relatively small. Many of the crudes produced are very heavy, some being as low as 11º-12º API. Total output has slowly declined since 1991: all is processed in domestic refineries.

TURKMENISTAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	75
Production (crude oil and NGL's, million tonnes, 1999)	7.1
R/P ratio (years)	10.5
Year of first commercial production	1911

This republic has been an oil producer for 90 years, with a cumulative output of more that 5 billion barrels. According to *Oil & Gas Journal*, proved reserves are 546 million barrels: Riva (1994) quotes a considerably larger figure (1.5 billion), with inferred reserves as a further billion barrels and undiscovered resources as 5 billion (within a range of 2-10 billion). Known hydrocarbon resources are located in two main areas: the South Caspian Basin to the west and the Amu-Daria Basin in the eastern half of the country. After a period of decline, oil output (including NGL's) has grown quite strongly since 1995.

UKRAINE

Proved recoverable reserves (crude oil and NGL's, million tonnes)	173
Production (crude oil and NGL's, million tonnes, 1999)	3.7
R/P ratio (years)	46.3

Ukraine's oil resources are quite significant in a regional context, with the third largest proved volume of reserves in Europe (excluding the Russian Federation).Within proved amounts in place of 138 million tonnes of crude oil and almost 80 million tonnes of NGL's, the reported levels of recoverable reserves are 116 and 57 million tonnes, respectively. These levels (both in-situ and recoverable) are generally quite a lot lower than those advised for the 1998 Survey.

The principal oil-producing areas are the Dnepr-Donets Basin in the east, West Ukraine and the Crimea. Total oil output has followed a gently declining trend over the long term. All the crude produced is processed in domestic refineries.

UNITED ARAB EMIRATES

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	12 915
Production (crude oil and NGL’s, million tonnes, 1999)	107.5
R/P ratio (years)	>100
Year of first commercial production	1962

The United Arab Emirates comprises Abu Dhabi, Dubai, Sharjah, Ras al-Khaimah, Umm al-Qaiwain, Ajman and Fujairah. Exploration work in the three last-named has not found any evidence of oil deposits on a commercial scale. On the other hand, the four emirates endowed with oil resources have, in aggregate, proved reserves on a massive scale, in the same bracket as those of Iran, Iraq and Kuwait. Abu Dhabi has by far the largest share of UAE reserves and production, followed at some distance by Dubai. The other two oil-producing emirates are relatively minor operators.

At end-1999, the UAE’s proved oil reserves were quoted by OAPEC as 98.1 billion barrels, a level unchanged since 1990. According to OPEC, quoting a very similar figure for total reserves (97.8 billion barrels), Abu Dhabi accounts for 94.3% of proved reserves, Dubai for 4.1%, Sharjah for 1.5% and Ras al-Khaimah for 0.1%. Total crude output (including a considerable amount of production offshore) amounted to just over 2 million b/d in 1999, of which well over 90% was exported, mostly to Japan and other Asia/Pacific destinations. The UAE has been a member of OPEC since 1967 and is also a member of OAPEC.

UNITED KINGDOM

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	665
Production (crude oil and NGL’s, million tonnes, 1999)	137.1
R/P ratio (years)	4.7
Year of first commercial production	1919

Proved recoverable reserves are reported by the UK WEC Member Committee as 665 million tonnes at end-1999. This figure represents the difference between the proven amount of “initial recoverable oil reserves in present discoveries” (3 110 million tonnes) and cumulative production to end-1999 (2 444 million tonnes).

In addition, there are estimated to be 455 million tonnes of “probable” reserves, with “a better than 50% chance of being technically and economically producible”, and a further 545 million tonnes of “possible” reserves, with “a significant but less than 50% chance of being technically and economically producible”.

Total output of crude oil and NGL's increased from about 92 million tonnes/year in 1989-1991 to an all-time high of 137 million tonnes in 1999. The UK exported 62% of its oil output in 1999, with about two-thirds going to EU countries and a quarter to the USA.

UNITED STATES OF AMERICA

Proved recoverable reserves (crude oil and NGL’s, million tonnes)	3 728
Production (crude oil and NGL’s, million tonnes, 1999)	353.8
R/P ratio (years)	10.5
Year of first commercial production	1859

The United States has one of the largest and oldest oil industries in the world. Although its remaining recoverable reserves are dwarfed by some of the Middle East producers, it is second only to Saudi Arabia in terms of oil production. Proved reserves at end-1999, as published by the Energy Information Administration of the US Department of Energy, were 21 765 million barrels of crude oil and 7 906 million barrels of natural gas liquids. Crude oil production in 1999 was 5 881 000 b/d and that of NGL's (including "pentanes plus") was 1 850 000 b/d. The USA exported 118 000 b/d of crude oil in 1999, principally to Canada, the Republic of Korea, Japan and China.

UZBEKISTAN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	81
Production (crude oil and NGL's, million tonnes, 1999)	8.1
R/P ratio (years)	8.5

Although an oil producer for more than a century, large-scale developments in the republic mostly date from after 1950. Cumulative production is quoted by Riva (1994) as 0.4 billion barrels, leaving proved reserves as about 0.3 billion: the latest assessment published by *Oil & Gas Journal* shows proved reserves as 594 million barrels. Riva assesses inferred reserves as 1 billion barrels, with undiscovered resources as 3 billion (within a range of 2-8). Oil fields so far discovered are located in the south-west of the country (Amu-Daria Basin) and in the Tadzhik-Fergana Basin in the east.

Total oil output (including NGL's) has generally followed a rising trend since about 1988, with production more than trebling over the period. In recent years, crude oil output has tended to decrease, whilst condensates production has increased quite strongly. Relatively small proportions of both crude and NGL's are exported, with much the greater part of output being refined locally. In 1998, almost all the crude produced was processed in domestic refineries.

VENEZUELA

Proved recoverable reserves (crude oil and NGL's, million tonnes)	11 048
Production (crude oil and NGL's, million tonnes, 1999)	162.1
R/P ratio (years)	66.3
Year of first commercial production	1917

The oil resource base is truly massive, and proved recoverable reserves are easily the largest of any country in the Western Hemisphere. Starting in 1910, hydrocarbons exploration established the existence of four petroliferous basins: Maracaibo (in and around the lake), Apure to the south of the lake, Falcón to the north-east and Oriental in eastern Venezuela. The republic has been a global-scale oil producer and exporter ever since the 1920's, and was a founder member of OPEC in 1960.

The Venezuelan WEC Member Committee reports that end-1999 proved reserves were 76 785 million barrels (equivalent to 11 048 million tonnes): these figures include reserves of extra-heavy oil (less than 8^{o} API), which the state oil company PDVSA quotes as amounting to 35.7 billion barrels.

In 1998 about 49% of national oil output came from the Maracaibo Basin, 47% from the Oriental, 4% from the Apure and a minimal proportion from the Falcón Basin. Of total crude oil output of 3 329 000 b/d in 1998 (including condensate and bitumen for Orimulsion®), 2 261 000 b/d (68%) was exported, the bulk of which being consigned to North and South America.

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VIETNAM

Proved recoverable reserves (crude oil and NGL's, million tonnes)	82
Production (crude oil and NGL's, million tonnes, 1999)	14.6
R/P ratio (years)	5.6
Year of first commercial production	1986

During the first half of the 1980's oil was discovered offshore in three fields (Bach Ho, Rong and Dai Hung), and further discoveries have since been made: proved reserves are quoted by OGJ as 600 million barrels, a level unchanged since end-1996. *World Oil's* assessments of Vietnamese oil reserves have tended to change from year to year: the current figure for end-1999 is 1 800 million barrels. Production of crude oil (averaging 34º API) began in 1986 and has risen steadily: at present all output is exported.

YEMEN

Proved recoverable reserves (crude oil and NGL's, million tonnes)	525
Production (crude oil and NGL's, million tonnes, 1999)	18.8
R/P ratio (years)	27.7
Year of first commercial production	1986

After many years of fruitless searching, exploration in the 1980's and 1990's brought a degree of success, with the discovery of a number of fields in the Marib area, many yielding very light crudes. Oil discoveries have been made in two other areas of the country (Shabwa and Masila) and Yemen has evolved into a fairly substantial producer and exporter of crude. The level of proved recoverable reserves, as quoted by OAPEC and OGJ, has been unchanged at 4 billion barrels for the past ten years. Total output (including about 10 000 b/d of NGL's) in 1999 was nearly 400 0000 b/d, of which about three-quarters was exported, largely to Singapore, Japan, the Republic of Korea and other Asia/Pacific destinations.

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Chapter 3

OIL SHALE

If a technology can be developed to economically recover oil from oil shale, the potential is tantalisingly enormous. If the containing organic material could be converted to oil, the quantities would be far beyond all known conventional oil reserves. Oil shale in great quantities exists worldwide: including in Australia, Brazil, Canada, China, Estonia, France, Russia, Scotland, South Africa, Spain, Sweden and the USA.

The term “oil shale” is a misnomer. It does not contain oil nor is it commonly shale. The organic material is chiefly kerogen, and the “shale” is usually a relatively hard rock, called marl. Properly processed, kerogen can be converted into a substance somewhat similar to petroleum. However, it has not gone through the “oil window” of heat (nature’s way of producing oil) and therefore, to be changed into an oil-like substance, it must be heated to a high temperature. By this process the organic material is converted into a liquid, which must be further processed to produce an oil which is said to be better than the lowest grade of oil produced from conventional oil deposits, but of lower quality than the upper grades of conventional oil.

There are two conventional approaches to oil shale processing. In one, the shale is fractured in-situ and heated to obtain gases and liquids by wells. The second is by mining, transporting, and heating the shale to about 450^{o}C, adding hydrogen to the resulting product, and disposing of and stabilising the waste. Both processes use considerable water. The total energy and water requirements together with environmental and monetary costs (to produce shale oil in significant quantities) have so far made production uneconomic. During and following the oil crisis of the 1970’s, major oil companies, working on some of the richest oil shale deposits in the world in western United States, spent several billion dollars in various unsuccessful attempts to commercially extract shale oil.

Oil shale has been burned directly as a very low grade, high ash-content fuel in a few countries such as Estonia, whose energy economy remains dominated by shale. Minor quantities of oil have been obtained from oil shale in several countries at times over many years.

With increasing numbers of countries experiencing declines in conventional oil production, shale oil production may again be pursued. One project is now being undertaken in north-eastern Australia, but it seems unlikely that shale oil recovery operations can be expanded to the point where they could make a major contribution toward replacing the daily consumption of 73 million barrels of oil worldwide.

Perhaps oil shale will eventually find a place in the world economy, but the energy demands of blasting, transport, crushing, heating and adding hydrogen, together with the safe disposal of huge quantities of waste material, are large. On a small scale, and with good geological and other favourable conditions, such as water supply, oil shale may make a modest contribution but so far shale oil remains the “elusive energy”.

Walter Youngquist,
Consulting Geologist
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DEFINITIONS

In Table 3.1 the following definitions apply:

Oil Shales are sedimentary rocks containing a high proportion of organic matter (kerogen) which can be converted to synthetic oil or gas by processing.

Proved amount in place is the tonnage of oil shale that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology.

Proved recoverable reserves are the tonnage of synthetic crude oil that has been carefully measured and assessed as recoverable under present and expected local economic conditions with existing available technology.

Average yield of oil is based on Fischer assay or equivalent analytical technique.

Estimated additional reserves are the amount, expressed as tonnage of recoverable synthetic crude oil (*additional* to Proved Recoverable Reserves), that is of foreseeable economic interest. Speculative amounts are not included.

Table 3.1 Oil shale: resources, reserves and production at end-1999

Excel File	Recovery method	Proved amount in place	Proved recoverable reserves	Average yield of oil	Estimated additional reserves	Production in 1999
		million tonnes (shale)	million tonnes (oil)	kg oil/ tonne	million tonnes (oil)	thousand tonnes (oil)
Africa						
Morocco	surface	12 300	500	50 - 64	5 400	
South Africa	in-situ	73		10		
North America						
United States of America	surface	3 340 000	60 000 - 80 000	57	62 000	
South America						
Brazil	surface			70	9 646	195
Asia						
Thailand	in-situ	18 668	810	50		
Turkey	surface	1 640	269	56		
Europe						
Albania	surface	6			5	
Estonia	surface	590		167		151
	in-situ	910				
Ukraine	in-situ	2 674	300	126	6 200	
Middle East						
Israel	surface	15 360	600	62		
Jordan	surface	40 000	4 000	100	20 000	
Oceania						
Australia	in-situ	32 400	1 725	53	35 260	5

Notes:
1. Generally the data shown above are those reported by WEC Member Committees in 2000/2001
2. The data for Albania, Brazil, Israel, South Africa and Ukraine are those reported by WEC Member Committees for SER 1998
3. The data thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed

COUNTRY NOTES

The following Country Notes on oil shale have been compiled by the editors, drawing upon a wide variety of material, including information received from WEC Member Committees, national and international publications.

AUSTRALIA

For the present Survey, the Australian Geological Survey Organisation (AGSO) has reported a proved amount in place of 32.4 billion tonnes of oil shale, with proved recoverable reserves of oil put at 1 725 million tonnes. Additional reserves of shale oil are huge: in excess of 35 billion tonnes.

Production from oil shale deposits in south-eastern Australia began in the 1860's, coming to an end in the early 1950's when government funding ceased. Between 1865 and 1952 some 4 million tonnes of oil shale were processed.

During the 1970's and early 1980's a modern exploration programme was undertaken by two Australian companies, Southern Pacific Petroleum N.L. and Central Pacific Minerals N.L. (SPP/CPM). The aim was to find high-quality oil shale deposits amenable to open-pit mining operations in areas near infrastructure and deepwater ports. The programme was successful in finding a number of silica-based oil shale deposits of commercial significance along the coast of Queensland.

In 1995 SPP/CPM signed a joint venture agreement with the Canadian company Suncor Energy Inc. to commence development of one of the oil shale deposits, the Stuart Deposit. Located near Gladstone, it has a total in-situ shale oil resource of 2.6 billion barrels and the capacity to produce more than 200 000 b/d. Suncor had had the role of operator of the Stuart project, but in April 2001, SPP/CPM purchased Suncor's interest.

The Stuart project incorporates the Alberta-Taciuk Processor (ATP) retort technology (initially developed for potential application to the Alberta oil sands) and has three stages. The Stage 1 demonstration plant is currently being commissioned and tested, with full production being gradually attained during 2001. The plant is designed to process 6 000 t/d of run-of-mine (wet shale) to produce 4 500 b/d of shale oil products. After technical and economic feasibility has been proved, it is planned that the ATP in Stage 2 will be scaled up to a commercial-sized module processing 25 000 t/d and producing 14 800 b/d oil products. A Stage 3 commercial plant is conceived as processing 125 000 t/d of oil shale to give 65 000 b/d oil products, thus bringing total Stuart production to about 85 000 b/d by 2009.

The raw shale oil produced will constitute a relatively light crude with a 42^{o} API gravity, 0.4 wt% sulphur and 1.0 wt% nitrogen. To meet the needs of the market, the raw oil requires further processing, resulting in raw low-sulphur naphtha and medium shale oil (MSO). It is planned that the MSO will be sent directly to tankage for marketing as a 27^{o} API gravity, 0.4 wt% sulphur fuel oil cutter stock, while the raw naphtha will be hydrotreated to remove nitrogen and sulphur to below 1 ppm. It is claimed that the hydrotreated naphtha would provide an ideal feedstock in the manufacture of clean gasoline with low emissions characteristics. In future phases of Stuart, other product options would be available depending on market conditions.

It was announced in May 2001 that the first shipment of over 40 000 barrels (5 800 tonnes) of MSO had been made to the south-east Asian fuel oil market.

BRAZIL

The oil shale resource base is one of the largest in the world and was first exploited in the late nineteenth century in the State of Bahia. In 1935 shale oil was produced at a small plant in São Mateus do Sul in the State of Paraná and in 1950, following government support, a plant capable of producing 10 000 b/d shale oil was proposed for Tremembé, São Paulo.

Following the formation of Petrobras in 1953, the company developed the Petrosix process for shale transformation. Concentrating its operations on the reservoir of São Mateus do Sul, the company brought a pilot plant (8 inch internal diameter retort) into operation in 1982. Its purpose is for oil shale characterisation, retorting tests and developing data for economic evaluation of new commercial plants. A 6 foot (internal diameter) retort demonstration plant followed in 1984 and is used for the optimisation of the Petrosix technology.

A 2 200 (nominal) tons per day, 18 foot (internal diameter) semi works retort (the Irati Profile Plant), originally brought on line in 1972, began operating on a limited commercial scale in 1981 and a further commercial plant – the 36 foot (internal diameter) Industrial Module retort was brought into service in December 1991. Together the two commercial plants process some 7 800 tonnes of bituminous shale daily. The retort process (Petrosix) where the shale undergoes pyrolysis yields a nominal daily output of 3 870 barrels of shale oil, 120 tonnes of fuel gas, 45 tonnes of liquefied shale gas and 75 tonnes of sulphur. Output of shale oil in 1999 was 195.2 thousand tonnes.

The Ministry of Mines and Energy quotes end-1999 shale oil reserves as 445.1 million m^3 measured/indicated/inventoried and 9 402 million m^3 inferred/estimated with shale gas reserves as 111 billion m^3 measured/indicated/inventoried and 2 353 billion m^3 inferred/estimated.

CANADA

Oil shales occur throughout the country, with the best known and most explored deposits being those in the provinces of Nova Scotia and New Brunswick. Of the areas in Nova Scotia known to contain oil shales, development has been attempted at two - Stellarton and Antigonish. Mining took place at Stellarton from 1852-1859 and 1929-1930 and at Antigonish around 1865. The Stellarton Basin is estimated to hold some 825 million tonnes of oil shale, with an in-situ oil content of 168 million barrels. The Antigonish Basin has the second largest oil shale resource in Nova Scotia, with an estimated 738 million tonnes of shale and 76 million barrels of oil in situ.

Investigations into retorting and direct combustion of Albert Mines shale (New Brunswick) have been conducted, including some experimental processing in 1988 at the Petrobras plant in Brazil. Interest has been shown in the New Brunswick deposits for the potential they might offer to reduce sulphur emissions by co-combustion of carbonate-rich shale residue with high-sulphur coal in power stations.

CHINA

Fushun, a city in the north-eastern province of Liaoning, is known as the Chinese “Capital of Coal”. Within the Fushun coalfield the West Open Pit mine is the largest operation and is where, in addition to coal, oil shale from the Eocene Jijuntun Formation is mined.

The average thickness of the Jijuntun Formation is estimated to be 115 m (within a range of 48-190 m). The oil shale (known as “brown combustible shale” in China) in the formation can be divided into two parts of differing composition: the lower 15 m of light-brown oil shale of low-grade and the upper 100 m of brown to dark-brown, finely laminated oil shale. The oil content of the low-grade oil shale is less than 4.7% by weight and the richer upper grade is greater than 4.7%. However, depending on the exact location of the deposit, the maximum oil content can be as high as 16%. It has been reported that the average oil content is 7-8% which would produce in the region of 78-89 litres of oil per tonne of oil shale (assuming a 0.9 specific gravity).

In 1983 the Chinese reported that the oil shale resources in the area of the West Open Pit mine were 260 million tonnes, of which 235 million tonnes were considered mineable. It has also been reported that the entire Fushun area has a resource of approximately 3.6 billion tonnes.

The commercial extraction of oil shale and the operation of heating retorts for processing the oil shale were developed in Fushun between 1920-1930. After World War II, Refinery No. 1

had 200 retorts, each with a daily throughput of 100-200 tonnes of oil shale. It continued to operate and was joined by the Refinery No.2 starting up in 1954. In Refinery No. 3 shale oil was hydrotreated for producing light liquid fuels. Shale oil was also open-pit mined in Maoming, Guangdong Province and 64 retorts were put into operation there in the 1960's.

At the beginning of the 1960's 266 retorts were operating in Fushun's Refineries Nos. 1 and 2. However, by the early 1990's the availability of much cheaper crude oil had led to the Maoming operation and Fushun Refineries No. 1 and 2 being shut down.

A new facility – the Fushun Oil Shale Retorting Plant – came into operation in 1992 under the management of the Fushun Bureau of Mines. Its 60 retorts annually produce 60 000 tonnes of shale oil to be sold as fuel oil, with carbon black as a by-product.

ESTONIA

Oil shale was first scientifically researched in the 18th century. In 1838 work was undertaken to establish an open-cast pit near the town of Rakvere and an attempt was made to obtain oil by distillation. Although it was concluded that the rock could be used as solid fuel and, after processing, as liquid or gaseous fuel, the "kukersite" (derived from the name of the locality) was not exploited until the fuel shortages created by World War I began to impact.

The Baltic Oil Shale Basin is situated near the north-western boundary of the East European Platform. The Estonia and Tapa deposits are both situated in the west of the Basin, the former being the largest and highest-quality deposit within the Basin.

Since 1916 oil shale has had an enormous influence on the energy economy, particularly during the period of Soviet rule and then under the re-established Estonian Republic. At a very early stage, an oil shale development programme declared that kukersite could be used directly as a fuel in the domestic, industrial or transport sectors. Moreover, it is easily mined and could be even more effective as a combustible fuel in power plants or for oil distillation. Additionally kukersite ash could be used in the cement and brick-making industries.

Permanent mining began in 1918 and has continued until the present day, with capacity (both underground mining and open-cast) increasing as demand rose. By 1955 oil shale output had reached 7 million tonnes and was mainly used a power station/chemical plant fuel and in the production of cement. The opening of the 1 400 MW Baltic Thermal Power Station in 1965 followed, in 1973, by the 1 600 MW Estonian Thermal Power Station again boosted production and by 1980 (the year of maximum output) the figure had risen to 31.35 million tonnes.

In 1981, the opening of a nuclear power station in the Leningrad district of Russia signalled the beginning of the decline in Estonian oil shale production. No longer were vast quantities required for power generation and the export of electricity. The decline lasted until 1995, with some small annual increases thereafter.

The Estonian government has taken the first steps towards privatisation of the oil-shale industry and is beginning to tackle the air and water pollution problems that nearly a century of oil shale processing has brought.

In 1999 10.7 million tonnes of oil shale were produced. Imports amounted to 1.4 million tonnes, 0.01 million tonnes were exported, 11.1 million tonnes used for electricity and heat generation, and 1.3 million tonnes were distilled to produce 151 000 tonnes of shale oil.

The Development Plan states that the share of oil shale in the Estonian national primary energy balance must be reduced from 62% to 52-54% by 2005 and to 47-50% by 2010. In 1999 the Sompa and Tammiku mine fields were closed down and Ahtme and Kohtla are likely targets in the future.

Estonian oil shale resources are currently put at 5 billion tonnes including 1.5 billion tonnes of active (mineable) reserves. It is possible that the power production part of the industry will disappear by 2020 and that the resources could last for 30-50 years but scenarios abound on the replacement of oil shale by alternative resources.

GERMANY

The German WEC Member Committee reports that under existing or expected economic conditions there are no recoverable or additional reserves. A 1995 energy study quoted Germany oil shale resources as 3 billion tonnes “oil in place”.

A minimal quantity (0.5 million tonnes per annum) of oil shale is produced for use at the Rohrback cement works at Dotternhausen in southern Germany, where it is consumed directly as a fuel for power generation, the residue being used in the manufacture of cement.

ISRAEL

Sizeable deposits of oil shale have been discovered in various parts of Israel, with the principal resources located in the north of the Negev desert. The Israeli WEC Member Committee reported in 1998 that the proved amount of oil shale in place exceeded 15 billion tonnes, containing proved recoverable reserves of 600 million tonnes of shale oil. The largest deposit (Rotem Yamin) has shale beds with a thickness of 35-80 m, yielding 60-71 litres of oil per tonne. Generally speaking, Israeli oil shales are relatively low in heating value and oil yield, and high in sulphur content, compared with other major deposits. A pilot power plant fuelled by oil shale has been technically proven in the Negev region. Annual production of oil shale has averaged 450 000 tonnes in recent years.

JORDAN

There are extremely large proven and exploitable reserves of oil shale in the central and north-western regions of the country. The proved amount of oil shale in place is reported by the WEC Member Committee to be 40 billion tonnes; proved recoverable reserves of shale oil are put at 4 billion tonnes, with estimated additional reserves of 20 billion tonnes.

Jordanian shales are generally of quite good quality, with relatively low ash and moisture content. Gross calorific value (7.5 MJ/kg) and oil yield (8-12%) are on a par with those of western Colorado (USA) shale; however, Jordanian shale has an exceptionally high sulphur content (up to 9% by weight of the organic content). The reserves are exploitable by opencast mining and are easily accessible.

For several years the Ministry of Energy and Mineral Resources (MEMR) has been in contact with a number of companies with a view to reaching an acceptable agreement for constructing a shale-fired private power station and for the production of shale oil by retorting. International companies have been invited to carry out feasibility studies and to submit their offers to MEMR.

Suncor of Canada has conducted limited exploration in the Lajjun area, southwest of Amman. During 1999 the company was engaged in discussions with MEMR on the possible development of an oil shale extraction facility.

The eventual exploitation of what is Jordan’s only substantial fossil fuel resource to produce liquid fuels and/or electricity, together with chemicals and building materials, would be favoured by three factors – the high organic-matter content of Jordanian oil shale, the suitability of the deposits for surface-mining and their location near potential consumers (i.e. phosphate mines, potash and cement works).

MOROCCO

Morocco has very substantial oil shale reserves but to date they have not been exploited. During the early 1980's, Shell and the Moroccan state entity ONAREP conducted research into the exploitation of the oil-shale reserves at Tarfaya, and an experimental shale-processing plant was constructed at another major deposit (Timahdit). At the beginning of 1986, however, it was decided to postpone shale exploitation at both sites and to undertake a limited programme of laboratory and pilot-plant research.

The WEC Member Committee for Morocco quotes the proved amount of oil shale in place as 12.3 billion tonnes, with proved recoverable reserves of shale oil amounting to 3.42 billion barrels (equivalent to approximately 500 million tonnes).

RUSSIAN FEDERATION

There are oil shale deposits in Leningrad Oblast, across the border from those in Estonia. Annual output is estimated to be about 2 million tonnes, most of which is exported to the Baltic power station in Narva, Estonia. In 1999 Estonia imported 1.4 million tonnes of Russian shale but is aiming to reduce the amount involved, or eliminate the trade entirely. There is another oil-shale deposit near Syzran on the river Volga.

The exploitation of Volga Basin shales, which have a higher content of sulphur and ash, began in the 1930's. Although the use of such shale as a power-station fuel has been abandoned owing to environmental pollution, a small processing plant may still be operating at Syzran, with a throughput of less than 50 000 tonnes of shale per annum.

THAILAND

Some exploratory drilling by the government was made as early as 1935 near Mae Sot in Tak Province on the Thai-Burmese border. The oil-shale beds are relatively thin and the structure of the deposit is complicated by folding and faulting.

Some 18.7 billion tonnes of oil shale have been identified in Tak Province but to date it has not been economic to exploit the deposits. Proved recoverable reserves of shale oil are put at 810 million tonnes.

UNITED STATES OF AMERICA

It is estimated that nearly 62% of the world's potentially recoverable oil shale resources are concentrated in the USA. The largest of the deposits is found in the 42 700 km^2 Eocene Green River formation in north-western Colorado, north-eastern Utah and south-western Wyoming. The richest and most easily recoverable deposits are located in the Piceance Creek Basin in western Colorado and the Uinta Basin in eastern Utah. The shale oil can be extracted by surface and in-situ methods of retorting: depending upon the methods of mining and processing used, as much as one-third or more of this resource might be recoverable. There are also the Devonian-Mississippian black shales in the eastern United States.

Data reported for the present Survey indicate the vastness of US oil shale resources: the proved amount of shale in place is put at 3 340 billion tonnes, with a shale oil content of 242 billion tonnes, of which about 89% is located in the Green River deposits and 11% in the Devonian black shales. Recoverable reserves of shale oil are estimated to be within the range of 60-80 billion tonnes, with additional resources put at 62 billion tonnes.

Oil distilled from shale was burnt and used horticulturally in the second half of the 19th century in Utah and Colorado but very little development occurred at that time. It was not until the early 1900's that the deposits were first studied in detail by USGS and the government established the Naval Petroleum and Oil Shale Reserves, that for much of the 20th century served as a contingency source of fuel for the nation's military. These properties were originally envisioned as a way to provide a reserve supply of oil to fuel US naval vessels.

Oil shale development had always been on a small scale but the project that was to represent the greatest development of the shale deposits was begun immediately after World War II in 1946 - the US Bureau of Mines established the Anvils Point oil shale demonstration project in Colorado. However, processing plants had been small and the cost of production high. It was not until the USA had become a net oil importer, together with the oil crises of 1973 and 1979, that interest in oil shale was reawakened.

In the latter part of the 20th century military fuel needs changed and the strategic value of the shale reserves began to diminish. In the 1970's ways to maximise domestic oil supplies were devised and the oil shale fields were opened up for commercial production. Oil companies led the investigations: leases were obtained and consolidated but one-by-one these organisations gave up their oil shale interests. Unocal was the last to do so in 1991.

Recoverable resources of shale oil from the marine black shales in the eastern United States were estimated in 1980 to exceed 400 billion barrels. These deposits differ significantly in chemical and mineralogical composition from Green River oil shale. Owing to its lower H:C ratio, the organic matter in eastern oil shale yields only about one-third as much oil as Green River oil shale, as determined by conventional Fischer assay analyses. However, when retorted in a hydrogen atmosphere, the oil yield of eastern oil shale increases by as much as 2.0-2.5 times the Fischer assay yield.

Green River oil shale contains abundant carbonate minerals including dolomite, nahcolite, and dawsonite. The latter two minerals have potential by-product value for their soda ash and alumina content, respectively. The eastern oil shales are low in carbonate content but contain notable quantities of metals, including uranium, vanadium, molybdenum, and others which could add significant by-product value to these deposits.

All field operations have ceased and at the present time shale oil is not being produced in the USA. Large-scale commercial production of oil shale is not anticipated before the second or third decade of the 21st century.

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Chapter 4

NATURAL BITUMEN AND EXTRA-HEAVY OIL

Natural bitumen and extra-heavy oil are closely related types of petroleum, differing from each other, and from the petroleum from which they are derived, only to the degree by which they have been degraded. This alteration, through bacterial attack, water washing, and inspissation, has resulted in severe loss of the light ends of the petroleum, notably the paraffins, and subsequent relative enrichment of the heavy molecules, leading to increased density and viscosity. Of these molecules, the asphaltenes are very large and incorporate such non-hydrocarbons as nitrogen, sulphur, oxygen, and metals, in particular nickel and vanadium. The result of this chemistry is an array of problems beyond those encountered with conventional petroleum with respect to exploitation, transportation, storage, and refining. This, of course, is reflected in the increased cost of extraction and processing and the physical limitations on production capacity.

Although natural bitumen and extra-heavy oil are worldwide in occurrence, a single extraordinary deposit in each category is dominant. The Alberta, Canada natural bitumen deposits comprise at least 85% of the world total bitumen in place but are so concentrated as to be virtually the only such deposits that are economically recoverable for conversion to oil. The deposits amount to about 1 700 billion barrels of bitumen in place. Similarly, the extra-heavy crude oil deposit of the Orinoco Oil Belt, a part of the Eastern Venezuela basin, represents nearly 90% of the known extra-heavy oil in place. Between them, these two deposits, each located up-dip against a continental craton, represent about 3 600 billion barrels of oil in place. This is only the remaining, degraded remnant of petroleum deposits once totaling as much as 18 000 billion barrels.

Extra-heavy oil is recorded in 219 separate deposits; some of these are different reservoirs in a single field, some are producing, some are abandoned. The deposits are found in 30 countries and in 54 different geological basins, with 11 of the deposits being offshore and 5 partially offshore. The following data are average values. Most of the reservoirs are sandstone at depths of 5 400 feet, thicknesses of 126 feet, porosities of 21%, and permeabilities of 1 255 - 6 160 millidarcies. The API gravity is 8º and viscosity 22 700 centipoises. The SUS viscosity varies from 6 000 at 70ºF to 4 600 at 100º F to 1 400 at 130º F and the gas-oil ratio is only 431. The chemical data for the whole crude demonstrate the processing difficulties with extra-heavy crude. The Conradson Carbon is 11.5 wt%, asphaltenes 16 wt%, sulphur 4.69 wt%, and nickel 260 ppm and vanadium 972 wt%. Especially significant is the residuum yield of 62 vol% and its specific gravity of 1.06 and Conradson Carbon of 17.8 wt%. These data suggest for extra-heavy crude a content of 56 wt% asphalt and 23 wt% coke.

Oil resource data are very incomplete but those that are available for extra-heavy crude, especially from Canada, the United States, and Venezuela, are as follows, all in millions of barrels: original oil in place, 2 133 912; cumulative production, 17 214; annual production, 432; reserves, 45 575; and probable reserves, 193 203.

Because of the chemical nature of the crude, it may be assumed that enhanced recovery methods are required for production. In certain areas diluents are introduced into the well bore and gas lift is sometimes used but cyclic steam injection, usually followed by steam flood, is the common practice. A notable addition to technology has been the SAGD, or steam-assisted gravity drainage, following the evolution of the horizontal well. For transporting extra-heavy crude it is generally necessary to add a diluent, such as gas condensate, to improve the mobility; the diluent is then recovered for re-use. These heavy crudes are often upgraded in the field to a refinery-acceptable 21º API. At the refinery the processing most commonly involves carbon rejection although hydrogen-addition methods may be utilised to maximise fluid yields and reduce coke production. The higher pressures and the hydrogen requirement add appreciably to the cost of the hydrogen-addition technology.

Natural bitumen is found ubiquitously in the world in the form of seepages and accumulations of various sizes. The bitumen may be waxy, as in the case of ozocerite, or hard and brittle, as exemplified by gilsonite. Most commonly, however, it occurs as natural asphalt, also called tar sand or oil sand, so much so that the term natural bitumen is applied almost exclusively to natural asphalt. Chemically, this material is degraded to a greater extent than extra-heavy oil so that it is not unlike the residuum from a refinery. Minor amounts of bitumen are still produced for road material and mastic, as with the Trinidad Pitch Lake deposit. Essentially, however, natural asphalt as a source of synthetic oil is the domain of the Alberta oil sand and its importance can hardly be understated.

The chemical constitution of natural asphalt imposes the same difficulties as are entailed with extra-heavy oil. However, the production of the material differs with its depth of burial. To depths of about 150 feet the bitumen and rock may be surface mined, with the bitumen subsequently separated from the rock by a hot water process. Where the bitumen is buried deeply enough to prevent severe heat loss, the bitumen may be produced from wells by the use of steam injection. For the section of rock between, a combination of mining and steam injection has been developed, with injection wells emplaced from within the mine tunnel, the oil being recovered by gravity drainage. The development of horizontal well drilling has led to a significant advance in bitumen recovery, the SAGD process, through use of a higher horizontal steam injection well and a lower horizontal well to receive the mobilised oil by gravity drainage.

The exploitation of the Orinoco Oil Belt is a matter of great concern to Venezuela and the subject of intense research relative to improved recovery. An interim technology which permits recovery in the form of an emulsion has proved successful. This emulsion, called Orimulsion®, solves the production-transportation problem and eliminates refining by permitting the emulsion to be burned directly. The long-term desire is no doubt to upgrade the extra-heavy oil to refinery feed, which will be economically advantageous.

Exploitation of the Alberta natural bitumen is well advanced, with 1999 production of 323 000 barrels per day of synthetic oil from mining plants and 244 000 barrels per day in situ from wells. Present day activity represents a long evolution in the technology of recovery, separation, and upgrading.

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US Geological Survey
United States of America

DEFINITIONS

In Table 4.1 the following definitions apply:

Natural bitumen comprises bitumen or other petroleum with very high viscosity (contained in bituminous sands, oil sands or tar sands), which is not recoverable by conventional means; the petroleum is obtained either as raw bitumen (through in-situ recovery) or as a synthetic crude oil (via an integrated surface-mining plus upgrading process).

Proved amount in place is the tonnage of natural bitumen that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology.

Proved recoverable reserves are the tonnage of synthetic crude oil or raw bitumen that has been carefully measured and assessed as recoverable under present and expected local economic conditions with existing available technology.

Estimated additional reserves are the amount, expressed as tonnage of recoverable synthetic crude oil or raw bitumen (*additional* to the Proved Recoverable Reserves), that is of foreseeable economic interest. Speculative amounts are not included.

Table 4.1 Natural bitumen: resources, reserves and production at end-1999

Excel files	Recovery method	million tonnes			
		Proved amount in place	Proved recoverable reserves	Estimated additional reserves	Production in 1999
North America					
Canada		45 300	979		30.0
of which:	surface	9 000	747		15.9
	in-situ	36 300	232		14.1
United States of America	in-situ			4 231	
South America					
Venezuela	in-situ	3 880	373	118	3.3
Europe					
Romania	in-situ	4	1		
Middle East					
Jordan	surface	40	5		

Notes:

1. The data shown above are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. WEC Member Committees have been unable to provide sufficient numerical data for extra-heavy oil to be included in this table

COUNTRY NOTES

The Country Notes on natural bitumen and extra-heavy oil have been compiled by the editors. During the period since 1998 there has been considerable activity on both the Canadian and Venezuelan fronts - a relatively large amount of information has consequently become available.

Information has been drawn from the companies directly involved with the resource extraction and from national and governmental organisations. In addition, recourse was also made to the papers given at the 7th Unitar International Conference on Heavy Crude and Tar Sands (1998).

CANADA

The National Energy Board (NEB) distinguishes between two types of non-conventional oil obtained from deposits of oil sands, defining them as follows:

- Bitumen (also known as crude bitumen) – "a highly viscous mixture, mainly of hydrocarbons heavier than pentanes. In its natural state, it is not usually recoverable at a commercial rate through a well".
- Upgraded Crude Oil (also known as synthetic crude) – "a mixture of hydrocarbons similar to light crude oil derived by upgrading oil sands bitumen".

Canada's "discovered recoverable resources" of oil sands bitumen are quoted by the NEB as 49 billion m^3 (over 300 billion barrels), of which about 475 million m^3 had been produced by the end of 1999. Of the remainder (shown as "proved amount in place" in Table 4.1), 9 650 million m^3 (9 billion tonnes) consists of synthetic crude recoverable through mining projects and 38 850 million m^3 (36.3 billion tonnes) consists of crude bitumen recoverable through in-situ extraction.

Within these huge resources, the "remaining established reserves" at end-1999 (shown as "proved recoverable reserves" in Table 4.1) have been assessed by the Canadian Association of Petroleum Producers (CAPP) as 799.9 million m^3 (equivalent to about 747 million tonnes) of mining-integrated synthetic crude oil and 248.1 million m^3 (approximately 232 million tonnes) of in-situ bitumen.

The major deposits are in four geographic and geologic regions of Alberta: Athabasca, Wabasca, Cold Lake and Peace River.

Although the existence of oil sands deposits was noted in the 18th century, it was not until 1875 that a complete survey was undertaken and it was the 20th century before exploitation was embarked upon. The deposits range from being several hundred metres below ground to surface outcroppings. The extraction of bitumen from the oil sands was initially based on surface-mining but in-situ techniques became necessary in order to reach the deeper deposits.

There was much experimentation with oil sands technology in the first half of the 20th century but it was not until the effects of the economic climate of the 1950's and early 1960's began to be felt that commercial development became viable. The Government of Alberta's oil sands development policy was announced in 1962 and the Great Canadian Oil Sands Project (GCOS) was conceived and approved. The ownership of GCOS passed to Sun Oil Company and in 1967 the world's first integrated oil sands production and upgrading plant was started up by Suncor (formerly Sun Oil).

Suncor's area of operation, 40 km north of Fort McMurray, is within the Athabasca deposits. The processing capability of the original Oil Sands Plant has been steadily increased and the expansion of the Steepbank Mine (on the opposite side of the Athabasca River) resulted in record production of 105 600 b/d in 1999. At the beginning of 1999 the company announced its "Project Millennium", a phased series of expansions to the Steepbank mine, adding bitumen extraction plants and increasing upgrader capacity. The first phase is expected to increase production to 130 000 b/d by 2001; the second phase to 225 000 b/d in 2003. In 2000, the establishment (subject to the necessary approval) of an in-situ project at Firebag (40 km north-east of the Oil Sands Plant) was announced. It is planned that Firebag, in conjunction with the open pit mining operation, will result in production reaching 260 000 b/d in 2004. Through a combination of mining and in-situ development Suncor envisages an oil sands production of 400 000-450 000 b/d in 2008.

Syncrude, a joint venture with ten participants (Imperial Oil, a subsidiary of Exxon, is the majority shareholder with 25%) operates the Lake Mildred plant, also 40 km north of Fort

McMurray. Production began in 1978 and, using open-pit mining methods, the shallow deposits are recovered for bitumen extraction and the production of upgraded crude oil. Gross production was 223 000 b/d in 1999. A new project – the Aurora mine - a 35 km extension from Lake Mildred, opened in August 2000. The mine's output is partially processed on-site and then pipelined to the upgrader for further treatment. In 1999 a major expansion to Syncrude's upgrading capacity was approved by the federal government – construction is expected to begin in 2001. It is planned that the work under development will result in a capacity in the region of 350 000 b/d by 2004.

The Cold Lake oil sands deposits area is operated by Imperial Oil. The company began commercial development in 1983 and has since gradually expanded facilities – total production of bitumen in 1999 was 132 000 b/d. Imperial plans to bring further expansion on stream so that by late 2002, bitumen production could be increased by 30 000 b/d.

Commercial production of Shell Canada's Peace River in-situ deposits (north-western Alberta) began in 1986. Bitumen production capacity is set at approximately 12 000 b/d although during 2000 the actual production from existing wells was considerably lower. In an attempt to boost declining bitumen production, Shell announced in late 2000 that it will drill 18 new wells.

Albian Sands Energy, a joint venture, has been created to build and operate the Muskeg River Mine on behalf of its owners: Shell Canada (majority shareholder, with 60%), Chevron Canada and Western Oil Sands (with 20% each). The mine, already under construction, is located 75 km north of Fort McMurray (Athabasca). In addition, a pipeline is to be constructed to link the mine to an upgrader to be built next to Shell's Scotford refinery. The start-up of the project is scheduled for late-2002, with production of 155 000 b/d of bitumen.

Taking into account all operations, total output from Canadian oil sands in 1999 was 323 000 b/d of synthetic crude and 244 000 b/d of crude bitumen from the in-situ plants; together these represented 22% of Canada's total production of crude oil and NGL.

TRINIDAD & TOBAGO

The famous Pitch Lake at La Brea (named after the Spanish word for tar or pitch) was reputedly discovered at the end of the 16th century. Trinidad Lake Asphalt, a semi-solid emulsion of soluble bitumen, mineral matter and other minor constituents (mainly water), was mined and used as a road surfacing material as long ago as 1815.

The Lake contains 10 million tonnes of reserves which at the current rate of extraction are expected to last for another 400 years. Lake Asphalt of Trinidad and Tobago (1978) Ltd. (TLA), a state-owned company, produces between 10 000 and 15 000 tonnes per annum and exports most of this amount, after removal of water etc.

In combination with bitumen (asphalt) from refined crude oil, the product has featured significantly in the road construction industry over a long period of time and in many countries. In addition to mining it, TLA also distributes the natural bitumen, and in recent years has incorporated it into a range of paints and coatings. The company has also developed a process for making cationic bitumen emulsions. Production of these emulsified bitumen, water and soap solutions began in late-1996 and they are now used widely throughout the industrialised world in place of solvent-based bitumen emulsions.

UNITED STATES OF AMERICA

Distillation of tar sands, occurring as a surface outcrop in California, was carried out in the 1870's. During the following century efforts were periodically made to establish the industry in both California and various other states, but the availability of low-priced, indigenous conventional oil meant that there was never a persistently strong incentive for the development of tar sands deposits.

The US classifies tar sands as: M*easured* or *Demonstrated* – "the bitumen resource based on core and log analyses" and *Speculative* or *Inferred* – "the bitumen that is presumed to exist from reported tar shows on drillers' lithological logs and/or geological interpretations".

The tar sands resource of 58.1 billion barrels (22.4 "measured", 35.7 "speculative") is widely distributed through the country, with 33% located in Utah, 17% in Alaska and the remaining 50% in California, Alabama, Kentucky, Texas and elsewhere. There are eight giant (> 1 billion barrels) deposits of natural asphalt in-situ, which represent nearly 80% of the total US demonstrated and inferred resource.

Up to the present time, the geological conditions of the Utah deposits have meant that recovery is difficult and expensive. Likewise, the Texan deposits, mostly deep and relatively thin, have also proved difficult to recover. Currently, the only state where small volumes of tar sand hydrocarbons are being produced from sub-surface deposits (associated with heavy oil) is California.

Gilsonite (a naturally occurring solid hydrocarbon) is being produced by three companies from a number of vertical veins in the Green River Formation and overlying Eocene Uinta Formation in Uintah County, eastern Utah. Production figures for the gilsonite district are not available, but probably total several hundred thousand tons per year. Gilsonite is used in a variety of speciality products such as printing inks, paints and protective coatings, drilling and foundry sand additives, briquetting, and others.

VENEZUELA

There are vast deposits of bitumen and extra-heavy oil in the Orinoco Oil Belt (OOB) in eastern Venezuela, north of the Orinoco river. The original-oil-in-place of the extra heavy oil reservoirs of the OOB has been estimated as about 1 200 billion barrels, with some 270 billion barrels of oil recoverable. Venezuela's total proved reserves of crude oil (76.8 billion barrels as at end-1999) include 35.7 billion barrels of extra-heavy crudes.

There are four joint ventures for the exploitation of extra-heavy crude. Petróleos de Venezuela (PDVSA), the state oil company, has a minority interest in all four and all are at different stages of development:

- The Hamaca project (a joint venture between Phillips Petroleum, Texaco and PDVSA) has been delayed owing to financing problems but is planned to produce 190 000 b/d.
- The Sincor project, (a joint venture between TotalFinaElf, Statoil and PDVSA) was reported to have started bitumen production in December 2000, with its upgrading plant scheduled to come on stream a year later. The project is planned to produce 180 000 b/d.
- Production from the Petrozuata project, a joint venture between Conoco and PDVSA, has begun and had reached its target of 120 000 b/d by February 2001. Work to enable production to increase to 150 000 b/d by 2003 is under way. An upgrader will

process the 120 000 b/d of 9^o API oil, turning it into 103 000 b/d of lighter, synthetic crude, some of which will be used as refinery feedstock to obtain gasoline and diesel for the domestic and export markets. Beginning early in 2001, the remainder will be shipped to the US for processing into higher-value products.

- The Cerro Negro is a joint venture project between ExxonMobil, Veba and PDVSA. Output was expected to rise from 60 000 b/d in 2000 to 120 000 b/d by March 2001, following the completion of a new coking unit.

In the early 1980's Intevep, the research affiliate of the state oil company PDVSA, developed a method of utilizing some of the hitherto untouched potential of Venezuela's extra-heavy oil/natural bitumen resources. Natural bitumen (7.5^o-8.5^o API) extracted from the reservoir is emulsified with water (70% natural bitumen, 30% water, <1% surfactants), the resulting product being called Orimulsion®. Orimulsion® can be pumped, stored, transported and burnt under boilers using conventional equipment with only minor modifications. Initial tests were conducted in Japan, Canada and the UK and exports began in 1988.

Orimulsion® is processed, shipped and marketed by Bitúmenes del Orinoco S.A. (Bitor), a PDVSA subsidiary, but with the fuel's relatively high sulphur content and its emission of particulates, Intevep continues to seek improvements in its characteristics in order to match increasingly strict international environmental regulations. Bitor operates an Orimulsion® plant at Morichal in Cerro Negro with a capacity of 5.2 million tonnes per year. The company hopes to produce 20 million tonnes per year by 2006.

Following manufacture at the plant, the Orimulsion® is transported by pipeline about 320 km to the José export terminal for shipment. During the 1990's other markets were developed and currently Barbados, Brazil, Canada, China, Costa Rica, Denmark, Finland, Germany, Guatemala, Italy, Japan, Lithuania, Northern Ireland, Philippines, South Korea, Taiwan, Thailand and Turkey either consume or are considering consuming the product. In 1999 4.9 million tonnes of Orimulsion® were exported, bringing the cumulative total to in excess of 27 million tonnes.

In addition to being used in conventional power plants using steam turbines, Orimulsion® can be used in diesel engines for power generation, in cement plants, as a feedstock for Integrated Gasification Combined Cycle and as a "reburning" fuel (a method of reducing NO_x by staging combustion in the boiler).

Orimulsion® is a registered trademark belonging to Bitúmenes Orinoco S.A.

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Chapter 5

NATURAL GAS

As we enter the new millennium, humanity faces a unique and far-reaching challenge. Our energy needs are growing as a result of continued population increases, economic growth and individual energy consumption. At the same time, emissions from fossil fuels, the main energy source for heating our homes and powering our economies, are contributing to climate change and affecting local air quality.

Alternative energy technologies offer one promising solution, although it will be some time before they will become cost-effective and widely available. Energy conservation is also a logical part of the solution, but even the most stringent conservation methods will not eliminate our need for energy. Other viable options are clearly needed.

Natural gas, as a cleaner burning source of fossil fuel than oil or coal, is now commonly believed to offer part of the solution to climate change and problems associated with poor air quality. Once considered largely a waste product of oil production, natural gas is currently experiencing a huge increase in demand around the world. As a plentiful, economically viable, and less polluting fuel, natural gas makes sense for developing economies looking for new sources of power. Technology transfer from developed countries will be required to meet this need.

The increased use of natural gas offers reduced emissions and significant environmental benefits now – locally, regionally and globally – and fulfils an important energy transition role as we look towards the future.

A Cleaner Source of Energy

Climate Change

As the global community moves towards a less carbon-intensive energy future, it is important to recognise that natural gas occupies a unique and strategic position in the hierarchy of energy resource options.

Unlike coal and oil, natural gas has a higher hydrogen/carbon ratio and emits less carbon dioxide for a given quantity of energy consumed. However, to fully understand the greenhouse gas profile of any fuel source, it is important to look at its total lifecycle: all of the emissions associated with the fuel, including emissions from initial extraction, processing and delivery as well as those from its final combustion.

In the natural gas industry, greenhouse gases are emitted as a result of:

- processing and compression of the gas;
- fugitive emissions (unintended losses of gas during transmission and distribution);

- blowdowns (the deliberate release of gas during maintenance operations);
- the combustion of natural gas during day-to-day operations (i.e. for vehicle use, heating).

Once natural gas is delivered to end users, greenhouse gas emissions are also created during combustion.

Despite these lifecycle emissions, however, natural gas compares very favourably against oil and coal. Taking a range of global warming potentials[1], even under the most conservative conditions of analysis (a 50-year timeframe), oil contributes 20% more CO_2 equivalent emissions than natural gas, and coal contributes 50% more. Additional analysis suggests that even on a conservative analytical basis, using natural gas in place of other fossil fuels is an effective way of reducing the world's greenhouse gas emissions and still meeting our energy needs.

Air Emissions: Fewer Impacts on Local Air Quality than Other Fossil Fuels

As the cleanest burning fossil fuel, natural gas offers an immediate, cost-effective means to improve air quality. Unlike coal and oil, it releases virtually no particulate matter, which impedes photosynthesis in plants and aggravates heart and lung disease in humans. Particulate matter is also a contributor to smog.

The production and combustion of fossil fuels also generates nitrogen and sulphur oxide emissions. Nitrogen oxides result in various environmental impacts – including smog and acid rain. Sulphur oxides are also a primary contributor to acid rain.

In stressed urban airsheds[2], where most natural gas is consumed for residential and industrial purposes, combustion of natural gas can have a positive impact on local air quality because it creates fewer air emissions (Figure 5.1). Nonetheless, addressing the issue of air quality has become a priority concern for the natural gas industry.

Figure 5.1: Comparison of Air Pollution from the Combustion of Fossil Fuels (kilograms of emission per TJ of energy consumed)

	Natural Gas	Oil	Coal
Nitrogen Oxides	43	142	359
Sulphur Dioxide	0.3	430	731
Particulates	2	36	1 333

Sources: U.S. Environmental Protection Agency; American Gas Association

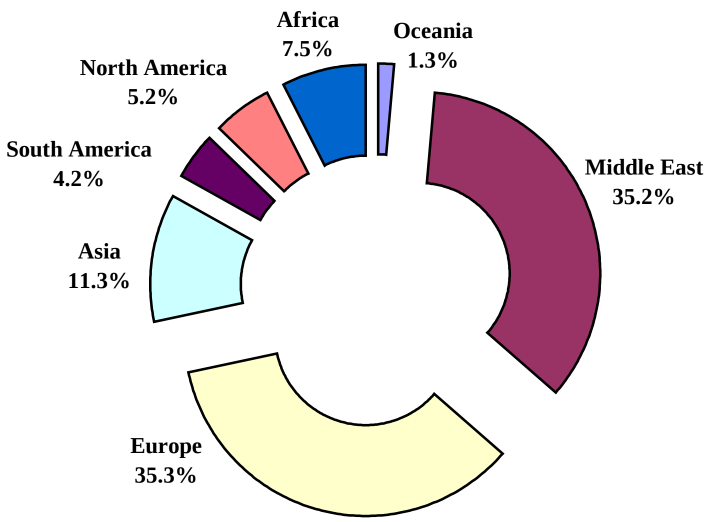
[1] On a per unit of weight basis, greenhouse gases such as methane (CH_4) and nitrous oxide have a different impact on climate change relative to the effect of a similar weight of carbon dioxide over the same time period. To allow comparisons between various greenhouse gases, the emissions are expressed according to their individual Global Warming Potential. For example, the GWP of natural gas is 6.5 over 500 years and 34 over 50 years. A GWP of 21, the mean of 6.5–34, is generally used by the industry, as recommended by the Intergovernmental Panel on Climate Change.

[2] An airshed is an area in the lower troposphere where air movement is restricted by factors such as geography or meteorology.

Increasing Demand for Natural Gas

The environmental benefits provided by natural gas and advances in technology are ensuring its role as the preferred fuel. There has been a steady increase in natural gas production over the past ten years. Data reported by WEC Member Committees for the present Survey, supplemented by information derived from other sources (including Cédigaz), indicate that world production of dry marketable natural gas was some 2.4 trillion cubic metres (85 trillion cubic feet) in 1999, an increase of 4.1% over the comparable 1996 total published in the 1998 Survey. Trends indicate that this steady increase will continue in the coming years as the world moves towards less carbon-intensive energy strategies. Early indications point to accelerated growth during 2000, reflecting (inter alia) the implementation of new and expanded LNG export schemes in Nigeria, Oman, Qatar and Trinidad.

Figure 5.2: Proved gas reserves at end-1999 - regional distribution



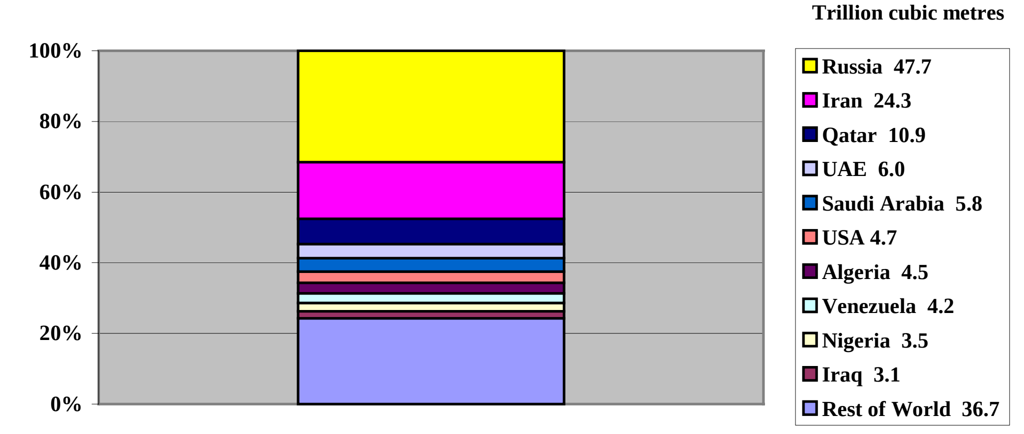
China's consumption of coal in 1999 decreased; at the same time it increased its natural gas consumption by 10.9% over 1998. In the Asia Pacific region, consumption of natural gas increased by 6.5%. With nearly 50% of the world's population, and growing economies that demand energy, this region has the potential to significantly impact the future demand curve for all energy sources. It is anticipated that a fairly significant portion of the demand will be met by natural gas.

Viewed regionally, the African continent had the fastest rate of growth in consumption, with an increase of 9.1% in 1999. Africa has a growing potential not only as a market for natural gas, but as a producer.

The transfer of technology from industrialised nations to developing countries will play an important role in balancing increasing consumption with the need for reducing emissions from fossil fuels. As a relatively abundant, economically feasible and cleaner fossil fuel, natural gas has many benefits for developing countries, especially as population migration from rural areas to urban centres puts increasing loads on urban airsheds. Foreign capital investment will be essential for developing the appropriate infrastructure, where required, and expanding existing infrastructures.

The International Gas Union (IGU), which represents both developing and industrialised countries, provides an ideal venue to foster the co-operative spirit required to take advantage of these development opportunities. Market instruments, such as the Clean Development Mechanism proposed by the Kyoto Protocol, would deliver the incentive for industry to act on the opportunities.

Figure 5.3: Proved gas reserves at end-1999 - leading countries



In short, the current increase in demand for natural gas is not a short-term scenario. Rather, the gas industry is experiencing steady growth on a world-wide basis, which is likely to continue for many years to come. The challenge is to ensure that the focus is not just on meeting the demands of an expanding market, but on reducing harmful emissions and achieving greater efficiencies in the production and consumption of natural gas.

New Technologies and the Role of Natural Gas

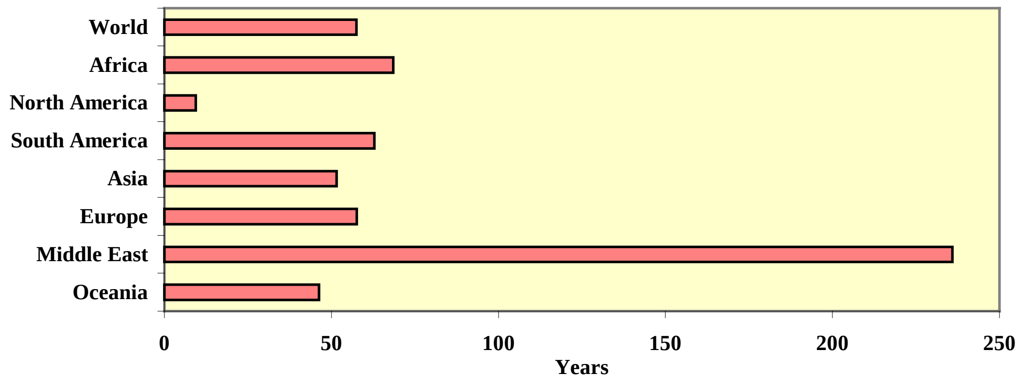
The international climate change policy process is likely to produce powerful market incentives for businesses to invest in cleaner technologies and increased efficiencies. Successful industry leaders will be those that capture this opportunity.

Several new technologies in the natural gas industry have emerged in recent years as a result of this market trend. One such technology is combined-cycle power plants. Conventional power plants use coal and oil to produce the steam that turns the turbines, which produce power. Gas turbines can be directly powered by natural gas. Exhaust heat is captured and used to produce steam for additional power production. Combined-cycle technology can increase the efficiency of a fossil fuel from an average of 40% to over 80%, thereby reducing emissions of atmospheric pollutants.

Acid gas re-injection is also increasing efficiencies in the production of natural gas. Processing of raw gas involves stripping the gas of hydrogen sulphide and most of its carbon dioxide content to produce marketable gas. The most common traditional method of handling these by-products, referred to as acid gas, is to convert it to elemental sulphur, which is then pelletized. Injection of the acid gas into a suitable underground formation, such as a depleted reservoir, is gaining recognition as a method of significantly reducing emissions.

Hydrogen fuel cells are a promising new innovation that could potentially replace internal combustion engines, which emit harmful air emissions. In order for fuel cells to capture their full environmental advantage, the hydrogen they require would have to be derived from a renewable energy source, which is not yet economically feasible. Once again, considering the emissions produced by current available sources of hydrogen, there is a clear advantage to using hydrogen from natural gas for this and other future hydrogen-based technologies. Methane (CH_4) has a distinct hydrogen-rich molecular structure, which seems to make it well prepared for becoming a hydrogen carrier as well, as we move from the present combustion technologies to future hydrogen technologies.

Figure 5.4: Gas reserves/production ratio, 1999 - regional distribution



Supply

Another factor in favour of natural gas is its relative abundance. The IGU is currently conducting a special project on global energy scenarios. The study intends to show that natural gas reserves will be available for more than 100 years, as most recent forecasts suggest. The final results will be presented at the World Gas Conference in Tokyo in June 2003.

The development of new technology has improved forecasts. Geologists are now discovering natural gas at deeper levels than previous exploration indicated, leading to a greater understanding and certainty about natural gas reserves that will be available in the future.

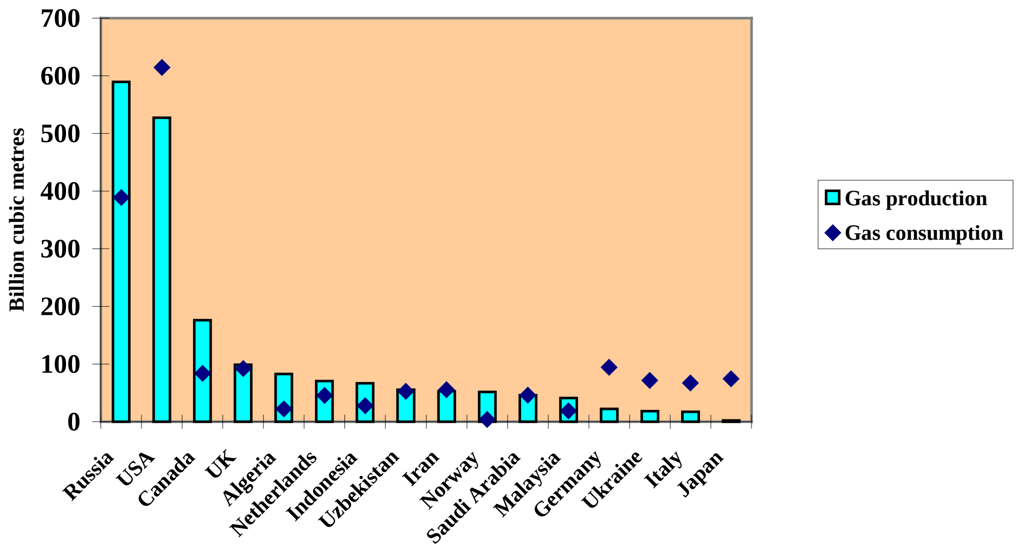
While the exact amount of natural gas reserves is still not clear, reserve forecasts have been steadily increasing as existing reserves are more extensively explored. High prices for natural gas and strong demand have made new development more economically feasible.

In the 1980 Survey of Energy Resources the proven reserves of natural gas in the world were put at 70 trillion cubic metres. Some twenty years later, proven reserves are over 150 trillion cubic metres – see Table 5.1.

According to Enron Inc., the current annual investment in new infrastructure for natural gas is approximately US$ 25 billion. This is certainly a sign that the market players expect growth in the natural gas sector in the coming years.

An important part of the supply picture is, that out of the 485 billion cubic metres of gas exported around the world in 1999, approximately 25% or 124 billion cubic metres was in the form of Liquefied Natural Gas (LNG), 75 % of which is transported to Asia Pacific.

Figure 5.5: Gas production and consumption, 1999 - leading countries



LNG is currently a booming business, but with the growing energy demand – especially in Asia – this will be a continuous upward trend, challenging the gas industry and the IGU to develop cheaper and more advanced LNG technology.

A Bridge to the Future

Professor Nebojsa Nakicenovic of the International Institute for Applied Systems Analysis in Austria is a well-known lead author in IPCC, the Intergovernmental Panel on Climate Change.

With colleagues from the Institute, Professor Nakicenovic has produced a report called: "Global Natural Gas Perspectives" in which he concludes that:

"…energy gases could become the means to reduce energy-related emissions of greenhouse-gases and to provide affordable and sufficient energy services for further development of the world…"

The natural gas industry is aware of the environmental advantages of its product and of the need to improve efficiencies. Methods to reduce emission of greenhouse gases are on the agenda nationally and globally.

The IGU is focused on advancing this awareness and promoting the important role of natural gas as a partial solution to climate change and in improving air quality. In combination with energy conservation, natural gas will help to bridge our current energy needs with the non-carbon emitting and renewable energy sources that will become viable in the future.

As demand for energy grows, increased effort should be focused on the transfer of technology from developed countries to developing countries. The IGU, with members from both categories, will take the opportunity during the next few years to explore opportunities for joint projects that involve technology transfer.

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International Gas Union

&

Jane McRae
Program Analyst
Westcoast Energy Inc.
Canada

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DEFINITIONS

Natural gas is a mixture of hydrocarbon and small quantities of non-hydrocarbons that exists either in the gaseous phase or is in solution in crude oil in natural underground reservoirs, and which is gaseous at atmospheric conditions of pressure and temperature.

Natural gas liquids (hydrocarbons that exist in the reservoir as constituents of natural gas but which are recovered as liquids in separators, field facilities or gas-processing plants) are discussed in Chapter 2 – Crude Oil and Natural Gas Liquids.

Proved amount in place is the volume originally occurring in known natural reservoirs which has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology.

Proved recoverable reserves is the volume within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology.

Estimated additional amount in place is the volume additional to the proved amount in place that is of foreseeable economic interest. Speculative amounts are not included.

Estimated additional reserves recoverable is the volume within the estimated additional amount in place which geological and engineering information indicates with reasonable certainty might be recovered in the future.

Production - where available, gross and net (marketed) volumes are given, together with the quantities re-injected, flared and lost in shrinkage (due to the extraction of natural gas liquids, etc.).

Consumption - natural gas consumed within the country, including imports but excluding amounts re-injected, flared and lost in shrinkage.

R/P (reserves/production) ratio is calculated by dividing proved recoverable reserves at the end of 1999 by production (gross less re-injected) in that year. The resulting figure is the time in years that the proved recoverable reserves would last if production were to continue at the 1999 level.

As far as possible, natural gas volumes are expressed in standard cubic metres, measured dry at 15^{o}C and 1013 mb, and the corresponding cubic feet (at 35.315 cubic feet per cubic metre).

Table 5.1 Natural gas: proved recoverable reserves at end-1999

Excel files	billion cubic metres	billion cubic feet
Algeria	4 522	159 694
Angola	46	1 620
Benin	1	43
Cameroon	110	3 900
Congo (Brazzaville)	91	3 200
Congo (Democratic Rep.)	1	35
Côte d'Ivoire	30	1 059
Egypt (Arab Rep.)	1 223	43 190
Equatorial Guinea	37	1 300
Ethiopia	25	883
Gabon	33	1 165
Ghana	24	848
Libya/GSPLAJ	1 313	46 369
Madagascar	2	70
Morocco	1	47
Mozambique	57	2 000
Namibia	85	3 000
Nigeria	3 515	124 132
Rwanda	57	2 000
Senegal	11	388
Somalia	6	200
South Africa	19	671
Sudan	85	3 002
Tanzania	28	989
Tunisia	78	2 755
Total Africa	**11 400**	**402 560**
Barbados	N	7
Canada	1 719	60 706
Cuba	18	636
Guatemala	3	109
Mexico	861	30 392
Trinidad & Tobago	602	21 260
United States of America	4 740	167 406
Total North America	**7 943**	**280 516**
Argentina	748	26 416
Bolivia	518	18 293
Brazil	231	8 165
Chile	98	3 460
Colombia	193	6 816
Ecuador	104	3 670
Peru	255	9 000
Venezuela	4 152	146 611
Total South America	**6 299**	**222 431**
Afghanistan	100	3 530
Armenia	176	6 215
Azerbaijan	1 370	48 382
Bangladesh	301	10 615
Brunei	391	13 800
China	1 368	48 300
Georgia	8	300
India	647	22 849
Indonesia	2 212	78 127
Japan	39	1 381
Kazakhstan	1 841	65 000
Kyrgyzstan	6	200
Malaysia	2 313	81 700
Myanmar (Burma)	283	10 000
Nepal	N	2
Pakistan	581	20 507

Table 5.1 Natural gas: proved recoverable reserves at end-1999 contd.

	billion cubic metres	billion cubic feet
Philippines	106	3 750
Taiwan, China	76	2 700
Tajikistan	6	200
Thailand	345	12 184
Turkey	9	311
Turkmenistan	2 860	101 000
Uzbekistan	1 875	66 200
Vietnam	193	6 800
Total Asia	**17 106**	**604 053**
Albania	3	100
Austria	26	915
Belarus	3	100
Bulgaria	6	210
Croatia	34	1 187
Czech Republic	4	141
Denmark	90	3 178
France	14	505
Germany	285	10 065
Greece	1	35
Hungary	24	851
Ireland	6	211
Italy	191	6 745
Netherlands	1 714	60 530
Norway	1 245	43 967
Poland	122	4 291
Romania	406	14 324
Russian Federation	47 730	1 685 585
Serbia, Montenegro	48	1 700
Slovakia	15	530
Slovenia	N	2
Spain	N	N
Ukraine	825	29 142
United Kingdom	760	26 839
Total Europe	**53 552**	**1 891 153**
Bahrain	110	3 885
Iran (Islamic Rep.)	24 308	858 437
Iraq	3 110	109 830
Israel	44	1 554
Jordan	6	201
Kuwait	1 480	52 266
Oman	805	28 429
Qatar	10 900	384 934
Saudi Arabia	5 777	204 015
Syria (Arab Rep.)	241	8 511
United Arab Emirates	6 003	211 996
Yemen	479	16 916
Total Middle East	**53 263**	**1 880 974**
Australia	1 443	50 960
New Zealand	68	2 418
Papua New Guinea	428	15 115
Total Oceania	**1 939**	**68 493**
TOTAL WORLD	**151 502**	**5 350 180**

Notes:

1. The relationship between cubic metres and cubic feet is on the basis of one cubic metre = 35.315 cubic feet throughout
2. Sources: WEC Member Committees, 2000/2001; *Oil & Gas Journal,* December 18, 2000; *Natural Gas in the World 2000*, Cédigaz; *Annual Statistical Report 2000*, OAPEC; Various national sources

Table 5.2 Natural gas: resources at end-1999

[Excel files]

	Proved amount in place	Estimated additional amount in place	Estimated additional reserves recoverable	Proved amount in place	Estimated additional amount in place	Estimated additional reserves recoverable
	billion cubic metres			trillion cubic feet		
Africa						
Ghana	7			0.2		
Morocco	2			0.1		
South Africa	33			1.2		
North America						
Canada		12 800	8 880		452.0	313.6
Mexico	1 160	412		41.0	14.5	
South America						
Argentina			258			9.1
Brazil	1 211		173	42.8		6.1
Venezuela	9 457	1 190	1 069	334.0	42.0	37.7
Asia						
Indonesia	3 339	1 899	1 324	117.9	67.1	46.7
Thailand	575	490	220	20.3	17.3	7.8
Turkey	13			0.5		
Europe						
Austria	26			0.9		
Croatia	34			1.2		
Czech Republic	9		2	0.3		0.1
Denmark	412	151	60	14.5	5.3	2.1
France	375			13.2		
Germany	1 530		98	54.0		3.5
Hungary	63	112	111	2.2	3.9	3.9
Ireland	7	31	25	0.2	1.1	0.9
Italy			44			1.5
Netherlands	4 245		122	149.9		4.3
Norway	3 795	2 320		134.0	81.9	
Poland	146	650		5.2	23.0	
Romania		371			13.1	
Slovenia	N	1	N	N	N	N
Spain	N	N	N	N	N	N
Ukraine	1 118	368	10	39.5	13.0	0.4
United Kingdom		500	490		17.7	17.3
Middle East						
Iran (Islamic Rep.)	32 699			1 154.8		
Israel	55	150	130	1.9	5.3	4.6
Jordan	15		6	0.5		0.2
Oceania						
Australia			1 287			45.5
New Zealand	165			5.8		

Notes:
1. The data on resources are predominantly those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Sources: WEC Member Committees, 2000/2001; *1999 Oil and Gas Resources of Australia*, Australian Geological Survey Organisation

Table 5.3 Natural gas: 1999 production

[Excel Files]()	billion cubic metres					billion cubic feet	R/P ratio
	Gross	Re-injected	Flared	Shrinkage	Net	Net	
Algeria	152.8	58.2	7.0	4.8	82.8	2 924	47.8
Angola	7.3	2.3	4.3	0.1	0.6	20	9.2
Cameroon	2.1		2.1				52.4
Congo (Brazzaville)	3.8	2.3	1.4	0.1	N	N	60.7
Côte d'Ivoire	1.3				1.3	47	23.1
Egypt (Arab Rep.)	20.5	0.9	0.9	3.2	15.5	548	62.4
Equatorial Guinea	1.1		0.9	0.2	N	1	33.6
Gabon	2.6	0.6	1.8	0.1	0.1	4	16.5
Libya/GSPLAJ	12.2	3.7	1.8	0.6	6.1	217	> 100
Morocco	N				N	2	22.7
Mozambique	0.1				0.1	2	> 100
Nigeria	30.7	4.0	18.8	0.9	7.0	245	> 100
Senegal	N				N	1	> 100
South Africa	1.6		0.2		1.4	49	11.9
Tunisia	2.4		0.4	0.1	1.9	67	32.5
Total Africa	**238.5**	**72.0**	**39.6**	**10.1**	**116.8**	**4 127**	**68.5**
Barbados	N				N	2	3.5
Canada	209.7	12.6	2.5	18.4	176.2	6 223	8.7
Cuba	0.7		0.1	0.1	0.5	18	25.7
Mexico	49.5		5.9	8.8	34.8	1 229	17.4
Trinidad & Tobago	14.2		2.5		11.7	414	42.4
United States of America	672.7	93.6	6.9	44.9	527.3	18 623	8.2
Total North America	**946.8**	**106.2**	**17.9**	**72.2**	**750.5**	**26 509**	**9.4**
Argentina	42.4	3.0	0.9	0.5	38.0	1 342	19.0
Bolivia	5.1	1.9	0.4	0.3	2.5	87	>100
Brazil	11.9	1.8	2.3	1.1	6.7	237	22.9
Chile	3.1	0.7	0.1	0.1	2.2	79	40.8
Colombia	15.1	9.0	0.6	0.3	5.2	183	31.6
Ecuador	1.1	0.2	0.8		0.1	4	> 100
Peru	0.9	0.3	0.2		0.4	15	> 100
Venezuela	57.1	19.7	3.7	6.9	26.8	945	> 100
Total South America	**136.7**	**36.6**	**9.0**	**9.2**	**81.9**	**2 892**	**62.9**
Afghanistan	0.2				0.2	8	> 100
Azerbaijan	13.4		7.1	0.3	6.0	212	> 100
Bangladesh	8.3				8.3	293	36.3
Brunei	11.3	1.7		0.2	9.4	334	40.7
China	24.2				24.2	854	56.5
Georgia	0.1				0.1	2	80.0
India	28.0	3.6	1.5	3.4	19.5	690	26.5
Indonesia	86.9	13.8	5.0	1.7	66.4	2 345	30.3
Japan	2.3				2.3	82	17.0
Kazakhstan	9.8				9.8	346	> 100
Kyrgyzstan	N				N	1	> 100
Malaysia	41.7			0.6	41.1	1 450	55.5
Myanmar (Burma)	1.7				1.7	59	> 100
Pakistan	22.0				22.0	775	26.4
Philippines	N				N	N	> 100
Taiwan, China	0.9				0.9	31	84.4
Tajikistan	N				N	1	>100
Thailand	19.2			1.5	17.7	625	18.0
Turkey	0.7				0.7	26	12.9
Turkmenistan	22.8				22.8	805	>100
Uzbekistan	55.6				55.6	1 963	33.7
Vietnam	1.4		0.4		1.0	35	> 100
Total Asia	**350.5**	**19.1**	**14.0**	**7.7**	**309.7**	**10 937**	**51.6**

Table 5.3 Natural gas: 1999 production contd.

	billion cubic metres					billion cubic feet	R/P ratio
	Gross	**Re-injected**	**Flared**	**Shrinkage**	**Net**	**Net**	
Albania	N	N			N	1	>100
Austria	1.7				1.7	61	15.3
Belarus	0.3				0.3	9	12.0
Bulgaria	N				N	1	> 100
Croatia	1.6				1.6	55	21.3
Czech Republic	2.3	2.0			0.3	10	13.3
Denmark	11.5	3.3	0.4		7.8	276	11.0
France	3.0		N	0.9	2.1	72	4.7
Germany	23.2			0.8	22.4	792	12.3
Greece	0.1			N	0.1	1	10.0
Hungary	3.6			0.2	3.4	118	6.7
Ireland	1.4				1.4	51	4.3
Italy	17.5				17.5	617	10.9
Netherlands	72.4	2.0	0.1		70.3	2 481	24.3
Norway	81.8	28.6	0.7	0.9	51.6	1 822	23.4
Poland	4.7				4.7	166	26.0
Romania	14.4			0.2	14.2	501	28.2
Russian Federation	599.9			10.2	589.7	20 825	79.6
Serbia, Montenegro	0.7				0.7	23	68.6
Slovakia	3.2	1.4	1.6		0.2	7	8.3
Slovenia	N				N	N	9.5
Spain	0.6				0.6	20	
Ukraine	18.6	0.4	0.1		18.1	639	45.3
United Kingdom	107.1	2.7	2.1	3.6	98.7	3 486	7.3
Total Europe	**969.6**	**40.4**	**5.0**	**16.8**	**907.4**	**32 034**	**57.6**
Bahrain	11.5	2.8		0.3	8.4	297	12.6
Iran (Islamic Rep.)	94.7	27.0	10.5	4.2	53.0	1 870	> 100
Iraq	4.4		0.9	0.3	3.2	112	> 100
Israel	0.5				0.5	18	88.0
Jordan	0.3				0.3	11	20.0
Kuwait	9.6		0.5	1.0	8.1	286	> 100
Oman	11.6	3.4	1.3	1.3	5.6	197	98.2
Qatar	31.1	3.8		3.3	24.0	848	> 100
Saudi Arabia	48.7	0.1	0.3	2.1	46.2	1 632	> 100
Syria (Arab Rep.)	7.9	0.5	0.4	1.0	6.0	213	32.6
United Arab Emirates	50.3	7.5	1.4	3.4	38.0	1 343	> 100
Yemen	16.1	15.8		0.3			> 100
Total Middle East	**286.7**	**60.9**	**15.3**	**17.2**	**193.3**	**6 827**	**> 100**
Australia	35.8			4.1	31.7	1 119	40.3
New Zealand	6.7	0.7	0.1	0.1	5.8	203	11.3
Papua New Guinea	0.1	N			0.1	4	> 100
Total Oceania	**42.6**	**0.7**	**0.1**	**4.2**	**37.6**	**1 326**	**46.3**
TOTAL WORLD	**2 971.4**	**335.9**	**100.9**	**137.4**	**2 397.2**	**84 652**	**57.5**

Notes:
1. Sources: WEC Member Committees, 2000/2001; *Natural Gas in the World 2000*, Cédigaz; various national sources

Table 5.4 Natural gas: 1999 consumption

Excel files

	billion cubic metres	billion cubic feet
Algeria	22.2	784
Angola	0.6	20
Congo (Brazzaville)	N	N
Côte d'Ivoire	1.3	47
Egypt (Arab Rep.)	15.5	548
Equatorial Guinea	N	1
Gabon	0.1	4
Libya/GSPLAJ	5.2	183
Morocco	N	2
Mozambique	0.1	2
Nigeria	6.2	219
Senegal	N	1
South Africa	1.4	49
Tunisia	3.0	106
Total Africa	**55.6**	**1 966**
Barbados	N	2
Canada	84.1	2 970
Cuba	0.5	18
Mexico	37.2	1 313
Trinidad & Tobago	9.6	339
United States of America	614.3	21 694
Total North America	**745.7**	**26 336**
Argentina	32.0	1 130
Bolivia	0.9	31
Brazil	8.2	290
Chile	5.8	203
Colombia	5.2	183
Ecuador	0.1	4
Peru	0.4	15
Uruguay	N	1
Venezuela	26.8	945
Total South America	**79.4**	**2 802**
Afghanistan	0.2	8
Armenia	1.3	46
Azerbaijan	6.0	212
Bangladesh	8.3	293
Brunei	1.0	37
China	21.5	759
Georgia	1.2	41
Hong Kong, China	2.7	96
India	19.5	690
Indonesia	27.6	974
Japan	74.5	2 631
Kazakhstan	10.5	369
Korea (Republic)	18.7	661
Kyrgyzstan	1.0	37
Malaysia	19.0	671
Myanmar (Burma)	1.7	59
Pakistan	22.0	775
Philippines	N	N
Singapore	1.5	53
Taiwan, China	5.9	210
Tajikistan	0.8	28
Thailand	17.7	625
Turkey	12.9	456
Turkmenistan	13.2	467

Table 5.4 Natural gas: 1999 consumption contd.

	billion cubic metres	billion cubic feet
Uzbekistan	52.9	1 869
Vietnam	1.0	35
Total Asia	**342.6**	**12 102**
Albania	N	1
Austria	8.1	285
Belarus	16.3	576
Belgium	14.8	524
Bosnia-Herzogovina	0.2	7
Bulgaria	3.4	119
Croatia	2.7	95
Czech Republic	9.5	337
Denmark	5.1	180
Estonia	0.7	25
Finland	4.1	145
France	44.9	1 586
Germany	94.2	3 326
Greece	1.5	54
Hungary	12.6	445
Ireland	3.5	125
Italy	67.0	2 365
Latvia	1.2	44
Lithuania	2.3	81
Luxembourg	0.8	28
Moldova	3.3	115
Netherlands	45.8	1 617
Norway	3.8	134
Poland	12.1	427
Portugal	0.8	28
Romania	17.3	613
Russian Federation	388.7	13 728
Serbia, Montenegro	1.8	62
Slovakia	7.1	251
Slovenia	1.0	35
Spain	15.0	530
Sweden	0.9	30
Switzerland	2.8	100
Ukraine	71.5	2 525
United Kingdom	92.3	3 259
Total Europe	**957.1**	**33 802**
Bahrain	8.4	297
Iran (Islamic Rep.)	55.5	1 960
Iraq	3.2	112
Israel	0.5	18
Jordan	0.3	11
Kuwait	8.1	286
Oman	4.9	174
Qatar	15.9	562
Saudi Arabia	46.2	1 632
Syria (Arab Rep.)	6.0	213
United Arab Emirates	31.4	1 110
Total Middle East	**180.4**	**6 375**
Australia	21.6	763
New Zealand	5.8	203
Papua New Guinea	0.1	4
Total Oceania	**27.5**	**970**
TOTAL WORLD	**2 388.3**	**84 353**

Notes:

1. Sources: WEC Member Committees, 2000/2001; *Natural Gas in the World 2000*, Cédigaz; other international and national sources; estimates by the editors

COUNTRY NOTES

The following Country Notes on natural gas provide a brief account of countries with significant gas resources. They have been compiled by the editors, drawing upon a wide variety of material including information received from WEC Member Committees, national and international publications.

The principal published sources consulted were:

- *Natural Gas in the World, 2000 Survey*; Cédigaz;
- *BP Statistical Review of World Energy 2001*; The British Petroleum Company p.l.c.;
- *Energy Balances of OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Energy Balances of Non-OECD Countries 1997-1998*; 2000; International Energy Agency;
- *Energy Statistics of OECD Countries 1997-1998*; 2000; International Energy Agency.
- *Energy Statistics of Non-OECD Countries 1997-1998*; 2000; International Energy Agency.

Brief salient data are shown for each country, including the year of first commercial production of natural gas (where ascertained).

ALGERIA

Proved recoverable reserves (billion cubic metres)	4 522
Production (net billion cubic metres, 1999)	82.8
R/P ratio (years)	47.8
Year of first commercial production	1961

The gas resource base is the largest in Africa and one of the largest in the world. Almost all of Algeria's natural gas is non-associated with crude oil. Successful exploration efforts during recent years have enabled additions to reserves to outweigh the gas produced.

For the purposes of the present Survey, the level of proved recoverable reserves adopted is that quoted by OAPEC, which was increased in 1999 by 22.5% above the previous level of 3 690 bcm.

Gross production in 1999 was the fourth highest in the world, after the USA, the Russian Federation and Canada. About 38% was re-injected, while much smaller proportions (in the order of 5% of production in each case) were flared or abstracted as NGL's. Nearly 73% of net production was exported: 43% of gas exports were in the form of LNG, consigned to France, Spain, Belgium, Turkey, the USA and Italy. Apart from oil and gas industry use, the main internal markets for Algerian gas are power stations, industrial fuel/feedstock and households.

ARGENTINA

Proved recoverable reserves (billion cubic metres)	748
Production (net billion cubic metres, 1999)	38.0
R/P ratio (years)	19.0

Argentina's proved reserves of natural gas are the second largest in South America, after Venezuela. Most of the gas reserves have been discovered in the course of exploration for oil; at end-1999, 51.8% of proved reserves were located in the Neuquén Basin, 23.5% in the Austral Basin, 20.1% in the Noroeste, 4.5% in the Golfo San Jorge and 0.1% in the Cuyo-Mendoza Basin.

The proved recoverable reserves reported by the Argentinean WEC Member Committee are some 9% higher than those contributed to the 1998 Survey. Additional reserves, not yet proven but considered to be eventually recoverable, now stand at 258 billion m^3.

Gross production of natural gas increased by 84% between 1990 and 1999; about 7% of current output is re-injected. Marketed production (after relatively small amounts are deducted through flaring and shrinkage) now exceeds that of Venezuela, and is the highest in South America. For many years, gas supplies have been augmented by imports from Bolivia, but this flow ceased in October 1999, as the focus of Bolivia’s gas exports shifted to Brazil. In a further re-orientation of the South American gas supply structure, Argentina has become a significant exporter in its own right, with a number of pipelines supplying Chile and others to Uruguay and Brazil.

Consumption of indigenous and imported gas in 1998 (outside the energy sector) was divided approximately equally between the power generation market (38%), industrial fuel/feedstock (29%) and residential/commercial uses (28%); about 5% was consumed in road transport.

AUSTRALIA

Proved recoverable reserves (billion cubic metres)	1 443
Production (net billion cubic metres, 1999)	31.7
R/P ratio (years)	40.3
Year of first commercial production	1969

Exploration for hydrocarbons has discovered more natural gas than oil: Australian proved reserves of gas as reported for the present Survey are in the same bracket as those of China, Kuwait and Libya.

Gross production grew by over 60% between 1990 and 1996, reflecting in part a growth in domestic demand but more especially a substantial increase in exports of LNG (principally to Japan) from the North West Shelf fields.

The main gas-consuming sectors in Australia are public electricity generation, the non-ferrous metals industry and the residential sector.

The level of proved recoverable reserves quoted above corresponds with “Economic Demonstrated Resources” (EDR) (as at 31 December 1997), as given in *1999 Oil and Gas Resources of Australia*, Australian Geological Survey Organisation. EDR is defined as “resources judged to be economically extractable and for which the quantity and quality are computed partly from specific measurements and partly from extrapolation for a reasonable distance on geological evidence”.

AZERBAIJAN

Proved recoverable reserves (billion cubic metres)	1 370
Production (net billion cubic metres, 1999)	6.0
R/P ratio (years)	>100

Azerbaijan is one of the world's oldest producers of natural gas. After years of falling production the outlook has been transformed by recent developments. Proved reserves of gas, as quoted by Cédigaz, rose by 470 bcm in 1999 to a total of 1 370 bcm, reflecting new discoveries - in particular, the major Shah Deniz offshore field. The same source quotes Azerbaijan's gas resources as 3-5 trillion m^3.

Marketed production in 1999 was 6 bcm, of which 85% came from offshore fields. Over half of current gross production is reported to be flared or vented.

BANGLADESH

Proved recoverable reserves (billion cubic metres)	301
Production (net billion cubic metres, 1999)	8.3
R/P ratio (years)	36.3
Year of first commercial production	pre-1971

Whilst the published volumes of proved gas reserves (e.g. OGJ 301 bcm, Cédigaz 315 bcm) are not particularly large, much of Bangladesh is poorly explored and the potential for further discoveries is thought to be substantial.

Gas production has followed a rising trend for many years and is currently approaching 10 bcm per annum. Natural gas contributes more than two-thirds of Bangladesh's commercial energy supplies; its principal outlets are power stations and fertiliser plants. Consumption by other industrial users and the residential/commercial sector is growing rapidly.

BOLIVIA

Proved recoverable reserves (billion cubic metres)	518
Production (net billion cubic metres, 1999)	2.5
R/P ratio (years)	>100
Year of first commercial production	1955

Following recent major discoveries, Bolivia's proved reserves of natural gas, as reported by Cédigaz, have been increased more than three-fold, from 150 to 518 billion m^3. Probable reserves have been raised from 93 to 394 bcm and possible reserves from 155 to 500 bcm.

Exports to Argentina used to be the major outlet for Bolivia's natural gas, but this flow ceased during 1999. The focus of Bolivia's gas export trade has now shifted towards Brazil, with the inauguration of two major export lines, one from Santa Cruz de la Sierra to south-east Brazil in 1999 and another in 2000 from San Miguel to Cuiaba.

Internal consumption of gas has been on a small scale (less than 1 bcm/year), and confined almost entirely to electricity generation and industrial fuel markets; residential use is presently minimal.

BRAZIL

Proved recoverable reserves (billion cubic metres)	231
Production (net billion cubic metres, 1999)	6.7
R/P ratio (years)	22.9
Year of first commercial production	1954

Brazil's natural gas industry is relatively small at present compared with its oil sector. Proved reserves, as reported by the Brazilian WEC Member Committee, are now the fifth largest in South America, having increased only marginally over the past three years. The proved amount of gas in place is reported as 1 211 bcm, over twice the level notified for the 1998 Survey. Of the latest assessment of proved recoverable reserves, approximately 26% is non-associated with crude oil. Additional recoverable reserves, not classified as proved, are put at just under 173 bcm.

Gross production rose by nearly 90% between 1990 and 1999; over one-third of current output is either re-injected or flared. Marketed production is mostly used as industrial fuel or as feedstock for the production of petrochemicals and fertilizers. As a consequence of Brazil's huge hydro-electric resources, use of natural gas as a power-station fuel has been minimal. The consumption picture will change as imported gas (from Bolivia and Argentina) fuels the large number of gas-fired power plants that are being built in Brazil.

BRUNEI

Proved recoverable reserves (billion cubic metres)	391
Production (net billion cubic metres, 1999)	9.4
R/P ratio (years)	40.7

Natural gas was found in association with oil at Seria and other fields in Brunei. For many years this resource was virtually unexploited, but in the 1960's a realisation of the resource potential, coupled with the availability of new technology for producing and transporting liquefied natural gas, enabled a major gas export scheme to be devised. Since 1972 Brunei has been exporting LNG to Japan, and more recently to the Korean Republic.

Despite annual exports of around 8 bcm, proved reserves (as published by OGJ) have remained virtually steady at just under 400 bcm since 1992.

Nearly 90% of Brunei's marketed production is exported, the balance being mostly used in the liquefaction plant, local power stations and offshore oil and gas installations. Small quantities are used for residential purposes in Seria and Kuala Belait.

CANADA

Proved recoverable reserves (billion cubic metres)	1 719
Production (net billion cubic metres, 1999)	176.2
R/P ratio (years)	8.7

Canada’s gas reserves are the third largest in the Western Hemisphere. The proved recoverable reserves reported by the Canadian WEC Member Committee for the present Survey correspond with “remaining established reserves” of marketable natural gas as assessed by the Canadian Association of Petroleum Producers (CAPP). “Initial established reserves” of marketable natural gas (which include cumulative production to date) are quoted by CAPP as 4 974 bcm at end-1999. In addition to its “established” resources, Canada is estimated to have 12 800 bcm of “undiscovered in-place resources” of gas.

At end-1999, 85% of proved recoverable reserves consisted of non-associated deposits: the provinces with the largest gas resources were Alberta (with 76% of remaining established reserves), British Columbia (14%) and Saskatchewan (4%).

Gross production of Canadian natural gas was the third highest in the world in 1999. Of the net output remaining after allowance for re-injection, flaring and shrinkage, approximately 57 % was exported to the United States. The largest users of gas within Canada are the industrial, residential and commercial sectors.

CHINA

Proved recoverable reserves (billion cubic metres)	1 368
Production (net billion cubic metres, 1999)	24.2
R/P ratio (years)	56.5
Year of first commercial production	1955

Past gas discoveries have been fewer than those of crude oil, which is reflected in the fairly moderate level of proved reserves. Gas reservoirs have been identified in many parts of China, including in particular the Sichuan Basin in the central region, the Tarim Basin in the north-west and the Yinggehai (South China Sea). The estimate of proved reserves adopted for the present Survey is, as in the case of the 1998 edition, derived from that reported by OGJ: the end-1999 level is some 17% higher than the comparable figure for end-1996. Other published assessments tend to fall within a fairly narrow band (1 169-1 375 bcm). China’s gas resource base is thought to be enormous: estimates by the Research Institute of Petroleum Exploration and Development, quoted by Cédigaz, put total resources at some 38 000 bcm, of which 21% are located offshore. Most of the onshore gas-bearing basins are in the central and western parts of China.

In January 1996, China began delivering natural gas to the Castle Peak power station in Hong Kong via a pipeline from the offshore Yacheng field; deliveries in 1999 totalled 2.7 bcm.

COLOMBIA

Proved recoverable reserves (billion cubic metres)	193
Production (net billion cubic metres, 1999)	5.2
R/P ratio (years)	31.6

The early gas discoveries were made in the north-west of the country and in the Middle and Upper Magdalena Basins; in more recent times, major gas finds have been made in the Llanos Basin to the east of the Andes. Proved reserves at end-1999 are quoted by Cédigaz as 193 bcm, of which the Cusiana-Cupiagua fields in the Llanos Basin account for 85 bcm. Other published sources quote closely similar total reserves, ranging from 188 to 196 bcm.

Gross production virtually doubled between 1995 and 1999, reflecting (in particular) the development of the Cusiana field. At present a high proportion of Colombia's gas output (60% in 1999) is re-injected in order to maintain or enhance reservoir pressures.

The major outlet for natural gas is the power generation market (41% of marketed production in 1998).

EGYPT (ARAB REP.)

Proved recoverable reserves (billion cubic metres)	1 223
Production (net billion cubic metres, 1999)	15.5
R/P ratio (years)	62.4
Year of first commercial production	1964

Proved reserves are the fourth largest in Africa, having been increased by a factor of more than 3 between 1990 and 1999, according to the OAPEC data adopted for the present Survey. Egypt's reserves are fast approaching those of its neighbour Libya.

The major producing area is the Mediterranean Sea region (mostly from offshore fields), although output of associated gas from a number of fields in the Western Desert and the Red Sea region is also important.

Marketed production has grown steadily in recent years and is now the second largest in Africa. The main outlets at present are power stations, fertiliser plants and industrial users such as the iron and steel sector and cement works.

GERMANY

Proved recoverable reserves (billion cubic metres)	285
Production (net billion cubic metres, 1999)	22.4
R/P ratio (years)	12.3

Although it is one of Europe's oldest gas producers, Germany's remaining proved reserves are still sizeable, and (apart from the Netherlands) they now rank as the largest onshore reserves in Western Europe. The principal producing area is in north Germany, between the rivers Weser and Elbe; westward from the Weser to the Netherlands border lies the other main producing zone, with more mature fields.

The proved recoverable reserves reported by the German WEC Member Committee are some 25% lower than the corresponding level in the 1998 Survey. The proved amount in place is assessed as equivalent to 1 530 billion standard m^3. All the proved recoverable reserves are non-associated with crude oil. An additional 98 billion standard m^3 is considered to be eventually recoverable.

Indigenous production provides about one-quarter of Germany's gas supplies; the greater part of demand is met by imports from the Russian Federation, the Netherlands, Norway, the UK and Denmark.

Underground gas storage (UGS) provides an important contribution to the security of supply and load-balancing of natural gas. At the end of 1999 about 18 bcm of working gas volume was provided by 39 facilities in aquifers, depleted fields and salt-caverns. An additional 4.6 bcm of UGS capacity is under construction or planned.

INDIA

Proved recoverable reserves (billion cubic metres)	647
Production (net billion cubic metres, 1999)	19.5
R/P ratio (years)	26.5
Year of first commercial production	1961

A sizeable natural gas industry has been developed on the basis of the offshore Bombay gas and oil/gas fields. Proved reserves at end-1999 have been reported by the Indian WEC Member Committee as 647 billion m^3. Data published by the Ministry of Petroleum and

Natural Gas indicate that the Bombay High fields accounted for 59% of India's gas reserves in 1998, with the eastern state of Assam possessing 28% and the western states of Gujarat and Rajasthan 13%.

Out of a gross production of 28 bcm in 1999, 13% is reported to have been re-injected and about 5% flared or vented.

Marketed production is principally used as feedstock for fertiliser and petrochemical manufacture, for electricity generation and as industrial fuel. The recorded use in the residential and agricultural sectors is exceedingly small.

INDONESIA

Proved recoverable reserves (billion cubic metres)	2 212
Production (net billion cubic metres, 1999)	66.4
R/P ratio (years)	30.3

The Indonesian WEC Member Committee reports proved recoverable gas reserves as 78 127 billion standard cubic feet (2 212 bcm), within a proved amount in place of 117 918 bscf (3 339 bcm). About 72% of the proved reserves are non-associated with crude oil. The Committee reports an additional amount in place of 67 055 bscf (1 899 bcm), of which 46 745 bscf (1 324 bcm) is regarded as recoverable in the future.

Indonesia's gas production is the highest in Asia. The main producing areas are in northern Sumatra, Java and eastern Kalimantan.

Exports of LNG from Arun (Sumatra) and Bontang (Kalimantan) to Japan began in 1977-1978. Indonesia has for many years been the world's leading exporter of LNG. Shipments in 1999 were chiefly to Japan (64%) but also to the Republic of Korea (29%) and Taiwan, China (7%). Indonesia exports well over half of its marketed production, including (from early 2001) supplies by pipeline to Singapore.

The principal domestic consumers of natural gas are power stations, fertiliser plants and the steel industry; the residential and commercial sectors have relatively small shares.

IRAN (ISLAMIC REP.)

Proved recoverable reserves (billion cubic metres)	24 308
Production (net billion cubic metres, 1999)	53.0
R/P ratio (years)	>100
Year of first commercial production	1955

Iran's proved reserves are second only to those of the Russian Federation, and account for 16% of the world total; they exceed the combined proved reserves of North America, South America and Europe (excluding the Russian Federation). The Iranian WEC Member Committee reports that at the end of 1999 proved reserves of natural gas were 24 308 billion m^3, approximately 5% higher than the level reported for the 1998 Survey. Of the end-1999 reserves, 63% were non-associated with crude oil. The proved amount of gas in place is stated to be 32 699 bcm, a figure almost unchanged from that reported three years ago.

For many years only minute quantities of associated gas output were utilised as fuel in fields or at Abadan refinery: by far the greater part was flared. Utilisation of gas in the industrial, residential and commercial sectors began in 1962 after the construction of a pipeline from Gach Saran to Shiraz.

In 1999, according to Cédigaz, 56% of Iran's gross production of gas was marketed. Some 28.5% of Iran's gross production of nearly 95 bcm was re-injected into formations in order to maintain or enhance pressure; about 11% was flared or vented and 4%-5% lost through shrinkage. The marketed production volume of about 53 bcm was augmented by 2 bcm of gas imported from Turkmenistan. Iran's principal gas-consuming sectors are electricity generation (38% of total consumption in 1998) and industrial and residential users (27% each).

IRAQ

Proved recoverable reserves (billion cubic metres)	3 110
Production (net billion cubic metres, 1999)	3.2
R/P ratio (years)	>100
Year of first commercial production	1955

Gas resources are not particularly large, by Middle East standards: proved reserves (as reported by OAPEC) account for less than 6% of the regional total. According to data reported by Cédigaz, 70% of Iraq's proved reserves consist of associated gas, whilst cap gas and non-associated gas account for 15% each.

Although non-associated gas has played a part since 1990, a high proportion of gas output is still associated with oil production: some of the associated gas is flared.

Between 1986 and 1990 Iraq exported gas to Kuwait. Currently all gas usage is internal, as fuel for electricity generation, as a feedstock and fuel for the production of fertilisers and petrochemicals, and as a fuel in oil and gas industry operations.

KAZAKHSTAN

Proved recoverable reserves (billion cubic metres)	1 841
Production (net billion cubic metres, 1999)	9.8
R/P ratio (years)	>100

The estimated proved reserves of some 1.8 trillion m^3 quoted by OGJ and Cédigaz include 1.3 trillion for the giant Karachaganak field, located in the north of Kazakhstan, near the border with the Russian Federation. Another major field is Tengiz, close to the north-east coast of the Caspian Sea.

Kazakhstan exports natural gas to Russia from its western producing areas and imports gas into the south-eastern region from Turkmenistan and Uzbekistan.

Electricity generation is estimated to have accounted for about 30% of total gas consumption in 1998.

KUWAIT

Proved recoverable reserves (billion cubic metres)	1 480
Production (net billion cubic metres, 1999)	8.1
R/P ratio (years)	>100
Year of first commercial production	1960

Note: Kuwait data include its share of Neutral Zone.

Gas reserves (as quoted by OAPEC) are relatively low in regional terms and represent less than 3% of the Middle East total. All Kuwait's natural gas is associated with crude oil, so that its availability is basically dependent on the level of oil output.

After allowing for a limited amount of flaring and for shrinkage due to the extraction of NGL's, Kuwait's gas consumption is currently about 8 bcm/year, one-third of which is used for electricity generation and desalination of sea-water.

LIBYA/GSPLAJ

Proved recoverable reserves (billion cubic metres)	1 313
Production (net billion cubic metres, 1999)	6.1
R/P ratio (years)	>100
Year of first commercial production	1970

Proved reserves - the third largest in Africa - increased marginally during the 1990's according to OAPEC. Utilisation of the resource is on a comparatively small scale: net production in 1999 was less than half that of Egypt, a country with a somewhat smaller reserve base.

Since 1970 Libya has operated a liquefaction plant at Marsa el Brega, but LNG exports (in recent years, only to Spain) have fallen away to under 1 billion m^3 per annum.

Local consumption of gas is largely attributable to power stations, industrial plants and oil and gas industry own use.

MALAYSIA

Proved recoverable reserves (billion cubic metres)	2 313
Production (net billion cubic metres, 1999)	41.1
R/P ratio (years)	55.5
Year of first commercial production	1983

Exploration of Malaysia's offshore waters has located numerous fields yielding natural gas or gas/condensates, mainly in the areas east of the peninsula and north of the Sarawak coast. Proved reserves (as quoted by OGJ) have risen to over 80 tcf and now rank as the second highest in Asia, after Turkmenistan. Other published reserve figures differ only marginally from OGJ's assessment.

Malaysia became a major gas producer in 1983, when it commenced exporting LNG to Japan. This trade has continued ever since, supplemented in recent years by LNG sales to the Republic of Korea and Taiwan, China and by gas supplies by pipeline to Singapore. In 1999, Malaysia was the world's fourth largest producer of offshore natural gas.

Domestic consumption of gas has also been expanding rapidly in recent years, the major market being power generation. The other principal outlet for natural gas, apart from own use within the oil/gas industry, is as feedstock/fuel for industrial users. Small amounts of CNG are used in transport, following the launching of a government programme to promote its use.

MEXICO

Proved recoverable reserves (billion cubic metres)	861
Production (net billion cubic metres, 1999)	34.8
R/P ratio (years)	17.4

The Mexican WEC Member Committee reports that proved recoverable reserves of natural gas at the end of 1999 were 860.6 billion m^3, of which 21% were non-associated with crude oil. Further resources are represented by probable reserves of 299 bcm and possible reserves of 412 bcm. Within the total amount of proved reserves, 54% were located in the northern region, 30% in the southern region, 11% in the marine north-east region and 5% in the marine south-east region.

Mexico announced the results of a radical revision of its official assessment of hydrocarbon reserves in 1999: consequently the current levels of proved reserves are not directly comparable with the much higher level quoted in the 1998 *Survey of Energy Resources*.

Production of natural gas was on a plateau during the early 1990's but rose sharply in 1996-1998, owing to the availability of associated gas from new offshore fields.

The greater part of Mexico's gas production is associated with crude oil output, mostly in the southern producing areas, both onshore and offshore.

The largest outlet for gas is as industrial fuel/feedstock (44% of total inland disposals in 1998); the energy industry consumed about 35%, power stations 19% and households about 2%. Mexico habitually exports relatively small amounts of gas to the USA and imports somewhat larger quantities.

MYANMAR

Proved recoverable reserves (billion cubic metres)	283
Production (net billion cubic metres, 1999)	1.7
R/P ratio (years)	>100

Myanmar has long been a small-scale producer of natural gas, as of crude oil, but its resource base would support a substantially higher output of gas. Proved reserves are put at 10 tcf by OGJ, with *World Oil* and Cédigaz quoting broadly similar levels, as at end-1999.

Until 2000, gas production tended to oscillate around a slowly rising trend. With the commencement of exports of natural gas to Thailand from two offshore fields, first Yadana and subsequently Yetagun, Myanmar’s gas industry has entered a new phase. As offtake by Thailand’s 3 200 MW Ratchaburi Power Plant builds up, gas production in Myanmar will move onto a significantly higher level than in the past.

NETHERLANDS

Proved recoverable reserves (billion cubic metres)	1 714
Production (net billion cubic metres, 1999)	70.3
R/P ratio (years)	24.3

Proved reserves, as reported by the Netherlands WEC Member Committee, have been gradually declining during the last ten years, but still represent one of the largest gas resources in Western Europe. The giant Groningen field in the north-west of the Netherlands accounts for almost two-thirds of the country’s proved reserves.

Gas production has tended to fluctuate in recent years, depending on weather conditions in Europe, thus demonstrating the flexibility that enables the Netherlands to play the role of a swing producer. Nearly 60% of 1999 output came from onshore fields, with Groningen contributing about 40%.

Nearly half of Netherlands gas output is exported, principally to Germany but also to France, Belgium, Italy, Luxembourg and Switzerland. The principal domestic markets are electricity and heat generation, industrial fuel and feedstock, and the residential sector.

NEW ZEALAND

Proved recoverable reserves (billion cubic metres)	68
Production (net billion cubic metres, 1999)	5.8
R/P ratio (years)	11.3
Year of first commercial production	1970

The Maui offshore gas/condensate field (discovered in 1969) is by far the largest hydrocarbon deposit so far discovered in New Zealand: it presently accounts for 58% of the country's economically recoverable gas reserves. Effective utilisation of its gas resources has been a key factor in New Zealand's energy policy since the early 1980's.

The proved recoverable reserves reported for the present Survey correspond with estimates of "proven and probable" reserves (or P50 values) that have been compiled by the Ministry of Economic Development, on the basis of information provided by field operators. These reserves have been assessed within the context of a reported proved amount in place ("ultimately recoverable reserves") of about 165 billion m^3.

The Maui field came into commercial production in 1979 when a pipeline to the mainland was completed. Three plants were commissioned in the 1980's to use indigenous gas, producing (respectively) methanol, ammonia/urea and synthetic gasoline. Eight gas fields were in production in 1999, with Maui accounting for three-quarters of total output.

An extensive transmission and distribution network serves industrial, commercial and residential consumers in the North Island. Small (and declining) amounts of CNG are used in motor vehicles.

NIGERIA

Proved recoverable reserves (billion cubic metres)	3 515
Production (net billion cubic metres, 1999)	7.0
R/P ratio (years)	>100
Year of first commercial production	1963

Published assessments of Nigeria's proved reserves of natural gas all fall within a narrow band: the level adopted for the present Survey is that quoted by Cédigaz. Nigeria's proved reserves are the second largest in Africa, after those of Algeria, but historically its degree of gas utilisation has been very low. Much of the associated gas produced has had to be flared, in the absence of sufficient market outlets. Efforts are being made to develop gas markets, both locally and internationally, and to reduce flaring to a minimum. There are projects to replace non-associated gas by associated gas in supplies to power stations and industrial users. Just over 60% of Nigeria's gross gas production of 30.7 bcm in 1999 was flared or vented.

The Bonny LNG plant was commissioned in the second half of 1999; exports of LNG during the year totalled 0.74 bcm, of which 0.5 bcm was destined for Italy, the balance going to France, Spain and Turkey in approximately equal amounts. An expansion of the plant is under way, with substantial sales to Spain and Portugal already contracted for. Further expansion of Bonny is under study.

A project is under way for the construction of a pipeline to supply Nigerian associated gas to power plants in Benin, Togo and Ghana.

NORWAY

Proved recoverable reserves (billion cubic metres)	1 245
Production (net billion cubic metres, 1999)	51.6
R/P ratio (years)	23.4
Year of first commercial production	1977

Norway's proved reserves are the second highest in Europe (excluding the Russian Federation). The bulk of reserves is located in the North Sea, the rest having been discovered in the Norwegian Sea and the Barents Sea. The level of proved recoverable reserves reported by the Norwegian WEC Member Committee has fallen from 1 570 billion m^3 at end-1996 to 1 245 bcm at end-1999. The latter figure is set within the context of a proved amount in place of 3 795 bcm. In addition, some 2 320 bcm of non-proved gas is believed to be in situ, but no estimate is available of the quantity of gas likely to be recoverable therefrom.

Norway's gas production continues to follow a rising trend. A high proportion (35% in 1999) of output is re-injected; over 90% of marketed production is exported to other European countries, principally Germany, France, Belgium and the Netherlands.

OMAN

Proved recoverable reserves (billion cubic metres)	805
Production (net billion cubic metres, 1999)	5.6
R/P ratio (years)	98.2
Year of first commercial production	1978

One of the minor gas producers in the Middle East, Oman's proved reserves have been essentially unchanged since 1995, according to OAPEC.

Oman has developed its utilisation of gas to such an extent that oil has long been displaced as the Sultanate's leading energy supplier. Currently the principal outlet for marketed gas is the power generation/desalination complex at Ghubrah. Other gas consumers include mining and cement companies.

The Oman LNG project began operating in early 2000, with the first shipment (to the Republic of Korea) taking place in April. Regular supplies of LNG are also being made to Japan, whilst spot cargoes have been sold to the USA and Spain.

Small amounts of gas are delivered by pipeline to the northern emirates of the UAE.

PAKISTAN

Proved recoverable reserves (billion cubic metres)	581
Production (net billion cubic metres, 1999)	22.0
R/P ratio (years)	26.4
Year of first commercial production	1955

Although the level of proved reserves reported by the Pakistan WEC Member Committee has tended to drift downwards in recent years, natural gas remains a major energy asset for Pakistan. The major gas-producing fields are Sui in Balochistan and Mari in Sindh. Only 3% of current output is associated with oil production.

Production of natural gas increased by 30% over the five years up to 1999-2000. The major markets for gas in that year were power generation (32%), fertiliser plants (25%), households and commercial consumers (23%) and general industrial users (20%). Small quantities of CNG are consumed as a transport fuel.

PAPUA NEW GUINEA

Proved recoverable reserves (billion cubic metres)	428
Production (net billion cubic metres, 1999)	0.1
R/P ratio (years)	>100
Year of first commercial production	1991

The Hides gas field was discovered in 1987 and brought it into production in December 1991. Other resources of non-associated gas have been located in PNG, both on land and offshore. Proved reserves differ widely between the various standard published sources: for the present Survey, the level of 428 bcm quoted by Cédigaz has been retained.

Up to the present, the only marketing outlet for Hides gas has been a 42 MW gas-turbine power plant serving the Porgera gold mine; offtake averages about 10 million cubic feet/day. Associated gas produced in the Kutubu area is mostly re-injected into the formation.

A project exists for the construction of a gas export pipeline to Australia, including a 500 km undersea section across the Torres Strait and 2 100 km of line following a route southwards close to the coastline of Queensland.

PERU

Proved recoverable reserves (billion cubic metres)	255
Production (net billion cubic metres, 1999)	0.4
R/P ratio (years)	>100

After having been virtually stable at around 7 tcf (200 billion m^3) since 1990, proved reserves (as published by OGJ) were increased to 9 tcf in 1999, reflecting the proving-up of additional gas, notably in the giant Camisea field in the south-east of Peru. Gas output is mostly associated with oil production; an appreciable proportion of production (36% in 1999) is re-injected, whilst about 18% is flared or vented.

Marketed production of gas has averaged 0.4 bcm/year in recent times. Small quantities are consumed in power stations and as an industrial and household fuel, but the major part of current output is used in the upstream operations of the oil and gas industry.

QATAR

Proved recoverable reserves (billion cubic metres)	10 900
Production (net billion cubic metres, 1999)	24.0
R/P ratio (years)	>100
Year of first commercial production	1963

Qatar's gas resources far outweigh its oil endowment: its proved reserves of gas of almost 11 trillion m^3 (as quoted by OPEC and Cédigaz) are only exceeded within the Middle East by those reported by Iran, and account for about 7% of global gas reserves. Although associated gas has been discovered in oil fields both on land and offshore, the key factor in Qatar's gas situation is non-associated gas, particularly that in the offshore North Field, one of the largest gas reservoirs in the world.

Production of North Field gas began in 1991 and by 1999 Qatar's total gross production had risen to about 31 bcm; some 12% was re-injected and just over 10% lost through shrinkage. The gas consumed locally is principally for power generation/desalination, fertiliser and petrochemical production, and other industrial applications.

Since the end of 1996, Qatar has become a substantial exporter of LNG; in 1999, shipments exceeded 8 billion m^3 of gas, of which 73% was consigned to Japan, 10% to Spain and smaller percentages to the Republic of Korea, the USA, France and Italy.

ROMANIA

Proved recoverable reserves (billion cubic metres)	406
Production (net billion cubic metres, 1999)	14.2
R/P ratio (years)	28.2

The Romanian WEC Member Committee reports proved recoverable reserves of 405.6 billion m^3, a reduction of 39.4 bcm, or 8.9% on the level reported for the 1998 Survey.

After peaking in the mid-1980's, Romania's natural gas output has been in secular decline, falling to below 15 bcm in 1999, only one-third of its level fifteen years previously. Indigenous production currently supplies about 75% of Romania's gas demand; the principal users are CHP and district heating plants, the steel and chemical industries and the residential/commercial sector.

RUSSIAN FEDERATION

Proved recoverable reserves (billion cubic metres)	47 730
Production (net billion cubic metres, 1999)	589.7
R/P ratio (years)	79.6

The gas resource base is by far the largest in the world: current estimates of Russia's proved reserves (as quoted by Cédigaz) are virtually twice those of Iran and about ten times those of the USA. The greater part (77%) of the Federation's reserves are located in West Siberia, where the existence of many giant and a number of super-giant gas fields has been proved.

The 1999 output of the Russian gas company Gazprom (545.6 bcm) accounted for 92.5% of the Federation's output and nearly 23% of world gas production.

Russia is easily the largest exporter of natural gas in the world: in 1999, 86 bcm went to Western Europe, 39 bcm to Central Europe and 77 bcm to former republics of the Soviet Union.

SAUDI ARABIA

Proved recoverable reserves (billion cubic metres)	5 777
Production (net billion cubic metres, 1999)	46.2
R/P ratio (years)	>100
Year of first commercial production	1961

Note: Saudi Arabia data include its share of Neutral Zone.

Most of Saudi Arabia's proved reserves and production of natural gas are in the form of associated gas derived from oil fields, although a number of sources of non-associated gas have been discovered. In total, proved reserves of gas (as given by OAPEC) rank as the fourth largest in the Middle East; they have been quoted at the same level since end-1997.

Output of natural gas has advanced fairly steadily during the past ten years. A significant factor in increasing the utilisation of Saudi Arabia's gas resources has been the operation of the gas-processing plants set up under the Master Gas System, which was inaugurated in the mid-1980's. These plants produce large quantities of ethane and LPG, which are used within the country as petrochemical feedstock; a high proportion of the LPG's is exported. The main consumers of dry natural gas are power stations, desalination plants and petrochemical complexes.

THAILAND

Proved recoverable reserves (billion cubic metres)	345
Production (net billion cubic metres, 1999)	17.7
R/P ratio (years)	18.0
Year of first commercial production	1981

Thailand's WEC Member Committee reports proved recoverable reserves at end-1999 as 345 billion m^3, within a proved amount in place of 575 bcm. Some 82% of the reported level of proved reserves (which itself lies close to the mean of a wide range of published assessments) consist of non-associated gas. In addition to the proven quantities, the Committee reports an additional 490 bcm as in place, of which 220 bcm is deemed to be recoverable in due course.

Since its inception twenty years ago, Thailand's natural gas output has grown almost unremittingly year after year. Much the greater part of Thai gas output is used for electricity generation; industrial use for fuel or chemical feedstock is relatively small, whilst transport use (CNG) is at present minimal.

Thailand has begun to import natural gas from Myanmar.

TRINIDAD & TOBAGO

Proved recoverable reserves (billion cubic metres)	602
Production (net billion cubic metres, 1999)	11.7
R/P ratio (years)	42.4

Reflecting a period of successful exploration, Trinidad's proved reserves of natural gas, as assessed by Cédigaz, increased by 32% between end-1996 and end-1999.

Marketed production of gas has increased rapidly during the last two years, as exports from the Atlantic LNG plant (inaugurated in 1999) have built up. Local consumption is also on the increase, reflecting a government policy of promoting the utilisation of indigenous gas through the establishment of major gas-based industries: fertilisers, methanol, urea, and steel. In 1998 the chemical and petrochemical industries accounted for about 39% of Trinidad's gas consumption, power stations for 20% and other industry (including iron and steel) for 8%; the balance of consumption is accounted for by use/loss within the gas supply industry.

TURKMENISTAN

Proved recoverable reserves (billion cubic metres)	2 860
Production (net billion cubic metres, 1999)	22.8
R/P ratio (years)	>100

Apart from the Russian Federation, Turkmenistan has the largest proved reserves of any of the former Soviet republics: for the present Survey, the level quoted by OGJ has been retained. Cédigaz states that Turkmenistan's total gas resources have been evaluated at 22.9 trillion m^3. Many gas fields have been discovered in the west of the republic, near the Caspian Sea, but the most significant resources have been located in the Amu-Daria Basin, in the east.

Gas deposits were first discovered in 1951 and by 1980 production had reached 70 bcm/year. It continued to rise throughout the 1980's, but by 1992 a serious contraction of the republic's export markets had set in and output fell sharply. Natural gas output recovered in 1999, with sizeable exports to Ukraine and Iran being achieved.

UKRAINE

Proved recoverable reserves (billion cubic metres)	825
Production (net billion cubic metres, 1999)	18.1
R/P ratio (years)	45.3

Notwithstanding a long history as a gas producer, Ukraine has over 800 billion cubic metres of remaining proved reserves. Gas production has, however, stagnated primarily because of a lack of investment in the industry. Obsolete equipment and production methods have inhibited efficient depletion of Ukraine's gas fields.

The Ukrainian WEC Member Committee reports proved recoverable reserves as 825 bcm at end-1999, within a proved amount in place of 1 118 bcm. Gas associated with crude oil accounts for only about 4% of the proved reserves. Over and above the proved quantities, there are estimated to be about 368 bcm of gas in place, of which only some 10 bcm is likely to be recoverable. The levels of resources and reserves reported for the present Survey are all somewhat lower than those provided for the 1998 edition.

The republic is one of the world's largest consumers of natural gas: demand reached 137 bcm in 1990. Although consumption had fallen back to about 72 bcm by 1999, indigenous production met only 25% of local needs; the balance was imported from Russia and Turkmenistan.

UNITED ARAB EMIRATES

Proved recoverable reserves (billion cubic metres)	6 003
Production (net billion cubic metres, 1999)	38.0
R/P ratio (years)	>100
Year of first commercial production	1967

Four of the seven emirates possess proved reserves of natural gas, with Abu Dhabi accounting for by far the largest share. Dubai, Ras-al-Khaimah and Sharjah are relatively insignificant in regional or global terms. Overall, the UAE accounts for about 11% of Middle East proved gas reserves.

OAPEC’s published level of UAE gas reserves (6 003 bcm) is slightly higher (by 3%) than its end-1996 figure of 5 831 bcm, utilised for the 1998 *Survey of Energy Resources.*

Two major facilities - a gas liquefaction plant on Das Island (brought on-stream in 1977) and a gas-processing plant at Ruwais (in operation from 1981) - transformed the utilisation of Abu Dhabi's gas resources. Most of the plants' output (LNG and NGL's, respectively) is shipped to Japan. In 1999, other LNG customers comprised Spain, the Republic of Korea and the USA.

Within the UAE, gas is used mainly for electricity generation/desalination, and in plants producing aluminium, cement, fertilisers and chemicals.

UNITED KINGDOM

Proved recoverable reserves (billion cubic metres)	760
Production (net billion cubic metres, 1999)	98.7
R/P ratio (years)	7.3
Year of first commercial production	1955

The UK is Europe's leading offshore gas producer, but its proved reserves are much smaller than those of Norway. The data on gas resources and reserves reported by the UK WEC Member Committee are drawn from *Development of the Oil and Gas Resources of the United Kingdom 2000*, published by the Department of Trade & Industry. Proved recoverable reserves are reported as 760 bcm, being the remaining gas reserves which on available evidence are virtually certain to be technically and economically producible (i.e. have a better than 90 per cent chance of being produced). "Probable" reserves (with a better than 50 per cent chance) are put at 500 bcm, whilst "Possible" reserves (with a significant, but less than 50%, chance) are estimated as 490 bcm.

Natural gas production has risen strongly in recent years, reflecting, inter alia, sharply increased demand in the power generation sector and much higher exports, following the commissioning of the Interconnector pipeline in October 1998.

UNITED STATES OF AMERICA

Proved recoverable reserves (billion cubic metres)	4740
Production (net billion cubic metres, 1999)	527.3
R/P ratio (years)	8.2

During the three years since the last edition of the *Survey of Energy Resources*, US gas reserves registered a modest net increase (of 932 bcf, or about 26 bcm). Additions to reserves in 1997-1999 totalled 57.8 tcf, equivalent to 101.6% of the 56.9 tcf of gas produced during the same period.

The increase in reserves was partly due to revisions and adjustments to estimates for old fields and partly to discoveries (field extensions, new field discoveries and new reservoir discoveries in old fields). Total discoveries amounted to nearly 58 tcf; they were predominantly made in Texas and the Gulf of Mexico Federal Offshore. Offshore development is likely to continue to be spurred by technological advances in exploration and deepwater production.

About 82% of proved reserves consist of non-associated gas. The states with the largest gas reserves at end-1999 were Texas (24.0% of USA total), New Mexico (9.2%), Wyoming (8.5%) and Oklahoma (7.5%). Reserves in the Federal Offshore areas in the Gulf of Mexico represented 15.2% of the total.

UZBEKISTAN

Proved recoverable reserves (billion cubic metres)	1 875
Production (net billion cubic metres, 1999)	55.6
R/P ratio (years)	33.7

The republic's first major gas discovery (the Gazlinskoye field) was made in 1956 in the Amu-Daria Basin in western Uzbekistan. Subsequently other large fields were found in the same area, as well as smaller deposits in the Fergana Valley in the east.

For the present Survey, proved recoverable reserves have been retained at the level quoted by OGJ.

Uzbekistan is one of the world's largest producers of natural gas: its 1999 net output was, for example, greater than that of Norway or Iran. It exports gas to its neighbouring republics of Kazakhstan, Kyrgyzstan and Tajikistan.

The principal internal markets for natural gas are the residential/commercial sector, power stations, CHP and district heating plants, and fuel/feedstock for industrial users. Some use is made of CNG in road transport.

VENEZUELA

Proved recoverable reserves (billion cubic metres)	4 152
Production (net billion cubic metres, 1999)	26.8
R/P ratio (years)	>100

Venezuela has by far the biggest natural gas industry in South America, possessing two-thirds of its proved reserves and accounting for 36% of regional marketed production in 1999. In its 1999 Annual Report, the Venezuelan state oil and gas company Petróleos de Venezuela, S.A. (PDVSA) states that its proved reserves of natural gas at the end of 1999 were 146 611 billion cubic feet (4 152 bcm); this figure implies a 2.5% increase over the corresponding end-1996 level. Over 90% of gas reserves exist in association with crude oil.

Gas production followed a sharply upward trend between 1993 and 1998 but suffered a fall in 1999. Substantial quantities (amounting to nearly 32% of gross output in 1998) are re-injected in order to boost or maintain reservoir pressures, while smaller amounts (5%-6%) are vented or flared; about 11% of production volumes are subject to shrinkage as a result of the extraction of NGL's.

The principal outlets for Venezuelan gas are power stations, petrochemical plants and industrial users, notably the iron & steel and cement industries. Residential use is on a relatively small scale.

YEMEN

Proved recoverable reserves (billion cubic metres)	479
Production (net billion cubic metres, 1999)	-
R/P ratio (years)	-

Yemen has appreciable reserves of natural gas - quoted by OAPEC (and by Cédigaz and OGJ) as 479 billion m^3 at the end of 1999, but so far no commercial utilisation has been established.

A project is in hand for the construction of an LNG plant at Bal Haf, with a capacity of 6.2 million tonnes of LNG per annum; the markets envisaged for the output are in India.

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Chapter 6

Part I: URANIUM

Overview

Since the publication of the 1998 WEC Survey of Energy Resources, the international uranium industry has experienced continued change in response to the very low market prices.

World uranium mine production decreased from 1988 until 1994 despite the continuous growth in world uranium requirements. Production then increased in 1995, 1996 and 1997, before falling back in 1998 and 1999. Production in 1997 was about 36 700 tU, but then declined by about 5% to 35 000 tU in 1998 and by a further 7% to 32 600 tU in 1999. The decrease in production in 1998 was primarily caused by the oversupply of uranium offered at very low prices and the resulting decline in both the long-term and spot market price in 1997 and 1998. Since 1993 production from mines has met less than 60% of world reactor demand. Over much of the period to 1998 the balance was met by surplus uranium produced prior to 1990 to meet both expected civilian requirements and demand for military uses.

Following an increase in medium and long-term prices from 1994 to mid-1996, prices again sharply declined in 1997 and 1998. After medium and long-term prices on the US market increased by US$ 2-3/lbU_3O_8 for domestic and foreign purchases between 1995 and 1996 there was again a downturn of US$ 1.50-2/lbU_3O_8 through 1998. Following an increase of nearly US$ 3/lbU_3O_8 in 1997 the EURATOM multi-annual contract price fell by less than US$ 1/lbU_3O_8 in 1999. The spot-market price continued as a two-tiered system, with some countries allowing unlimited imports from the Newly Independent States (NIS) – Kazakhstan, Russian Federation, Ukraine and Uzbekistan, and others (mainly the USA and the European Union) imposing restrictions. Following a recovery of the unrestricted price from its lowest point of about US$ 7/lbU_3O_8 in 1994 to about US$ 15.50/lbU_3O_8 by mid-1996, the price plunged to US$ 9.65 by the end of 1997. It continued down to US$ 8.45 and US$ 7.60 respectively, by year-end 1998 and 1999. The corresponding restricted price increased to US$ 16.50/lbU_3O_8 by mid-1996. From September 1996, however, it started to decrease, reaching about US$ 12/lbU_3O_8 and US$ 8.75/lbU_3O_8 respectively by year-end 1997 and 1998. However, a price rally early in 1999 left the restricted spot price at US$ 9.60 by year-end.

Production

Now that nearly all of the 21 uranium-producing countries provide official reports of annual production, it is possible to have a better understanding of worldwide uranium production (China, India and Pakistan do not provide official reports). In 1999 over 90% of world production came from the 10 major producing countries (Australia, Canada, Kazakhstan, Namibia, Niger, the Russian Federation, South Africa, Ukraine, USA and Uzbekistan), each of which produced over 1000 tU. Canada continued to be the largest producer, with a 1999 output of 8 214 tU, or 25.2% of the world total;

Australia retained second place, with production of 5 984 tU and a share of 18.4%, while the third largest producer was Niger, with 2 918 tU (9.0%).

The NIS have a long history of uranium production and they continue as major suppliers. Following an ongoing production decline from 1988 (15 000 tU) to 1996 (6 274 tU), aggregate annual output from these countries stabilised over the next few years, subsequently regaining an upward path to reach nearly 7 300 tU in 1999, equivalent to about 22 % of world production. There are ongoing projects to develop new uranium mines in the four NIS, using in-situ leach (ISL) technology.

Nearly 50% of the production in 1997 was from open-pit mining, versus 32% from underground. About 13% was produced using ISL technology. The balance was produced by other methods. The distribution by mine-type remained about the same in 1998. The increasing importance of open-pit mining as compared with 1996 was caused by closure of underground mines and increased output from existing large open-pit mines.

Several significant changes have occurred at production facilities worldwide. The changes include the closure of smaller centres with higher production costs. This decrease in production capacity is being offset by the expansion of the facilities of some low-cost producers, and the opening of new mines that produce from high-grade ore bodies. As a result, the world uranium production capability of existing and committed centres increased about 7% from 1997 to 1999. In Canada all production has been coming from three high-grade ore bodies located in northern Saskatchewan. For three additional new mining projects the process of regulatory and environmental approval made progress in 1998. For example, authorisation was received to use the Key Lake processing facility to process ore from the new McArthur River mine. Construction and licensing activities continued on the new McClean mine-mill project. In 1999 both the McArthur River and McClean Lake mines received their production authorisation from regulatory authorities. Both mines then started production.

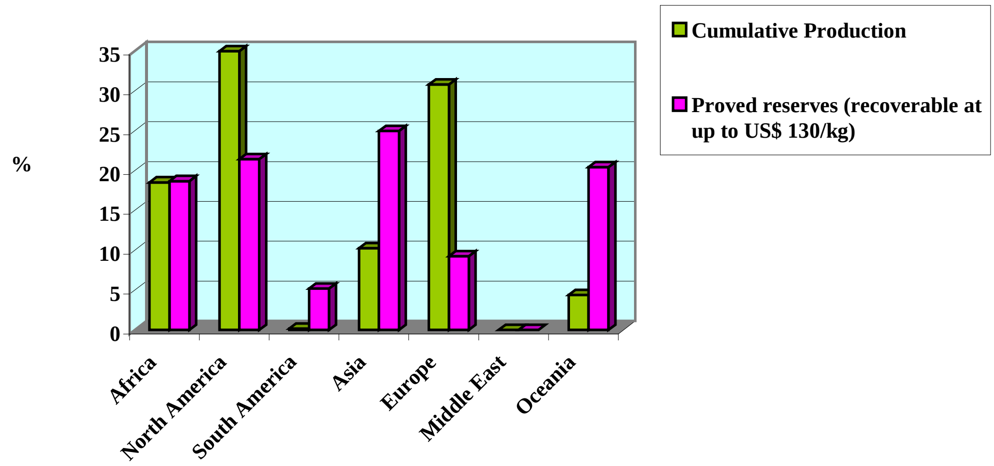
In Australia the milling capacity at Ranger was expanded to 4 240 tU/year by mid-1997, while construction was under way to increase the milling capacity at Olympic Dam by more than 200% to 3 900 tU/year. This project was completed in 1999. In early 1998 the operator of the Beverley in-situ leach project commenced field testing for a new operation planned to produce 850 tU/year starting by 2000. In the USA, production decreased from 2 432 tU in 1996 to 1 810 tU in 1998. In 1998 the Uncle Sam phosphate by-product operation closed, while the new Smith Ranch ISL operation started production. No additional new projects in the US are expected to come on-stream unless market conditions become more favourable.

In other countries in 1997, mines were closed in Brazil, France, Hungary and South Africa. In 1998 the small phosphate uranium by-product plant in Belgium was closed. In 1999 Gabon closed its only mine ending a long history of production. No other new mines were brought into production in either 1997 or 1998. Brazil started its new Lagoa Real facility in 1999. Increased production in Namibia and Niger was the result of improved capacity utilisation in existing mines and mills. South Africa experienced a cut in production, because uranium is recovered primarily as a by-product of gold mining, and is thus dependent on the gold market price. Increased production costs at deep underground mines in South Africa have forced unprofitable projects to close.

Resources and Exploration

Much more complete information on uranium resources with low production costs of US$ 40/kgU (US$ 15.40/lbU_3O_8) or less is available than at the time of the 1998 Survey. The more detailed information is reported in the recent publication *Uranium 1999–Resources Production and Demand,* (or "Red Book"), a joint report of the OECD Nuclear Energy Agency and the International Atomic Energy Agency. The Red Book contains information on nearly forty countries with reported uranium resources. The resources are classified by the level of confidence in the estimates, and by production cost categories. The known resources are classified as Reasonably Assured Resources (RAR) and Estimated Additional Resources I (EAR-I), while undiscovered resources are classified as Estimated Additional Resources II (EAR-II) and Speculative.

Figure 6.1: Cumulative production and proved reserves of uranium at end-1999 - regional distribution



As of 1 January 1999 (latest IAEA data available) world RAR recoverable at a cost of US$ 130/kgU (equivalent to US$ 50/lbU_3O_8) or less, are 2.96 million tU, while those recoverable at US$ 80/kgU (US$ 30/lbU_3O_8) or less, are 2.27 million tU. Furthermore RAR recoverable at US$ 40/kgU (US$ 15/lbU_3O_8) or less, for thirteen reporting countries, are more than 0.92 million tU. For the first time Canada, which holds 31% of these low-cost resources, reported in this category.

In addition, EAR-I recoverable at US$ 130/kgU or less, have been estimated as 990 000 tU; at US$ 80/kgU or less, as 728 000 tU; and at US$ 40/kgU or less, at 338 000 tU. (These totals exclude EAR for the USA, as the USA does not provide separate estimates for EAR-I and EAR-II).

By comparison with the world totals in Tables 6.1 and 6.2, the tonnages of RAR and EAR-I reported above have been adjusted by the NEA-IAEA to take into account estimated mining and milling losses not accounted for in some of the national estimates.

As complete estimates for individual resource categories were not reported in previous editions of the Red Book, it is difficult to account for all of the changes. However, the estimates available indicate that known world uranium resources recoverable at US$ 130/kgU or less, decreased by about 8% between 1 January 1997 and 1 January 1999. In comparison, a decrease of only about 2.5% for RAR recoverable at US$ 80/kgU or less, occurred. The more complete information for resources in the US$ 40/kgU or less category is very significant. This indicates that several countries possess uranium resources that may be recovered at low cost. These resources provide the potential for maintaining the economic competitiveness of nuclear electric programmes by helping to assure that a low-cost fuel supply is available for a sustained period of time.

As far as possible, the uranium data shown in Tables 6.1, 6.2 and 6.3 are as reported by WEC Member Committees for the present Survey, reflecting the situation at end-1999; in the absence of such information, Red Book levels (as at the beginning of 1999) are quoted.

Annual expenditures on uranium exploration for 24 reporting countries increased by 37% to US$ 153 million in 1997. The increase of expenditures from 1996 to 1997 resulted from activities associated with advanced projects in Australia, Canada, the USA, the Russian Federation and India. Twenty-one countries reported exploration expenditure in both 1997 and 1998. The total exploration expenditures for these countries decreased from US$ 148 million to US$ 132 million, with decreases outnumbering increases by more than two to one. Information is not presently available for 1999.

Outlook

To understand the outlook for uranium it is necessary to consider recent history. Uranium is an unusual commodity because a major portion of market demand is met from sources other than new mine production. From 1991 through 1999 about 215 000 tU, or over 40 % of the total world requirements, were met from non-mine supplies. During the early part of this period a major contribution came from drawdown of the commercial inventory held by nuclear utilities. However, with each year, the importance of other sources has been an increasing. For example, during the period 1992 to 1999 a total of 96 700 tU was delivered to the European Union from the NIS, with the bulk of this material coming from Russia. During this period Russia was also using around 5 700 tU annually for the production of nuclear fuel for reactors of Russian design. A total of about 30 900 t of Russian origin uranium was purchased by US utilities from 1993 to 1999. Information was not available for 1991 and 1992. Analysis indicates that as much as about 115 000 t or more, of Russian Federation stockpile origin uranium was either used domestically, or sold over the period 1991 through 1999. This is equivalent to over 50% of the balance of world uranium requirements met by non-mine supplies.

Another major source of uranium supply developed starting in 1995. This supply is based on a government-to-government agreement signed in February 1993 between the United States and the Russian Federation concerning the disposition and purchase of 500 t highly enriched uranium (HEU) from dismantled nuclear weapons. From 1995 to 1999 about 24 300 tU (natural equivalent) was delivered to the United States, leaving a balance of about 150 000 tU (natural equivalent) to be delivered. About 1 800 tU of the material delivered was purchased and transferred to the United States Enrichment Corporation (USEC) for sale. The balance was held in stockpiles in the USA. In addition to the material from the Russian Federation, the transfer of 50 t HEU from USDOE to USEC was started in 1999. Other supplies that are being used in place of new mine production include re-enrichment of tails from the enrichment of uranium, use of mixed oxide (MOX) fuel and re-processed uranium.

It is anticipated that most of these supplies will continue to be available over the next 10 years or so. The greatest uncertainty is the size of the stockpile of natural and low enriched uranium in Russia, and how long this stockpile will continue to supply world markets. The Russian Federation has for nearly a decade been one of the largest uranium market suppliers. If this supply should end, or decrease significantly, it will be necessary to increase the reliance on other supplies to make up the shortfall. Furthermore because of the ongoing closure of production facilities over the last decade or more, there is relatively little excess capacity, or flexibility, for mine production to increase over the short term.

World uranium requirements were about 61 600 tU in 1999 and are projected to lie within a range of 54 500 – 79 800 tU/year by 2015. The annual production capability in 1999 was 45 800 tU, or about 75% of requirements. Projections based on available capability developments and the phase-out of existing mines show that the capabilities for 2015 may range between 42 000 and 62 000 tU/year.

The total world uranium resources could supply ample quantities to cover the demands of existing and planned nuclear power stations over the next decade. However, because of the amount of anticipated supply from non-production sources, it is expected that mine production will continue to meet only a portion of the annual requirements over the next five to ten years.

Provided that non-production supplies continue to be available, the combination of mine and non-production supply could meet the requirements. However, if there is an unexpected interruption in supply a shortfall could develop. This could lead to unstable market conditions until the equilibrium between supply and demand is re-established.

Projections of production capabilities of planned and prospective centres supported by known resources indicate that major producer countries could increase their production from the current level by up to 30% by 2005. Viewed optimistically, this would help ensure that the supply remains in balance with the requirements. However, market uncertainties may postpone decisions regarding new facilities. Despite the uncertainties about converting military stockpiles to civilian use and the amount of weapons-grade material reaching the commercial market, the need for newly produced uranium will continue as long as nuclear electric generation continues.

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DEFINITIONS

Uranium does not occur in a free metallic state in nature. It is a highly reactive metal that interacts readily with non-metals, and is an element in many intermetallic compounds.

This Survey uses the system of ore classification developed by the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD) and the International Atomic Energy Agency (IAEA). However, the names given to the classes as defined below are different because the WEC tries to use similar terms to define comparable classes of reserve for each of the energy sources covered in the Survey.

Estimates are divided into separate categories according to different levels of confidence in the quantities reported.

The estimates are further separated into categories based on the cost of production. The cost categories are: less than US$ 40/kgU; US$ 40/kgU to US$ 80/kgU and US$ 80/kgU to US$ 130/kgU. Costs include the direct costs of mining, transporting and processing uranium ore, the associated costs of environmental and waste management, and the general costs associated with running the operation (as defined by the NEA). Data reported by WEC Member Committees for the present Survey relate, in principle, to costs in terms of the US$ at January 1 2000, whereas those quoted in the IAEA/NEA "Red Book" are associated with the US$ as at January 1 1999: in practice, the difference in base is largely immaterial.

The WEC follows the practice of the NEA/IAEA and defines estimates of discovered reserves in terms of uranium recoverable from mineable ore and not uranium contained in the ore (i.e. to allow for mining and processing losses). Although some countries continue to report in-situ quantities, the major producers generally conform to these definitions.

All resource estimates are expressed in terms of tonnes of recoverable uranium (U), not uranium oxide (U_3O_8).

Note:

1 tonne of uranium = approximately 1.3 short tons of uranium oxide;

US$ 1 per pound of uranium oxide = US$ 2.6 per kilogram of uranium;

1 short ton U_3O_8 = 0.769 tU.

Proved reserves correspond to the NEA category "Reasonably Assured Resources" (RAR), and refer to recoverable uranium that occurs in known mineral deposits of such size, grade and configuration that it could be recovered within the stated production cost ranges with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits, together with knowledge of deposit characteristics. Proved reserves have a high assurance of existence.

Estimated additional amounts recoverable corresponds to the NEA category "Estimated Additional Resources - Category I" (EAR-I), and refers to recoverable uranium (in addition to proved reserves) that is expected to occur (mostly on the basis of direct geological evidence) in extensions of well-explored deposits and in deposits for which geological continuity has been established, but where specific data and measurements of the deposits and knowledge of their characteristics are considered to be inadequate to classify the resource as a proved reserve.

Such deposits can be delineated and the uranium subsequently recovered, all within the stated production cost ranges. Estimates of tonnage and grade are based primarily on knowledge of the deposit characteristics as determined in its best known parts or in similar deposits. Less reliance can be placed on the estimates in this category than on those for proved reserves.

Other amounts expected to be recoverable at up to US$ 130/kgU refers to uranium in addition to proved reserves and estimated additional amounts recoverable, and corresponds to the sum of the two NEA categories, “Estimated Additional Resources - Category II” (EAR-II) and “Speculative Resources” (SR). This category includes estimates of undiscovered uranium resources. These may refer to deposits believed to exist in well-defined geological trends or areas of mineralisation with known deposits. Estimates of such deposits are on the basis that they can be discovered, delineated and the uranium subsequently recovered at up to US$ 130/kgU. Estimates of tonnage and grade are based primarily on the knowledge of the deposit characteristics in known deposits within the respective trends or areas and on such sampling, geological, geophysical or geochemical evidence as may be available. They include deposits that are thought to exist mostly on the basis of indirect evidence and geological extrapolations relating to deposits discoverable with existing exploration techniques.

Annual production is the production output of uranium ore concentrate from indigenous deposits, expressed as tonnes of uranium.

Cumulative production is the total cumulative production output of uranium ore concentrate from indigenous deposits, expressed as tonnes of uranium, produced in the period from the initiation of production until the end of the year stated.

Table 6.1 Uranium: proved reserves at end-1999
(conventional resources recoverable at up to US$130/kg)

Excel Files	Recoverable at				Total recoverable at up to US$130/kg
	< US$40/kg	US$40-80/kg	< US$80/kg	US$80-130/kg	
	thousand tonnes of uranium				
Algeria			26.0		26.0
Central African Republic			8.0	8.0	16.0
Congo (Democratic Rep.)			1.8		1.8
Gabon	4.8		4.8		4.8
Malawi			11.7		11.7
Namibia	67.3	82.0	149.3	31.2	180.5
Niger	43.6	27.5	71.1		71.1
Somalia				6.6	6.6
South Africa	121.0	111.9	232.9	59.9	292.8
Zimbabwe			1.8		1.8
Total Africa			**507.4**	**105.7**	**613.1**
Canada	284.5	41.9	326.4		326.4
Greenland				27.0	27.0
Mexico				1.7	1.7
United States of America			105.0	244.0	349.0
Total North America			**431.4**	**272.7**	**704.1**
Argentina	2.6	2.6	5.2	2.2	7.4
Brazil	56.1	105.9	162.0		162.0
Peru			1.8		1.8
Total South America			**169.0**	**2.2**	**171.2**
India				52.7	52.7
Indonesia			0.5	5.8	6.3
Japan				6.6	6.6
Kazakhstan	320.7	115.9	436.6	162.0	598.6
Mongolia	10.6	51.0	61.6		61.6
Thailand				N	N
Turkey				9.1	9.1
Uzbekistan	65.6		65.6	17.5	83.1
Vietnam				1.3	1.3
Total Asia			**564.3**	**255.0**	**819.3**
Bulgaria	2.2	5.6	7.8		7.8
Czech Republic		4.1	4.1	2.9	7.0
Finland				1.5	1.5
France			12.5	1.8	14.3
Germany				3.0	3.0
Greece	1.0		1.0		1.0
Hungary				14.7	14.7
Italy			4.8		4.8
Portugal			7.5		7.5
Romania				6.9	6.9
Russian Federation	64.3	76.6	140.9		140.9
Slovenia			2.2		2.2
Spain			3.1	3.6	6.7
Sweden			2.0	2.0	4.0
Ukraine			42.6	38.4	81.0
Total Europe			**228.5**	**74.8**	**303.3**
Iran (Islamic Rep.)				0.5	0.5
Total Middle East				**0.5**	**0.5**
Australia			571.0	99.0	670.0
Total Oceania			**571.0**	**99.0**	**670.0**
TOTAL WORLD			**2 471.6**	**809.9**	**3 281.5**

See below for Notes to Table

Notes to Table 6.1:

1. Reserves shown for the following countries are on an in-situ basis (I.e. no allowance has been made for losses incurred in mining and processing the ore): Algeria, Brazil; Bulgaria; Congo (Democratic Rep.); Finland; India; Indonesia; Kazakhstan; Malawi; Mexico; Mongolia; Peru; Russian Federation; Somalia; Turkey Ukraine; Zimbabwe
2. Data for the < US$40 and US$40-80 categories are only available for certain countries; thus regional and global aggregates have not been computed for these categories
3. Sources: WEC Member Committees 2000/2001; *Uranium 1999: Resources, Production and Demand*, 2000, OECD Nuclear Energy Agency and International Atomic Energy Agency

Table 6.2 Uranium: estimated additional amounts recoverable at end-1999 (conventional resources recoverable at up to US$130/kg)

[Excel Files](#)

	Recoverable at				Total additional amount recoverable at up to US$130/kg	Other amounts recoverable at up to US$130/kg
	< US$40/kg	US$40-80/kg	< US$80/kg	US$80-130/kg		
	thousand tonnes of uranium					
Algeria			0.7	1.0	1.7	
Congo (Democratic Rep.)			1.7		1.7	
Gabon	1.0		1.0		1.0	2.0
Namibia	70.5	20.3	90.8	16.7	107.5	
Niger				18.6	18.6	
Somalia				3.4	3.4	
South Africa	48.1	18.7	66.8	9.6	76.4	1 261.0
Zambia						22.0
Zimbabwe						25.0
Total Africa			**161.0**	**49.3**	**210.3**	**1 310.0**
Canada	87.0	19.6	106.6		106.6	850.0
Greenland				16.0	16.0	60.0
Mexico				0.7	0.7	12.7
United States of America			839.0	434.0	1 273.0	1 340.0
Total North America			**945.6**	**450.7**	**1 396.3**	**2 262.7**
Argentina	2.0	0.4	2.4	0.1	2.5	1.4
Brazil			100.2		100.2	620.0
Chile						5.0
Colombia						228.0
Peru			1.9		1.9	32.0
Venezuela						163.0
Total South America			**104.5**	**0.1**	**104.6**	**1 049.4**
China						1 770.0
India				25.2	25.2	30.0
Indonesia				1.7	1.7	2.6
Kazakhstan	113.2	82.4	195.6	63.7	259.3	810.0
Mongolia	11.0	10.0	21.0		21.0	1 390.0
Thailand				N	N	N
Uzbekistan	39.9		39.9	7.1	47.0	170.0
Vietnam			0.5	6.2	6.7	236.0
Total Asia			**257.0**	**103.9**	**360.9**	**4 408.6**
Austria			0.7	1.1	1.8	
Bulgaria	2.2	6.2	8.4		8.4	18.0
Czech Republic			1.1	21.6	22.7	188.7
France			0.6		0.6	
Germany				4.0	4.0	74.0
Greece			6.0		6.0	6.0
Hungary				13.0	13.0	
Italy				1.3	1.3	10.0
Portugal				1.5	1.5	7.0
Romania				9.0	9.0	5.0
Russian Federation	17.2	19.3	36.5		36.5	1 105.0
Slovenia			5.0	5.0	10.0	1.1
Spain				7.5	7.5	
Sweden			1.0	5.3	6.3	
Ukraine			20.0	30.0	50.0	235.0
Total Europe			**79.3**	**99.3**	**178.6**	**1 649.8**
Iran (Islamic Rep.)				0.9	0.9	9.5
Total Middle East				**0.9**	**0.9**	**9.5**
Australia			177.0	59.0	236.0	
Total Oceania			**177.0**	**59.0**	**236.0**	
TOTAL WORLD			**1 724.4**	**763.2**	**2 487.6**	**10 690.0**

See below for Notes to Table

Notes to Table 6.2:

1. The data shown for the USA in this table reflect the whole of its Estimated Additional Resources: the USA does not separate such resources into EAR-I and EAR-II
2. Reserves shown for the following countries are on an in-situ basis (I.e. no allowance has been made for losses incurred in mining and processing the ore): Algeria, Brazil; Bulgaria; Congo (Democratic Rep.); India; Indonesia; Kazakhstan; Mexico; Mongolia; Namibia; Peru; Portugal; Russian Federation; Somalia; Ukraine
3. Data for the < US$40 and US$40-80 categories are only available for certain countries; thus regional and global aggregates have not been computed for these categories
4. "Other amounts recoverable at up to US$130/kg" include some speculative resources with their cost range unassigned - see Country Notes
5. Sources: WEC Member Committees 2000/2001; *Uranium 1999: Resources, Production and Demand*, 2000, OECD Nuclear Energy Agency and International Atomic Energy Agency

Table 6.3 Uranium: annual and cumulative production at end-1999

Excel Files

	1999 production	cumulative production to end-1999
	tonnes of uranium	
Congo (Democratic Rep.)		25 600
Gabon	294	26 190
Namibia	2 689	69 411
Niger	2 918	78 904
South Africa	1 093	152 694
Total Africa	**6 994**	**352 799**
Canada	8 214	329 840
Mexico		49
United States of America	1 773	352 300
Total North America	**9 987**	**682 189**
Argentina	4	2 509
Brazil		1 030
Total South America	**4**	**3 539**
China	650	6 685
India	210	7 069
Japan		87
Kazakhstan	1 560	86 502
Mongolia		535
Pakistan	23	814
Uzbekistan	2 130	93 701
Total Asia	**4 573**	**195 393**
Belgium		686
Bulgaria		16 720
Czech Republic	605	106 588
Estonia		65
Finland		30
France	439	74 598
Germany	30	218 815
Hungary		21 177
Poland		660
Portugal	10	3 703
Romania	105	17 630
Russian Federation	2 600	111 253
Slovenia		382
Spain	255	5 487
Sweden		200
Ukraine	1 000	9 000
Total Europe	**5 044**	**586 994**
Australia	5 984	83 578
Total Oceania	**5 984**	**83 578**
TOTAL WORLD	**32 586**	**1 904 492**

Notes:
1. The cumulative production shown for China covers only the period 1990-1999 inclusive, as data for earlier years are not available
2. Sources: WEC Member Committees 2000/2001; *Uranium 1999: Resources, Production and Demand*, 2000, OECD Nuclear Energy Agency and International Atomic Energy Agency

COUNTRY NOTES

The Country Notes on uranium have been compiled by the editors, drawing principally upon the following publication (known as the Red Book): *Uranium 1999: Resources, Production and Demand;* 2000; OECD Nuclear Energy Agency and International Atomic Energy Agency.

Information provided by WEC Member Committees and from other sources has been incorporated when available.

ARGENTINA

Exploration for uranium started in the early 1950's, since when deposits have been discovered in a number of locations, mostly in the western part of the country and in the southern province of Chubut in Patagonia. During the 1990's, a country-wide programme of exploration directed at the evaluation of areas with uranium potential was undertaken. Recent activity has centred on the Cerro Solo and Laguna Colorada deposits in Chubut and the Las Termas discovery in the north-western province of Catamarca.

Uranium has been produced on a small scale since the mid-1950's, with cumulative production reaching 2 509 tonnes by the end of 1999. Argentina's uranium industry has been shrinking fast: 1999 output was only 4 tonnes. The sole production centre currently in operation is the San Rafael facility in the province of Mendoza, which processes ore from the Sierra Pintada deposit - its nominal production capacity of 120 tU/year is severely underutilised. Exploitation of the Cerro Solo deposit is being planned by the state agency CNEA, which since 1996 has owned and operated Argentina's uranium industry.

Proved reserves of uranium, recoverable at less than US$ 80/kgU, were 5 240 tonnes at end-1999, a slight increase on the end-1996 estimate, which is attributable to a revised assessment of the Cerro Solo deposit. Further known conventional resources consist of 2 240 tonnes of reasonably assured resources (RAR), recoverable at US$ 80-130/kgU and 2 450 tonnes of estimated additional resources (EAR-1) recoverable at less than US$ 130/kgU. Undiscovered resources (at the latter cost level) are put at 1 440 tonnes.

AUSTRALIA

Exploration activities between 1947 and 1961 led to a number of uranium discoveries, including the deposits at Mary Kathleen (Queensland), Rum Jungle (Northern Territory) and Radium Hill (South Australia). A decrease in uranium requirements for defence purposes induced a virtual cessation in exploration between 1961 and 1966. Activity picked up again during the late 1960's, as civilian export demand accelerated, and numerous major deposits were located.

In 1983 the Government introduced the so-called "three mines" policy, which permitted uranium exports only from the Nabarlek, Ranger and Olympic Dam mines. This restrictive measure, with its dampening effect on uranium exploration, lasted until 1996. Exploration expenditure and drilling activity rose in the latter half of the 1990's.

Australia produced nearly 6 000 tonnes of uranium in 1999, bringing cumulative output to more than 83 500 tonnes since 1954. Two uranium production centres were in operation in 1999: Ranger (capacity 4 240 tU/year) and Olympic Dam (capacity 1 442 tU/year). New centres are being brought into operation at Jabiluka and Beverley, and others are planned for the Honeymoon and Kintyre deposits.

Proved reserves of uranium are reported by the Australian Geological Survey Organisation as 571 000 tonnes at less than US$ 80/kgU and 99 000 tonnes at US$ 80-130/kgU. Estimated additional amounts recoverable at these cost levels are 177 000 and 59 000 tonnes respectively.

BRAZIL

Exploration activity over a period of some forty years, ending in 1991, resulted in the discovery of occurrences and deposits of uranium in eight different states of Brazil. Known conventional resources are substantial, consisting of proved reserves (=RAR) of 162 000 tonnes (recoverable at less than US$ 80/kgU) plus estimated additional resources (EAR-1) of about 100 000 tonnes.

Although Brazil's RAR are the fifth largest in the world, its uranium output has never been on a commensurately large scale: cumulative production to the end of 1995 was only just over 1 000 tonnes, and output was zero in 1996-1998.

After two years on stand-by, the 360 tU/year Poços de Caldas production centre in Minas Gerais state was definitively shut down in 1997 and is now being decommissioned. It is being replaced by a new plant at Lagoa Real in the eastern state of Bahia, utilising ore from the Cachoeira deposit. With an initial nominal production capacity of 250 tU/year, Lagoa Real is planned for eventual expansion to 430 tU/year.

Another production centre, planned for construction at Itataia in north-eastern Brazil, is at the feasibility stage: its annual uranium production capacity, as a by-product of phosphate output, would be 325 tonnes. Implementation of this project will depend on the way the markets for both products are seen as developing.

Brazil's large known resources are supplemented by considerable tonnages of undiscovered resources, comprising 120 000 tonnes of EAR-II recoverable at less than US$ 130/kgU and 500 000 tonnes of speculative resources (with no cost range assigned).

There are, in addition, unconventional resources for which there are at present no plans for recovery:

- carbonatite containing 13 000 tonnes U;
- marine phosphates (28 000 tonnes U);
- quartz-pebble conglomerates (2 000 tonnes U).

CANADA

From 1942, uranium was obtained from the Port Radium deposit of pitchblende in the Northwest Territories, which had previously been mined for radium. Exploration directed specifically towards finding uranium led to the discovery of many deposits, the most important being in the Blind River/Elliot Lake area of southern Ontario and the Athabasca Basin in northern Saskatchewan.

Uranium production peaked at 12 200 tonnes in 1959, when the last defence contracts were signed, and output fell rapidly to less than 3 000 tonnes in 1966. Increases in uranium demand and rising prices led to renewed growth from the mid-1970's, with the focus of production moving westwards. Three out of four production centres in Ontario were phased out in the early 1990's, and the last closed in mid-1996, leaving Saskatchewan the sole producing province.

Canadian primary uranium output totalled 8 214 tonnes in 1999, by far the largest in the world and equivalent to a quarter of global production. Its reasonably assured resources (at up to US$ 80/kgU) amount to 326 000 tonnes, or 13% of the world total.

All Canadian uranium mining takes place in northern Saskatchewan. Cameco Corporation and Cogema Resources Inc. (CRI) own and operate the three uranium production centres now in operation - Cluff Lake (owned by CRI), and Key Lake and Rabbit Lake (both owned by Cameco).

Since local resources are nearly depleted at these sites, new production centres are being developed in northern Saskatchewan. All have cleared a public federal-provincial environmental assessment review process. McClean Lake and McArthur River entered into production in 1999. Cigar Lake and Midwest should begin production in 2002 and 2003, respectively. Bringing these developments on stream ensures that Canada will remain the world leader in uranium production well into the foreseeable future.

CHILE

During the 1950’s, the US Atomic Energy Commission undertook exploration work in Chile, and found various instances of uranium mineralisation. A long period of low activity followed, but from 1970 onwards the Chilean Nuclear Energy Commission (CCHEN) carried out more intensive regional surveys. The postponement of Chile’s nuclear power plans in 1983 resulted in a curtailment of uranium exploration activities, which have since remained at a very low level.

Known conventional resources of uranium (as at beginning-1999) reported to the NEA totalled 954 tonnes, with undiscovered conventional resources estimated as 4 500 tonnes; neither total was categorised by type of resource or by range of costs.

No production of uranium has yet occurred.

CHINA

More than 40 years of exploration for uranium has resulted in the discovery of deposits in various parts of the country. The major resources are in Jiangxi and Guangdong provinces in the south-east, in Liaoning province to the north-east of Beijing and in the Xinjiang Autonomous Region of north-western China. Total known resources in eight locations are stated to be 70 000 tonnes (in situ), but are not classified by production cost. Output in 1999 was 650 tonnes.

The NEA/IAEA 1999 Red Book quotes China’s speculative resources of uranium as 1.77 million tonnes (with no cost level assigned), but this estimate has been unchanged since at least the 1993 edition, and should be taken as no more than broadly indicative of possible undiscovered resources.

China has developed an in-situ leach mine at Yili in the north-west and is planning to increase the use of this technology to fuel its expanding nuclear power programme.

CZECH REPUBLIC

After an early start in 1946, uranium exploration in the republic was systematic and intensive during a period of more than forty years. From 1990, however, expenditure decreased sharply, with field exploration coming to an end early in 1994.

There are 24 uranium deposits, of which 20 have been mined-out or closed. Two deposits (Stráz and Rozná) are being mined and two others may be exploited in the future. In-situ leaching (ISL) operations at Stráz are being scaled down under a remediation programme. Output from Czechoslovakian mines began in 1946 and until 1990 was all exported to the Soviet Union. Production in 1999 amounted to 605 tonnes, with cumulative output of nearly 107 000 tonnes, of which about 86% had been obtained by underground mining and the balance by ISL.

Reasonably assured resources (at up to US$ 80/kgU) stood at just over 4 100 tonnes at the end of 1999; the decrease of around 2 500 tonnes in this category is due to a re-evalution of the Hamr and Stráz deposits, as well as to depletion of resources at the currently operating production centres. Other known conventional resources comprise approximately 2 900 tonnes of RAR recoverable at US$ 80-130/kgU, together with some 22 700 tonnes of EAR-I recoverable at up to US$ 130/kgU.

Undiscovered resources (on an in-situ basis) comprise nearly 10 000 tonnes of EAR-II recoverable at up to US$ 130/kgU and 179 000 tonnes of speculative resources, unassigned to a cost category.

EGYPT

The Nuclear Materials Authority has carried out exploration for uranium since the early 1960's. In recent years, attention has been concentrated on three mineralised areas in the Eastern Desert and one in Sinai.

Undiscovered conventional resources (in the NEA "Speculative Resources" category) are estimated to be 15 000 tonnes of uranium, not categorised by cost, and excluded from the Red Book resource tables. Undiscovered unconventional resources, occurring in sedimentary phosphate deposits and in association with monazite, are estimated to be 8 000 tonnes, of which half fall within the NEA category EAR-II and half are speculative resources.

No production of uranium has yet been reported.

FINLAND

Exploration for uranium took place during the period 1955-1989, resulting in the identification of four uranium provinces. Proved reserves (RAR recoverable at US$ 80-130/kgU) amount to 1 500 tonnes. Other known conventional resources would only be recoverable at a higher cost. Unconventional resources are represented by possible by-product production of 3 000-9 000 tU from Talvivaara black schists and 2 500 tU from Sokli carbonatite.

Finland's past production of uranium has been limited to the minor quantity (circa 30 tU) produced by a pilot plant at the Paukkajanvaara mine in eastern Finland, which was operated from 1958 to 1961.

FRANCE

Exploration for uranium commenced in 1946 and during the next 40 years a number of deposits were located. Since 1987, exploration activities have been on the decline, as has the level of production. Total output in 1999 was 439 tonnes, bringing the cumulative tonnage to 74 598 tonnes. Reasonably assured resources (at up to US$ 80/kg) are put at nearly 12 500 tonnes.

France is expected to cease production of uranium in the near future, as the ore reserves at the remaining operating mine (Le Bernardan) are approaching exhaustion.

GABON

Exploration by the French Commissariat à l'Energie Atomique (CEA) led to the discovery in 1956 of a substantial deposit of uranium ore near Mounana in south-eastern Gabon. Further deposits in the Franceville Basin were located during 1965-1982. Exploratory activity continued until the late 1990's.

Uranium production from the Mounana production centre began in 1961 and built up to a peak of around 1 250 tpa by the end of the 1970's. Since then output has followed a declining trend, ceasing altogether in early 1999. The deposits at Mounana and several other locations were depleted by around 1990. The last underground mine, exploiting the Okelobondo deposit (discovered in 1974), closed down in November 1997. An open-pit operation at the Mikouloungou deposit (discovered in 1965) was in production from June 1997 to March 1999, since when Gabon has ceased to be a uranium producer.

Gabon's cumulative production of over 26 000 tonnes of uranium indicates its historic significance as one of the leading minor producers.

As at the beginning of 1999, known conventional resources of uranium in Gabon amounted to just under 6 000 tonnes, comprising 4 830 tonnes of RAR recoverable at less than US$ 40/kgU, and 1 000 tonnes of EAR-I in the same price category. Undiscovered resources consisted of EAR-II of 2 000 tonnes, recoverable at less than US$ 80/kgU.

GERMANY

Prior to Germany's reunification in 1990, the GDR had been a major producer of uranium, with a cumulative output of some 213 000 tonnes. All uranium mines have now been closed and the only production relates to uranium recovered in clean-up operations in the former mining/milling areas: 1999 output from this source was 30 tonnes, obtained during the decommissioning of the Königstein mine in Saxony.

HUNGARY

Uranium exploration commenced in the early 1950's, with the Mecsek deposit in southern Hungary being discovered in 1954. An underground mine came into production at Mecsek in 1956. Initially the raw ore produced was shipped to the USSR, but from 1963 onwards it passed through a processing plant at Mecsek before shipment as uranium concentrates.

Mining and milling operations at the Mecsek site were shut down at the end of 1997. Cumulative production of uranium, including a relatively small amount derived from heap leaching, was about 21 000 tonnes.

After the closure of production operations (on economic grounds) Hungary's remaining known conventional resources of uranium, as reported by its WEC Member Committee, were 14 695 tonnes of proved reserves (RAR recoverable at US$ 80-130/kgU) and 12 995 tonnes of additional recoverable resources, in the same cost bracket.

INDIA

Exploration for uranium began in 1949, since when deposits have been located in many parts of the country. Exploratory activity is continuing, with expenditure of around US$ 14 million per annum.

Uranium has been produced at the Jaduguda mine in the eastern state of Bihar since 1967. In 1999 output from this and two other mines in the same area, plus some uranium recovered as a by-product of copper refining, was some 200 tonnes. Reasonably assured resources (with their cost range unassigned) are approximately 53 000 tonnes. Other known conventional resources consist of just over 25 000 tonnes classified as EAR-I, also without an assigned cost range. Both these amounts are expressed on an in-situ basis, and are included in the US$ 80-130 kg/U category in Tables 6.1 and 6.2 respectively.

Undiscovered conventional resources (in-situ) consist of about 13 000 tonnes of EAR-II and 17 000 tonnes of speculative resources. Unconventional resources are estimated to amount to 6 615 tonnes, recoverable from copper mine tailings in the Singhbhum district of the state of Bihar.

A new uranium production centre, using ISL technology, is planned for construction at Domiasiat in Meghalaya State, north-eastern India, with an estimated start-up date of 2004.

INDONESIA

The Nuclear Minerals Development Centre of the Indonesian National Atomic Energy Agency (BATAN) began exploring for uranium in the 1960's. Since 1988, exploratory work has been concentrated in the vicinity of Kalan in West Kalimantan, with a significant drilling programme being completed in 1992. Exploration work has continued, but since 1997 budgetary constraints have severely limited operations.

At the beginning of 1999, reasonably assured resources, on an in-situ basis and recoverable at less than US$ 130/kgU, amounted to 6 273 tonnes; estimated additional resources (on the same basis) were 1 666 tonnes. Over and above these amounts, the Indonesian WEC Member Committee reports an additional 2 586 tonnes as recoverable at this cost level – a somewhat larger sum than the 2 057 tonnes of speculative resources quoted in the NEA/IEA Red Book.

IRAN

Exploratory work has been undertaken for more than twenty years and a number of small prospects have been defined. In recent years the Exploration Division of the Atomic Energy Organisation of Iran has been active at several locations in the centre and north-west of the country.

Reasonably assured resources (in-situ) amount to 491 tonnes, with a further 876 tonnes of additional resources (EAR-I), both recoverable at US$ 80-130/kgU. Undiscovered conventional resources consist of 4 500 tonnes in category EAR-II, plus 5 000 tonnes of speculative resources, both recoverable at less than US$ 130/kgU.

JAPAN

Between 1956 and 1988, the Power Reactor and Nuclear Fuel Development Corporation (PNC) and its predecessor undertook domestic exploration for uranium, resulting in the discovery of deposits at two locations on the island of Honshu. Total discovered reserves, reported as recoverable at US$ 80-130/kgU, are some 6 600 tonnes.

Cumulative production of uranium in Japan amounts to only 87 tonnes, the bulk of which (84 tonnes) was produced by a test pilot plant operated by PNC at the Ningyo-Toge mine between 1969 and 1982.

KAZAKHSTAN

Uranium exploration commenced in 1948 and since then a large number of ore deposits have been located, initially in the districts of Pribalkhash (in south-eastern Kazakhstan), Kokchetau in the north of the republic, and Pricaspian near the Caspian Sea. Since 1970 extensive low-cost resources have been discovered in the Chu-Sarysu and Syr-Darya basins in south-central Kazakhstan. Exploration activity is presently confined to the northern part of the republic.

The companies responsible for producing and processing uranium ore are all controlled by the Government of Kazakhstan. Production started in 1953, initial output being processed in Kyrgyzstan. Production centres were started up by the Tselinny Mining and Processing Company in 1958 (based on underground-mined ore) and by the Kaskor Company in 1959 (based on open-pit mining). Economic pressures forced the closure of the Kaskor plant in 1993 and the Tselinny plant in 1995.

There are currently five production centres in operation in south-central Kazakhstan, all based on in-situ leaching (ISL). Output of uranium in 1999 was 1 560 tonnes; cumulative production has reached 86 502 tonnes, within which ISL has accounted for 26 221 tonnes, while open-pit mining has produced 21 618 tonnes and underground output has totalled 38 663 tonnes. The aggregate production capability of the five ISL plants is 4 000 tU/year.

Kazakhstan was the eighth largest producer in 1999, but its reasonably assured resources (436 600 tonnes, at up to US$ 80/kg) put it in a much higher ranking - second only to Australia - and give it a 17.7% share in global resources. In addition, there are more than 420 000 tonnes of other known resources deemed to be recoverable at costs of less than US$ 130/kgU: 162 000 tonnes of RAR and 259 000 tonnes of EAR-I.

Undiscovered resources recoverable at the same cost level are also massive: 310 000 tonnes of EAR-II and 500 000 tonnes of speculative resources.

All Kazakhstan's uranium resources are quoted on an in-situ basis.

MALAWI

Exploration during the 1980's led to the discovery of a uranium deposit at Kayelekera in northern Malawi. There was no exploratory activity during the period 1996-1998.

The uranium resources in the Kayelekera deposit amount to 11 700 tonnes, assessed on an in-situ basis; they are classified as reasonably assured resources, recoverable at less than US$ 80/kgU. No other uranium resources, either known or undiscovered, have been reported.

MEXICO

Exploration for uranium came to an end in 1983: at that point, known resources totaled 2 400 tonnes recoverable at US$ 80-130/kgU, comprising 1 700 tonnes of RAR and 700 tonnes of EAR-I. Additional undiscovered resources amounted to 12 700 tonnes, the bulk of which (10 000 tonnes) were speculative.

Unconventional resources (as assessed in the early 1980's) amount to about 150 000 tonnes, contained in marine phosphates in Baja California.

For a short period (1969-1971), molybdenum and by-product uranium were recovered from a variety of ores at a plant in Aldama, Chihuahua state. Uranium output totalled 49 tonnes; there are presently no plans for resuming production.

NAMIBIA

Although uranium mineralisation had been detected in the Rössing Mountains in the Namib desert in 1928, extensive exploration for uranium did not get under way until the late 1960's. The major discovery was the Rössing deposit, located to the north-east of Walvis Bay; other discoveries were made in the same area of west-central Namibia, notably the Trekkopje and Langer Heinrich deposits, but Rössing is the only one that has been developed.

A large open-pit mine operated by Rössing Uranium Ltd (56.3% owned by Rio Tinto Zinc, 3.5% by the Namibian Government and 40.2% by other interests) has been in production since 1976; output in 1999 was 2 689 tonnes, with cumulative production amounting to 69 411 tonnes. The 1999 output level represented 69.9% of the 3 845 tU/year design capacity of Rössing's processing plant.

Namibia is currently the fourth largest uranium producer in the world. Its reasonably assured reserves of 149 274 tonnes (at up to US$ 80/kgU) are equivalent to 6% of the global total. RAR recoverable at US$80-130/kgU are over 31 000 tonnes; estimated additional resources are also substantial, exceeding 107 000 tonnes (in-situ) recoverable at up to US$ 130/kgU.

NIGER

Exploration for uranium began in 1956, resulting in the discovery of a number of deposits in the Aïr region of north-central Niger. There are currently two uranium production centres, one near Arlit processing ore from the Arlette, Takriza and Tamou deposits and operated by Société des Mines de l'Aïr (Somaïr), and the other at Akouta processing ore from the Akouta and Akola deposits and operated by Compagnie Minière d'Akouta (Cominak). Niger's participation in the producing companies is 36.6% in Somaïr, and 31% in Cominak.

Somaïr has been producing uranium from open-pit operations since 1970, while Cominak has carried out underground mining since 1978. In 1999, Somaïr produced 1 000 tonnes, recording a cumulative output of around 36 000 tonnes; Cominak's output was about 1 900 tonnes in 1999, with a cumulative total of nearly 43 000 tonnes. The two companies have current production capabilities of 1 500 and 2 300 tU/year respectively.

Niger is the third largest producer of uranium, accounting for about 9% of global output, although its reasonably assured resources of just over 71 000 tonnes (at up to US$ 80/kgU) have a relatively low ranking in the world list. Estimated additional resources (EAR-I), recoverable at US$ 80-130/kgU, have been re-assessed and now stand at 18 579 tonnes; the 1997 Red Book quoted EAR-I as only 1 200 tonnes, recoverable at less than US$ 40/kgU. The increase is stated by the NEA to be probably attributable to the availability of additional drilling data relating to the Tamou and Akola deposits.

It is to be noted that all of Niger's uranium resource data are now quoted on an in-situ basis.

PERU

During the course of exploration carried out up to 1992, the Peruvian Nuclear Energy Institute (IPEN) discovered over 40 occurrences of uranium in the Department of Puno, in the south-east of the republic.

Known conventional resources in the Macusani area in northern Puno are estimated to amount to 3 650 tonnes, of which 1 790 are classified as RAR and 1 860 (in-situ) as EAR-I. Undiscovered resources consist of 6 610 tonnes in the EAR-II category (recoverable at less than US$ 80/kgU), 19 740 tonnes of speculative resources (recoverable at less than US$ 130/kgU) and 6 000 tonnes of other speculative resources, with their cost range unassigned.

POLAND

For some twenty years, starting in 1947, a systematic programme of uranium exploration and development was undertaken in the Lower Silesia region, under the direction of Soviet Union experts. Mines were developed at Kowary Podgórze, Radoniow and Kletno; operations between 1948 and 1963 resulted in the extraction of some 660 tonnes of uranium, all of which was consumed in the Soviet Union.

PORTUGAL

Uranium has been mined since 1951 from a large number of small deposits in two areas of central Portugal. Output is now minimal (10 tonnes in 1999), after cumulative production of about 3 700 tonnes. Reasonably assured resources (at up to US$ 80/kgU) are put at almost 7 500 tonnes. Other known conventional resources consist of EAR-I of 1 450 tonnes, recoverable at less than US$ 130/kgU; undiscovered conventional resources recoverable at this cost level comprise 1 500 tonnes of EAR-II and 5 000 tonnes of speculative resources.

ROMANIA

Since 1952, when uranium production started, 17 630 tonnes have been produced in Romania. There are deposits in three principal areas: the Apuseni Mountains in the west, the Banat Mountains in the south-west and the Eastern Carpathians. Since 1978, all of Romania’s production of uranium ore has been processed at the Feldiora mill in the centre of the country.

Uranium output in 1999 was 105 tonnes, with remaining reasonably assured resources (at up to US$ 130/kgU) reported as 6 900 tonnes. Further known conventional resources recoverable at the same cost level are 8 950 tonnes of EAR-I; undiscovered resources comprise 1 970 tonnes of EAR-II plus 3 000 tonnes of speculative resources.

RUSSIAN FEDERATION

Uranium exploration has been undertaken since 1944; eleven ore-bearing districts have been identified east of the Urals and four in the European part of Russia. Exploration and development activity in recent years has been largely concentrated on three east-of-Urals uranium districts (Transural, West Siberia and Vitim) in which there are deposits suitable for the application of in-situ leaching (ISL). A uranium production centre is being established in the Transural district and two are planned for construction in West Siberia and Vitim.

Mining and processing of uranium ore started in 1951 in the Stavropolsky region of European Russia, a source which had been exhausted by the late 1980’s, after 5 685 tonnes had been produced. Between 1968 and 1980, the Sanarskoye deposit in the Transural district produced 440 tonnes of uranium, using ISL technology.

Up to the present the most important producing region, and the only current source of Russian uranium output, is the Streltsovsky region near Krasnokamensk in eastern Siberia, which counts as one of the world’s major producing areas. Output in 1999 was about 2 600 tonnes, of which 92% was derived from ore obtained by underground mining, the balance being derived from low-grade ore by heap- or in-place leaching. Uranium exploration and production activities in the Russian Federation are totally state-owned: the state concern responsible for production in the Krasnokamensk area of the Chitinskaya Oblast is the Priargun Mining-Chemical Production Association.

The Russian Federation was the world’s fifth largest producer of uranium in 1999, accounting for 8% of global output. Its reasonably assured resources (at up to US$ 80/kgU) of 140 900 tonnes represented 5.7% of the global total at end 1999.

The balance of known conventional resources consists of 36 500 tonnes of EAR-I recoverable at less than US$ 80/kgU. Undiscovered resources are estimated to be exceedingly large: nearly 105 000 tonnes of EAR-II at up to US$ 130/kgU plus a million tonnes of speculative resources, of which more than half (54.4%) are deemed to be recoverable at less that US$ 80/kgU.

SOUTH AFRICA

Between the late 1940's and the early 1970's uranium exploration was pursued as an adjunct to exploration for gold, centred on the quartz-pebble conglomerates in the Witwatersrand Basin in the Transvaal. The 1973-1974 oil crisis triggered intensified exploration for uranium, leading to the country's first primary uranium mine (Beisa) coming into production in 1982. Output as a by-product of gold-mining had begun thirty years previously, and by 1959 26 mines in the Witwatersrand Basin were supplying 17 processing plants, resulting in an annual output of nearly 5 000 tonnes. In 1971 Palabora Mining Company began producing uranium as a by-product of its copper-mining operation in the Northern Province.

Between the late 1980's and the early 1990's, a substantial reduction in production capacity took place, nine plants being shut down.

Total uranium output in 1999 was 1 093 tonnes, the ninth largest national level in the world; at the end of the year, four mines were in production: Hartebeestfontein and Vaal Reefs at Klerksdorp, Western Areas on the West Rand and Palabora. The cumulative output of uranium in South Africa up to the end of 1999 was approximately 152 700 tonnes. The country's reasonably assured resources (at up to US$ 80/kgU), consisting to a considerable extent of quartz-pebble conglomerates, totalled about 233 000 tonnes at end-1999, equivalent to 9.4% of the total for the world.

SPAIN

The first uranium discoveries were made in the western province of Salamanca in 1957-1958. Subsequently other finds were made further to the south and, in one instance, in central Spain. Production began in 1958 and by the end of 1999, a cumulative total of 5 487 tonnes had been produced. Output in 1999 was 255 tonnes, leaving the remaining reasonably assured resources (at less than US$ 80/kgU) at 3 100 tonnes. Further known conventional resources recoverable at US$ 80-130/kgU comprise 3 620 tonnes of RAR and 7 540 tonnes of EAR-I.

SWEDEN

Exploration for uranium was carried out from 1950 until 1985, when low world prices for the metal brought domestic prospecting to a halt. Four principal uranium provinces were identified, two in south/central Sweden and two in the north.

Proved reserves are reported by the Swedish WEC Member Committee as 2 000 tonnes recoverable at less than US$ 80/kgU and 2 000 tonnes at US$ 80-130/kgU. Additional amounts recoverable comprise 1 000 tonnes recoverable at less than US$ 80/kgU and 5 300 tonnes at US$ 80-130/kgU.

There are substantial unconventional resources of uranium in alum shale, but the deposits are very low grade and recovery costs would exceed US$ 130/kgU. During the 1960's, a total of 200 tonnes of uranium was recovered from alum shale deposits at Ranstad, in the Billingen district of Västergötland, southern Sweden. This mining complex has now been rehabilitated, the open pit being transformed into a lake and the tailings area treated to prevent the formation of acid.

THAILAND

The Royal Thai Department of Mineral Resources (DMR) undertook exploration in the early 1970's and located a number of occurrences of uranium. During 1985-1987, a nationwide airborne geophysical survey was conducted by a contractor to the Canadian International Development Agency (CIDA). No exploration for uranium took place in Thailand from 1996 to 1999.

Known conventional resources are on a minimal scale: RAR recoverable at less than US$ 130/kgU amounting to 4.5 tonnes of uranium, with EAR-I (also at <US$ 130/kgU) adding another 7 tonnes.

TURKEY

Exploration activities have been conducted since the mid-1950's, resulting in the discovery of a number of deposits, mostly in western and central Anatolia.

Known conventional resources amount to 9 129 tonnes (in-situ basis), reported to be recoverable at US$ 80-130/kgU.

No production of uranium has been reported.

UKRAINE

Since the start of exploration for commercial resources of uranium in 1944, a total of 21 deposits have been discovered, mostly located in south-central Ukraine, between the rivers Bug and Dnepr. The most important orebodies are Vatutinskoye, Severinskoye and Michurinskoye, all in central Ukraine. Uranium has been produced since 1947, initially by the Prednieprovskiy Chemical Plant and since 1959 also by the Zheltiye Vody production centre. The first plant ceased producing uranium in 1990; the 1999 output of the other facility was 1 000 tonnes, in line with its nominal production capacity. All currently-processed ore comes from underground operations – 90% from the Ingul'skii mine on the Michurinskoye deposit and 10% from the Vatutinskii mine. Development of mining at the Severinskoye deposit is planned for post 2000.

In 1999 Ukraine was the tenth largest producer of uranium, accounting for just over 3% of the world total. Its reasonably assured resources (at up to US$ 80/kgU) are put at 42 600 tonnes. Further known conventional resources are represented by 38 400 tonnes of RAR recoverable at US$ 80-130/kgU and 50 000 tonnes of EAR-I recoverable at up to US$ 130/kgU.

Undiscovered resources comprise 3 900 tonnes of EAR-II recoverable at up to US$ 130/kgU plus 231 000 tonnes of speculative resources (with cost range unassigned).

All Ukraine's uranium resources are quoted on an in-situ basis.

UNITED STATES OF AMERICA

Between 1947 and 1970 the US Atomic Energy Commission (AEC) promoted the development of a private-sector uranium exploration and production industry; in late 1957 the AEC concluded its own exploration and development activities. Private-sector efforts accelerated in the 1970's in a context of rising prices and anticipated growth in the demand for the metal to fuel civilian power plants.

This exploration activity revealed the existence of extensive ore deposits in the western half of the United States, particularly in the states of Wyoming, Nebraska, Utah, Colorado, Arizona and New Mexico and in the Texas Gulf Coastal Plain. Numerous production centres were erected over the years, but many have now been closed down and either dismantled or put on stand-by.

Current production relies upon in-situ leaching (ISL), except for some uranium obtained as a by-product from phosphate processing or recovered from waste. At the beginning of 1999, six ISL plants (with an aggregate capacity of 3 060 tU/year) and one by-product plant (capacity 290 tU/year) were operational; 4 ISL plants, 3 by-product plants and 6 conventional mills were on stand-by.

US uranium output in 1999 amounted to 1 773 tonnes, the seventh highest national total. Reasonably assured resources (at up to US$ 80/kgU) are estimated to be 105 000 tonnes at end-1996, equivalent to 4.2% of the global total; RAR recoverable at US$ 80-130/kgU were 244 000 tonnes.

Estimated additional resources (not specified separately for EAR-I and EAR-II) are 839 000 tonnes at up to US$ 80/kgU and 434 000 at US$ 80-130/kgU. Speculative resources in the same cost brackets are 504 000 and 354 000 tonnes, respectively. Additional speculative resources (with cost range unassigned) amount to 482 000 tonnes.

UZBEKISTAN

Deposits of uranium ores have been found in at least 25 locations since the early 1950's, mostly lying in a central belt running from Uchkuduk in the north-west to Nurabad in the south-east. Although there was some production in the Fergana valley area, starting in 1946, commercial mining began in 1958 at Uchkuduk from open-pit and underground operations. In-situ leaching recovery methods were brought into use from 1965 and gradually came to dominate the production scene. The last of the open-pit and underground mines were closed in 1994, after conventional mining had produced a cumulative total of nearly 56 000 tonnes, 65% of which had come from open-pit operations.

Uranium output in 1999 by the state-owned Navoi Mining and Metallurgical Complex (NMMC), the sole producer, totaled 2 130 tonnes – equivalent to nearly 7% of global output. There are four production centres, one of which has been mothballed. The republic's nominal production capacity is 3 000 tU/year; its reasonably assured resources (at up to US$ 80/kgU) amounted to 65 600 tonnes at the beginning of 1999. The balance of known conventional resources consists of some 17 500 tonnes of RAR recoverable at US$ 80-130/kgU and 47 000 tonnes of EAR-I at up to US$ 130/kgU. Undiscovered conventional resources (on an in-situ basis) total about 170 000 tonnes, of which EAR-II recoverable at up to US$ 130/kgU account for 68 000 tonnes, the balance being speculative resources without a cost range assigned.

VIETNAM

Exploration for uranium in selected parts of the republic began in 1955, and since 1978 a systematic regional programme has been undertaken. Virtually the entire country has now been explored, with a number of occurrences and anomalies subjected to more intensive investigation. During 1997-1999, exploration activity was concentrated on the Nong Son basin in the Quang Nam province of central Vietnam.

Proved reserves (RAR recoverable at up to US$ 130/kgU, on an in-situ basis) are 1 337 tonnes; estimated additional amounts recoverable (on the same basis) are 6 744 tonnes. Undiscovered conventional resources (again on the same basis) consist of 5 700 tonnes in the

EAR-II category, plus 100 000 tonnes of speculative resources. Further speculative resources (without a cost range assigned) amount to 130 000 tonnes.

Unquantified amounts of unconventional resources have been reported to be present in deposits of coal, rare earths, phosphates and graphite.

No production of uranium has so far been achieved.

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Chapter 6

Part II: NUCLEAR

Almost 2 billion people around the world have no access to electricity and the problem will worsen as the global population continues to grow. The World Energy Council's *WEC Statement 2000* points out that although global reliance on fossil fuels and large hydro will remain strong through 2020, these will not be able to meet the world's long-term electricity demand sustainably. As a consequence, WEC concludes that the role of nuclear power must be stabilised with the aim of possible future extensions.

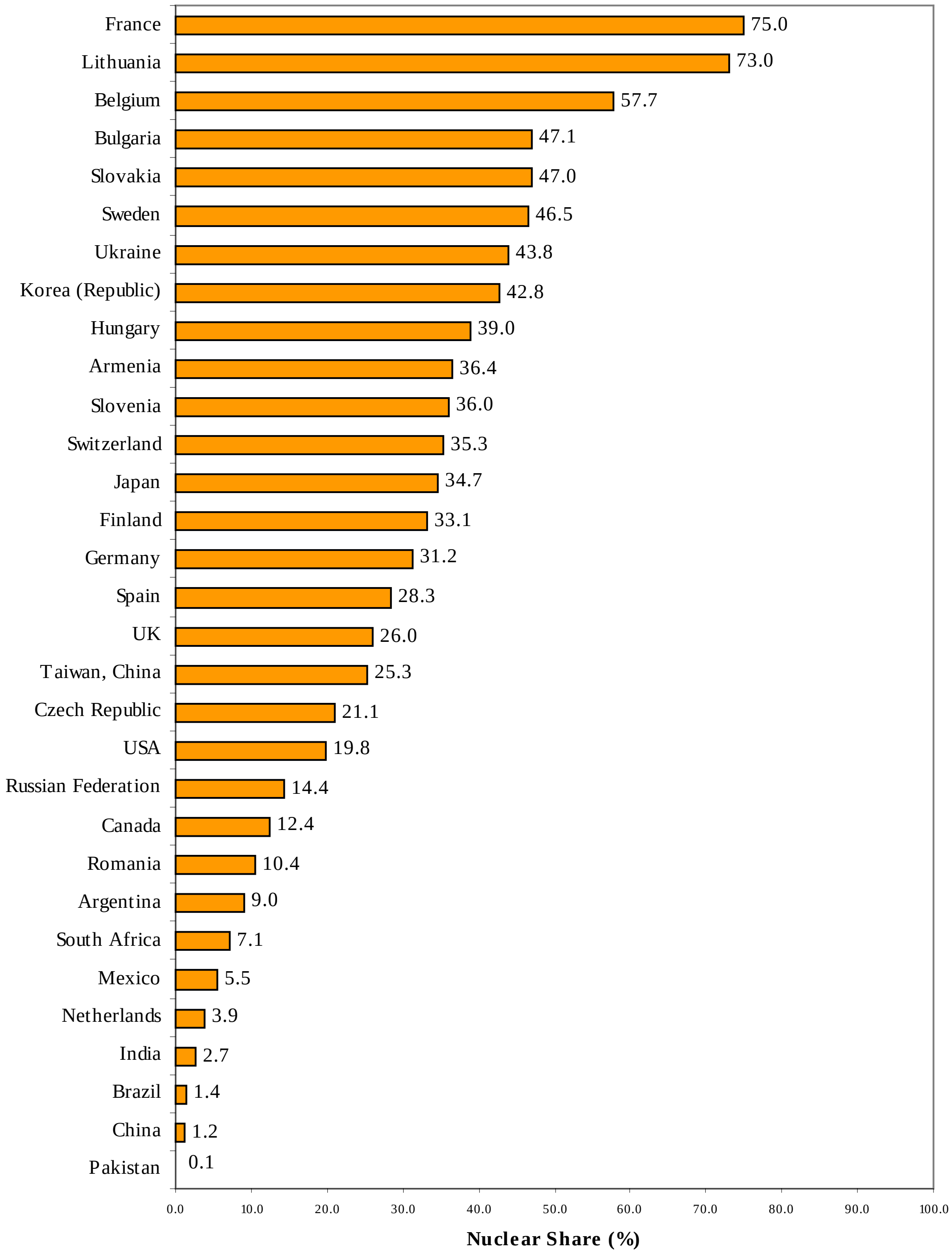
In the last three decades, nuclear power has played a significant role in electricity generation. Currently nuclear power supplies more than 16% of the world's total electricity. It produces little pollution and virtually no greenhouse gases. Well-designed, constructed and operated nuclear power plants (NPPs) have proven to be reliable, safe, economical and environmentally benign. Currently more than 9 000 reactor-years of operating experience have been accumulated worldwide.

According to information provided by WEC Member Committees for the present Survey, supplemented by data published by the IAEA, there were 430 NPPs in operation at the end of 1999, with an aggregate net generating capacity of 349 GW_e. There were reported to be 41 reactor units under construction, with a total capacity of just over 33 GW_e. These figures are generally in line with those contained in the IAEA's *Power Reactor Information System* (PRIS), which shows 433 NPPs (totalling 349 GW_e) in operation at end-1999, and 37 units (31 GW_e) under construction. The small number of discrepancies between the two data sets reflect differing views on the status of a few marginal plants and on the commencement of construction at a few reactor sites.

The country that produces the largest percentage of its electricity by nuclear power is France where, 75% of electricity was produced by nuclear. It is followed by Lithuania with 73%, Belgium with 58%, Bulgaria, Slovakia and Sweden with 47%, Ukraine with 44% and Republic of Korea with 43%. In ten other countries, more than 25% of the electricity was produced by nuclear power (see Figure 6.2). The largest contributor to the world's installed nuclear capacity was the USA with 28% of total capacity, followed by France with 18% and Japan with 12%.

In 2000, six new NPPs with a total capacity of 3 056 MW_e, went critical or were connected to the grid: three NPPs were added in India and one each in Pakistan, Brazil and the Czech Republic. One NPP was retired – the Chernobyl NPP unit 3 in Ukraine. During the last decade, the number of NPPs almost stagnated in North America and Western Europe, experienced a low growth in Eastern Europe and expanded only in East Asia, principally in China, the Republic of Korea and Japan. If this trend continues, nuclear power's share of world electricity supply will decline, according to the International Energy Agency's (IEA) *World Energy Outlook 2000*, from the current 16.3% to about 9% by 2020, even though the total number of NPPs world-wide will be slightly increased or maintained almost at the same level. The IAEA's projections also show similar results. Current and new additions in Asia and in countries with economies in transition roughly balance the NPPs being retired.

Figure 6.2: Nuclear Share of Electricity during 1999



Even though nuclear power is generally consistent with sustainable development goals, further expansion of nuclear power faces public concern on nuclear waste management and political issues on the potential proliferation of nuclear weapons. Another challenge is to further strengthen the high level of nuclear safety, while improving the economic competitiveness of nuclear power, in particular, to assure profitability in open and deregulated electricity markets. A number of NPPs in many countries have already made a successful transition from a monopoly, cost-plus environment to a competitive market. This has been achieved through an integrated approach to meeting interdependent safety and economic goals. The experience to date shows that safety, operational and economic performance have improved in both privatised NPPs (e.g. UK) and those where electricity markets are being opened to greater competition (e.g. USA). NPP unit capability factor in the world has improved during the last decade by about 7%, which is equivalent to the building of 28 GW_e of new NPPs. For the USA, the increase is more than 15% - from an average value of below 70% at the end of 1980’s to 86% in 1999 and it is estimated to have been around 88% in 2000. Analysis also shows that the NPPs with the best safety records had the highest availability and the lowest operating costs (which have fallen by as much as 40%).

Many existing NPPs have a significant economic advantage, particularly those which have had their capital investments depreciated or written-off. Well-managed NPPs, with their low fuel costs and steadily declining operating and maintenance costs, are often among the least expensive power plants to operate. This advantage has been sufficient to encourage the utilities to invest in plant life extension programmes. The liberalised or open market also rewards quick reactions and efficient operation of NPPs at competitive costs in some countries such as the USA. This has prompted consolidation in the nuclear industry, acquisitions, up-ratings and licence extension applications, rather than new construction.

The US Nuclear Regulatory Commission (NRC) has also adopted a risk-informed or performance-based approach for regulating the operations of NPPs, by which NPP lifetime extension programmes have been effectively carried out by many utilities or operators. As a result, the US NRC granted the first 20-year licence renewal to Calvert Cliffs units 1 & 2 (860 MW_e pressurised water reactors, PWRs) in March 2000 and the second 20-year renewal to Oconee units 1 to 3 (886 MW_e PWRs) in May 2000. These NPPs now have licensed operating life of 60 years. About 40% of operating NPPs in the USA have indicated an intention to seek licence renewals and the US NRC expects the figure to eventually reach 85%. On the other hand, the new anti-nuclear German government concluded an agreement with German utilities in June 2000 for an early phase-out of their 19 currently operating NPPs that will result in an average lifetime of 32 calendar years, while allowing utilities the option of closing less efficient NPPs sooner in order to run more efficient ones longer. Other initiatives by anti-nuclear governments in Western Europe focused on early termination or closure of some Eastern European NPPs and on negotiations to implement the “flexibility mechanisms” under the 1997 Kyoto Protocol, which seeks to limit future greenhouse gas emissions.

The capital-intensive nature of NPPs has also contributed to bringing new construction to a minimum, as is evident by only a handful of new construction starts over the past few years. Competing with fossil power plants and especially small gas units where an investment can often be recovered in less time than it takes to bring an NPP into operation, requires a lower capital investment for NPPs and substantially shorter construction period. Recent standardised NPPs with multiple units at the same site have seen construction periods shortened considerably and operating costs reduced as well. The French REP (PWR) 2000 series is estimated to have achieved savings of 20% in capital cost and a reduction in operating costs, such as those for staff training and spare parts storage. Such recently commissioned NPPs as Kashiwazaki Kariwa units 6 & 7 (1 356 MW_e advanced boiling water reactors, BWRs) in Japan and Ulchin units 3 & 4 (1 000 MW_e Korean standard PWRs) in the Republic of Korea were built in less than 5 years, which resulted in significantly reduced capital costs, compared with some nuclear units in other countries, where construction periods have been prolonged to even longer than 10 years.

With regard to nuclear waste management, plans for geological repositories in several countries have proceeded slowly and national policies have been re-examined to identify solutions that are both safe and publicly acceptable. Greater attention has been given to the idea of placing nuclear waste in deep underground repositories in a retrievable form, rather than as a permanent irreversible solution. This would allow adoption of a better solution that might be developed in the future.

The March 1999 opening of the Waste Isolation Pilot Plant (WIPP) in the USA was an important step towards demonstrating geological disposal of long-lived nuclear waste 700 metres deep in a natural salt formation. WIPP began to receive military trans-uranic nuclear waste for permanent disposal from March 1999. Commercial high-level nuclear waste acceptance in the USA is planned after 2010. In Sweden, a site selection for final nuclear waste repository is expected in around 2007 after detailed geological investigations at 3 candidate sites based on 6 proposals recently offered by 6 communities. In December 2000 the Finnish Cabinet approved a proposal to build a final repository for spent fuel in a cavern near the NPPs at Olkiluoto. If the Finnish Parliament approves the plan, construction will start in 2010 and operation will begin about 2020. The Canadian Government recently offered to the IAEA the use of its underground research facility at Lac du Bonnet for co-operative international research and training for demonstration of nuclear waste management. Other new R&D is also active in many countries, for example, to reduce actinide generation or to transmute long-lived nuclear waste to low or medium nuclear waste by using an accelerator driven system (ADS).

An increase in the number of countries with NPPs and nuclear fuel cycle facilities would result in new and increased demands for safeguards against the diversion of nuclear materials to other than peaceful uses. Protection against the misuse or diversion of nuclear materials requires both political and technological measures. As of December 2000 the IAEA had in force 224 Comprehensive Safeguards Agreements with 140 countries. And to further strengthen the capabilities of the IAEA to verify the exclusively peaceful nature of nuclear material and activities, the IAEA concluded 53 Additional Protocols to Comprehensive Safeguards Agreements, among which 18 are in force.

According to long-term energy projections by several international organisations, while global energy demand is projected to double in the next 50 years, electricity demand will more than triple, because it is a more convenient form of energy. The new demand is mostly expected in developing countries. The *WEC Statement 2000* also notes that, while in most developed countries the short-term impact of regulatory reforms in a context of over-capacity is to make new NPPs a less attractive option, this is not the case in developing countries where additional capacity is needed, nor will it be so in developed countries 10 years from now. For that reason, the WEC stresses that the nuclear option should be kept open, with R&D devoted to both evolutionary medium- and large-size NPPs and new innovative small-size designs for markets with less concentrated electricity demand, which would be the case in developing countries. Innovative designs may require a pilot or demonstration plant as a part of R&D programmes.

Considerable efforts are being made world-wide for development of new reactor technologies: evolutionary reactor technologies mainly by reactor vendors and utilities; and innovative designs mainly by universities and research institutes. The evolutionary design efforts centre on improving today's generation of light water reactors (LWRs) and heavy water reactors (HWRs). The innovative designs include these two reactor types and also gas cooled reactors, liquid metal cooled reactors and sub-critical hybrid systems like ADSs.

For evolutionary designs, there is a general drive for simplification, reduced construction periods, larger margins to limit system challenges, longer grace periods for response to emergency situations, improvement of the man-machine interface systems, and improved maintainability. All evolutionary designs incorporate features to meet stringent safety objectives by improving severe accident prevention and mitigation. Several evolutionary designs have reached a high degree of maturity, and some have been certified by nuclear regulatory authorities. In some cases design optimisation leads to higher plant output to take advantage of the economies of scale, while in other cases, economic competitiveness is pursued through simplification resulting from reliance on passive safety systems. Recently, within the US Department of Energy's (DOE) Nuclear Energy Research Initiative (NERI) programme, inter alia, further advances in evolutionary LWR technology are being pursued, as this approach represents the most likely means for near-term deployment of new NPPs.

Some 20 to 30 innovative reactor designs are under development in several countries with goals of low capital costs, short construction periods, high performance and enhanced safety. Features to address proliferation resistance are also being pursued. Several of the designs are of the small-to-medium size reactor (SMR) type, with construction based on factory-built structures and components, including complete modular units for on-site installation. For example, the Pebble Bed Modular Reactor (PBMR, 110 MW_e gas cooled reactor), for which the preliminary design was due to be completed in April 2001, is proposed to be built in two years in South Africa, mainly through factory-fabrication and on-site assembly of the modules. According to claims made by the developers, the base capital cost of the PBMR is claimed to be less than US$ 1 000 per kilowatt.

Some innovative designs could additionally be used for co-generation of electricity and heat, and for high-temperature heat applications: SMRs are of particular interest for non-electric applications. The BN-350 NPP, which was recently closed down in Kazakhstan, had been used for many years not only for production of electricity but for sea-water desalination. And several reactors in Russia and Eastern Europe are currently used for district heating. In Japan, nuclear sea-water desalination facilities are in operation with an accumulated 100 reactor years of operating experience. In addition, due to shortages of potable water in several parts of the world, a number of nuclear sea-water desalination projects are being studied. For example, in the Russian Federation, a floating NPP based on a 40 MW_e KLT-40 reactor has been developed for multipurpose use, including sea-water desalination. In the Republic of Korea, the basic design of SMART (330 MW_t integral reactor) is under way for sea-water desalination as well as electricity production.

The long-term outlook for nuclear energy needs to be considered in the broader perspective of future energy needs and environmental impact. In order for nuclear energy to play a meaningful and significant role in the global and long-term energy supply of the 21st century, innovative approaches are required to address concerns about economic competitiveness, safety, waste management and potential proliferation risks. In recent years, there have been a growing number of international, as well as national, initiatives and efforts to examine those issues. At the national level, development of evolutionary and innovative approaches to advanced nuclear reactor design and fuel-cycle concepts is proceeding, mainly in advanced nuclear countries such as the USA, the Russian Federation, Japan, the Republic of Korea, Canada and France. World-wide annual expenditures for this effort are currently estimated to exceed more than US$ 2 billion.

At the international level, the IEA, the OECD/Nuclear Energy Agency (NEA) and the IAEA have, since early 1999, jointly reviewed world-wide ongoing R&D efforts on innovative reactor designs and have identified options for collaboration. The US DOE inaugurated in January 2000 a new R&D programme, the so called “Generation IV” programme and formulated the “Generation IV International Forum” (GIF), in which around 10 countries are invited to participate as members with two international organisations (IAEA and OECD/NEA) as observers. In September 2000 at the UN Millennium Summit, the President of the Russian Federation called for interested countries to pool their efforts and join in an international project, to be led by the IAEA, for developing innovative nuclear power technology to further reduce nuclear proliferation risks. Against this background and taking account of its unique and global mandate in dealing with nuclear technology, safety and safeguards matters together, the IAEA established the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) to be implemented initially for two years from early 2001, mainly to focus on the identification of selection criteria and the development of methodologies and guidelines for comparing different innovative concepts and approaches, and to determine user requirements. All interested Member States are invited to participate in INPRO, which is designed to complement other initiatives such as the US GIF.

In conclusion, nuclear power alone may not ensure secure and sustainable electricity supply world-wide, nor may it be the only means to meet the Kyoto Protocol regarding global reduction of greenhouse gas emissions, but it should have an important role in both aspects through technology advancement and innovations. The challenge for reviving the nuclear power option in the 21st century is to address public and political concerns on economic competitiveness, nuclear safety, nuclear waste management and non-proliferation. Fortunately there are new initiatives to tackle these issues at both the national and the international level. In order to avoid duplication of efforts, international co-ordination and collaboration will be achieved through pooling of resources, sharing information, and co-operatively carrying out research and development.

In this context, the IAEA facilitates the exchange of non-commercial information and co-operation on technology development for improved and advanced nuclear power plant design and fuel-cycle concepts. It also provides support to developing countries in planning and implementing NPPs, and provides best practices for improvements in the design, construction, maintenance and operation of nuclear power and fuel-cycle facilities. Another important task is to promote the enlargement of non-commercial technology know-how, as well as the transfer and preservation of knowledge and competence in the areas of nuclear power and the fuel cycle. The IAEA also plans to provide an international forum for the co-ordination of development of criteria and user requirements for new innovative reactors and fuel cycles, taking into account economic competitiveness, nuclear safety, nuclear waste management and non-proliferation aspects.

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TABLE NOTES

The majority of the data shown in Table 6.4 were provided by WEC Member Committees in 2000/2001. If information was not available from this source, data have been derived from the following published sources:

- *International Energy Outlook 2001*; 2001; Energy Information Administration, US Department of Energy;
- *Nuclear Power Reactors in the World*; April 2000; International Atomic Energy Agency, Vienna;
- *Les Centrales Nucléaires dans le Monde 2000*; Commissariat à l’énergie atomique, France.

Table 6.4 Nuclear Energy: capacity and generation

Excel files

	In operation in 1999		Under construction at end-1999		In operation in 2010		Net generation in 1999	Nuclear share of electricity generation in 1999
	Units	Capacity	Units	Capacity	Units	Capacity		
	number	MW_e	number	MW_e	number	MW_e	TWh	%
South Africa	2	1 800			2	1 800	11.6	7.1
Total Africa	**2**	**1 800**				**1 800**	**11.6**	
Canada	14	9 998			22	14 902	69.3	12.4
Mexico	2	1 364			2	1 364	9.6	5.5
United States of America	104	97 557			98	93 730	727.7	19.8
Total North America	**120**	**108 919**				**109 996**	**806.6**	
Argentina	2	935	1	694	3	1 629	6.6	9.0
Brazil	1	617	2	2 506	3	3 123	4.0	1.4
Total South America	**3**	**1 552**	**3**	**3 200**		**4 752**	**10.6**	
Armenia	1	376					2.1	36.4
China	3	2 167	7	5 420		9 587	14.1	1.2
India	11	1 897	3	606		4 013	11.5	2.7
Japan	52	43 445	5	4 761	64	58 000	303.3	34.7
Korea (Democratic People's Rep.)			2	1 900	1	950		
Korea (Republic)	16	12 990	4	3 820	26	21 400	97.8	42.8
Pakistan	1	125	1	300	2	425	0.1	0.1
Taiwan, China	6	4 884	2	2 630	8	7 514	36.9	25.3
Total Asia	**90**	**65 884**	**24**	**19 437**		**101 889**	**465.8**	
Belgium	7	5 713			7	5 713	46.7	57.7
Bulgaria	6	3 538				2 314	14.5	47.1
Czech Republic	4	1 648	2	1 824	6	3 472	12.5	21.1
Finland	4	2 656			4	2 676	22.1	33.1
France	59	63 183			59	64 420	375.0	75.0
Germany	19	21 142			13	17 412	160.4	31.2
Hungary	4	1 729			4	1 729	14.0	39.0
Lithuania	2	2 370			1	1 185	8.7	73.0
Netherlands	1	449					3.3	3.9
Romania	1	648	4	2 592	2	1 296	4.8	10.4
Russian Federation	29	19 843	3	2 825		21 336	110.9	14.4
Slovakia	6	2 408	2	776		1 592	13.1	47.0
Slovenia	1	632			1	632	4.5	36.0
Spain	9	7 459			9	7 798	56.4	28.3
Sweden	11	9 452			10	8 852	70.2	46.5
Switzerland	5	3 127			5	3 127	23.5	35.3
Ukraine	14	12 115	2	1 900	15	13 090	67.4	43.8
United Kingdom	33	12 742			13	7 750	88.0	26.0
Total Europe	**215**	**170 854**	**13**	**9 917**		**164 394**	**1096.0**	
Iran			1	1 000	2	2 000		
Total Middle East			**1**	**1 000**		**2 000**		
TOTAL WORLD	**430**	**349 009**	**41**	**33 554**		**384 831**	**2390.6**	

Notes:

1. The estimates of nuclear generating capacity in 2010 for Armenia, China, India, Korea (Democratic People's Republic), Pakistan, Russian Federation and Slovakia reflect the Reference Case projections in *International Energy Outlook 2001*
2. As the number of reactor units in operation in 2010 is not available for all countries, no regional and global totals have been computed for this item
3. The capacity and output of the Krsko nuclear power plant, shown against Slovenia in the table, is shared 50/50 between Slovenia and Croatia

COUNTRY NOTES

The Country Notes on nuclear have been compiled by the editors, largely on the basis of material published in:

- *Nuclear Power Reactors in the World,* April 2000, International Atomic Energy Agency, Vienna;
- *Les Centrales Nucléaires dans le Monde 2000,* Commissariat à l'énergie atomique, France;
- *Daily Press Review,* IAEA.

Information provided by WEC Member Committees has been incorporated when available. Indications of nuclear plants planned for construction in the medium/longer term are generally based upon capacities and timings quoted in *Les Centrales Nucléaires dans le Monde 2000* (published August 2000).

ARGENTINA

There are two nuclear power plants: Atucha-1, a 335 MW_e PHWR supplied by Germany, and Embalse, a Canadian-designed 600 MW_e PHWR: Atucha-1 came on line in 1974, Embalse in 1983. In 1999 the two nuclear stations provided 9.0% of Argentina's electricity output. A third unit (Atucha-2), a 694 MW_e PHWR, is under construction, with completion set for 2005.

ARMENIA

A nuclear power plant came into operation at Medzamor, 64 km from the capital Yerevan, in 1976 but it was closed down in 1989 following an earthquake the previous year. Concern over the station's safety from a seismic point of view was exacerbated by the repercussions of the Chernobyl incident.

One of the two original WWER units (Medzamor-2) has been upgraded and refurbished, coming back into commercial operation in 1996 with a capacity of 376 MW_e. It provided about 36% of Armenia's electricity output in 1999. The rehabilitation of the other 376 MW_e unit at Medzamor has been deferred, possibly indefinitely. A 600 MW_e PWR has been planned to enter service in 2009, but a firm order has not yet been announced.

The US EIA's Reference Case scenario envisages that Armenia will not have any nuclear generating capacity in 2010-2020.

BANGLADESH

A 300 MW_e PWR is planned for construction at Rooppur, with a forecast year of 2009 for commencing operation.

BELARUS

Plans have been put forward for the construction of a 650 MW_e PHWR in the vicinity of Vitebsk, in the north-east of the republic.

BELGIUM

A total of seven reactors were constructed between 1975 and 1985: they are all of the PWR type, and have an aggregate net generating capacity of 5 713 MW_e. In 1999, nuclear power provided about 58% of Belgium's electricity generation. All of Belgium's reactors (four of which are located at Doel and three at Tihange) are expected to remain in service until at least 2010.

BRAZIL

At the end of 1999 Brazil had only one nuclear power plant in operation (Angra-1, a 617 MW_e net PWR); Angra-2 (1 253 MW_e net) started up in July 2000 and a third PWR (Angra-3) of equal size is forecast to be operating in 2006. This will bring net generating capacity at the Almirante Alvaro Alberto Nuclear Centre in Angra dos Reis, a coastal town in the south of the state of Rio de Janeiro, to 3 123 MW_e.

The construction and operation of nuclear power plants in Brazil are co-ordinated by the Ministry of Mines and Energy, through Eletronuclear, a subsidiary of Eletrobras. In July 2001, the National Energy Council was reported to be about to decide whether Angra-3 should be completed.

BULGARIA

There are six WWER units in operation at Kozloduy, in the north-west of the country, close to the border with Romania. Four units (each of 408 MW_e net capacity) were brought into operation between 1974 and 1982, and two others (each of 953 MW_e capacity) were commissioned in 1987 and 1991 respectively. The combined output of the Kozloduy reactors provided 47% of Bulgaria's electricity generation in 1999.

A contraction in nuclear capacity to just over 2 314 MW_e is foreseen by the end of 2010. Kozloduy-1 and -2 are scheduled to be shut down in 2002-2003; units -3 and -4 were due to be decommissioned in 2008-2010, but an updated programme announced in June 2001 specified closure at end-2009 and end-2011 respectively.

Russia has expressed interest in participating in the construction of a seventh unit at Kozloduy or one at Belene, about 110 km to the east. The European Commission has granted a loan of 212.5 million Euro to modernise and upgrade safety at Kozloduy-5 and -6.

CANADA

At the end of 1999, Canada had 14 reactor units in operation at five separate sites: all plants were of the PHWR type; total nuclear generating capacity was almost exactly 10 GW_e. In 1999 12.4% of Canada's electricity generation was provided by nuclear stations.

Eight reactors are currently laid up for repairs. It is anticipated that these units will be brought back into service by 2006. No new reactors are currently planned for construction during the period to 2010.

The Federal Government regulates the nuclear industry through the Canadian Nuclear Safety Commission (CNSL) and provides financial support for the research and development programme of Atomic Energy of Canada Limited.

CHINA

China's first nuclear power plant, a 279 MW_e PWR, came on-line at Qinshan, near Shanghai, in December 1991. Two larger PWR's (each 944 MW_e net) were brought into operation at Daya Bay (Guangdong province) in 1993-1994. At end-1999, China's nuclear generating capacity was 2 167 MW_e; output from the three units provided 1.2% of electricity generation.

Seven more nuclear units (two PHWR's and five PWR's) were under construction at the end of 1999, with an aggregate net capacity of about 5.4 GW_e.

China reported the completion of a 10 MW prototype high-temperature gas-cooled reactor at the end of 2000.

CROATIA

There are no nuclear plants on Croatian soil at present but the republic has a 50% share in the 632 MW_e Krsko PWR located across the border in Slovenia.

CUBA

The construction of two 417 MW_e PWR units (of the Soviet WWER-440 type) at Juragua was begun during the first half of the 1980's, but work was suspended in 1993. In mid-2000, Russia was reportedly still interested in completing the construction of nuclear generating capacity at Juragua. By the end of the year, however, Cuba had decided to abandon the completion of the Juragua NPP, which US experts had repeatedly criticised as a potential safety threat.

CZECH REPUBLIC

There are four 412 MW_e (net) reactors at Dukovany, which came into operation between 1985 and 1988. Their output in 1999 provided about 21% of the republic's net electricity generation. Two 912 MW_e (net) units have been under construction at Temelín: the first unit came on-line in October 2000, the second is expected to follow at the end of 2001.

The construction and commissioning of the Russian-designed WWER at Temelín has aroused considerable anxiety in neighbouring Austria, whose Government has sought assurances with regard to safety levels at the plant and attempted unsuccessfully to become officially involved in the final stages of inspection and testing. Eventually an agreement was signed by the two Governments in December 2000 that appeared to resolve the dispute. Austrian experts are to participate in an international assessment of the environmental impact of the Temelín NPP. However, the situation remains fluid.

The eventual commissioning of Temelín-2 would mark the completion of the Czech Republic's current nuclear programme. Any further developments will depend upon political decisions at government level. One of the long-term goals of the state energy policy after 2000 is to decide on the conditions for a continuation of the nuclear programme, for the prospective prolongation of the lifetime of the existing nuclear resources and for the eventual building of new plants.

EGYPT (ARAB REP.)

Egypt is planning the construction of a 600 MW_e plant at El Dabaa, with completion anticipated in about 2010. In May 2001 it was reported that the republic had signed a cooperation agreement with Russia on the peaceful use of atomic energy.

FINLAND

Four nuclear reactors were brought into operation between 1977 and 1980: two 488 MW_e WWER's at Loviisa, east of Helsinki, and two 840 MW_e BWR's at Olkiluoto. In 1999 the four units accounted for 33% of Finland's electricity output.

A fifth reactor (a 1 000 MW_e LWR) has been planned for construction in Finland: a formal application was lodged in November 2000, but opposition to the project on environmental grounds can be expected. In March 2001 it was reported that the town council of Loviisa had approved the project.

FRANCE

France has pursued a vigorous policy of nuclear power development since the mid-1970's and now has by far the largest nuclear generating capacity of any country in Europe, and is second only to the USA in the world. At end-1999 there were 59 reactors in operation, with an aggregate capacity of over 63 000 MW_e. Nuclear power plants provide three quarters of France's electricity output. PWR's account for virtually the whole of current nuclear capacity.

There are no nuclear reactors presently under construction: the completion of Civaux-2 in December 1999 marked the end of the current French nuclear programme. No more units are likely to be built before 2015, although plans exist for the construction of six further reactor units at three existing nuclear station sites (Flamanville, Penly and Saint Alban).

GERMANY

A total of 19 reactor units, with an aggregate net generating capacity of 21 142 MW_e, were operational at the end of 1999. Nuclear power provided about 31% of Germany's net electricity generation in that year.

In June 2000 the Federal Government concluded an agreement with the German utility companies that provides for an eventual phasing-out of nuclear generation. The agreement specifies a maximum of 2 623 TWh for the lifetime production of all existing nuclear reactors, which implies an average plant lifetime of 32 years. As the newest German reactor (Neckarwestheim-2) was connected to the grid in January 1989, it could be expected to survive until 2021; however, utilities will be allowed to switch productive capacity between stations, so that the life of the newer, more economic plants could be extended by prematurely shutting down other units. Moreover, the calculated 32-year average lifespan is predicated on a capacity factor of over 90%; using a somewhat lower (and more realistic) level of, say, 85% the average plant lifetime would approach 35 years.

The effect of the new agreement during the present decade will be to reduce the number of reactors in operation to 13 by the end of 2010, with nuclear generating capacity down to 17.4 GW_e.

HUNGARY

Four WWER reactors, with an aggregate net capacity of 1 729 MW_e, came into commercial operation at Paks in central Hungary, between 1983 and 1987. Their combined output in 1999 represented 39% of total net electrical generation.

No decision has been taken with regard to the future of nuclear energy in Hungary. There is a body of opinion which considers that the expansion of the Paks NPP is necessary in order to fulfill the objectives of national energy policy (security of supply, protection of the environment, reduction of emissions, etc.)

INDIA

At the end of 1999, India had 11 reactor units in operation, with an aggregate net generating capacity of 1 897 MW_e. Nine were PHWR's, the other two being of the BWR type: all were relatively small units, with individual capacities up to 202 MW_e. Output from India's nuclear plants represented 2.7% of total electricity generation in 1999.

Three 202 MWe PHWR's came into operation during 2000: Rajasthan-3 was connected to the grid in March and Kaiga-1 in October, while Rajasthan-4 entered commercial operation in December. Construction of two 450 MW_e PHWR's is under way at Tarapur and work on the first of two Russian-designed 950 MW_e WWER's was expected to begin at Kudankulam in Tamil Nadu during the first quarter of 2001.

Pre-project activities are in hand for four more 202 MW_e units at the Kaiga site near Karwar in the southern state of Karnataka and for four 450 MW_e reactors at the Rajasthan site near Kota in the northern state of Rajasthan. Six more 450 MW_e PHWR's are at the planning stage, with their siting not yet decided.

Nuclear generating capacity currently in operation, under construction and being planned totals some 10 600 MW_e net (11 600 MW_e gross). India's long-term objective for nuclear capacity is 20 000 MW_e (gross) by 2020: in order to achieve this aim, India plans to develop fast breeder reactors and to make use of its huge indigenous reserves of thorium.

INDONESIA

Plans exist for the construction of a 600 MW_e LWR (Muria-1), for completion post 2014.

IRAN (ISLAMIC REP.)

Construction started at Bushehr in the mid-1970's of two 1 200 MW_e PWR's, but work was suspended following the 1979 revolution. A 950 MW_e (net) unit was reported to be under construction at end of 1999, with an estimated in-service date of 2004. Reactor equipment supplied by Russia will reportedly be installed during 2001-2002. A press report in March 2001 indicated that Iran would order a second Russian reactor once work on the first unit has been completed. The Iranian WEC Member Committee expects both units to be in operation by the end of 2010.

ITALY

For the time being, nuclear electricity generation has been abandoned: Italy's last two nuclear plants were shut down in July 1990. A state-owned company (SOGIN) has acquired the assets constituted by the closed-down nuclear power stations (about 1 400 MW_e) and will take care of their decommissioning. A return to nuclear power in Italy is not presently foreseeable.

JAPAN

At the end of 1999 there were 52 operable nuclear reactors, with an aggregate gross generating capacity of 45 082 MW_e (43 445 MW_e net). Within this total there were 28 BWR's (24 872 MW_e net), 23 PWR's (18 425 MW_e net) and one HWLWR (148 MW_e net). The Monju prototype fast-breeder reactor (260 MW_e net) has not yet been put back into operation, five years after a serious leak of sodium caused it to be shut down.

In 1999, the output from Japan's nuclear power plants provided about 35% of its net generation of electricity. At the end of the year, there were five units under construction (including the restoration of Monju), with an aggregate generating capacity of 4 943 MW_e gross (4 761 MW_e net). By the end of 2010 there are expected to be 64 nuclear reactors in operation, with a total gross capacity of 60 316 MW_e (approximately 58 000 MW_e net).

Although the Atomic Energy Commission is currently revising its *Long-Term Programme for Research, Development and Utilisation of Nuclear Energy*, Japan's basic policy is unchanged: promoting the development and utilisation of nuclear energy for peaceful purposes only. For Japan, which possesses few energy resources, nuclear energy contributes to a stable supply of electricity, provides economic advantages and makes less impact on the environment. Japan's nuclear policy is a steadily continued expansion of generating capacity, coupled with a nuclear fuel recycling system, within a context of seeking domestic and international understanding.

KAZAKHSTAN

The only nuclear power plant to have operated in Kazakhstan was BN-350, a 70 MW_e fast breeder reactor located at Aktau on the Mangyshlak Peninsula in the Caspian Sea. It came into service in 1973 and was eventually shut down in June 1999. Reflecting its small generating capacity, and its additional use for desalination and the provision of process heat, BN-350's contribution to the republic's electricity supply was minimal: over its lifetime of operation, its average annual output was only about 70 GWh.

Plans exist for the construction of two 640 MW_e WWER units by around 2010 and, in the longer term, for a new fast breeder reactor (350 MW_e) and possibly two more WWER's.

KOREA (DEMOCRATIC PEOPLE'S REP.)

Two 950 MW_e PWR's are under construction at Shin Po, with completion envisaged for 2007-2008. During 2000, however, the US-led international consortium involved in the project encountered a number of delaying factors.

KOREA (REPUBLIC)

At end-1999, there were 16 nuclear reactors (12 PWR's and 4 PHWR's) in operation, with an aggregate net capacity of 12 990 MW_e. Four PWR's were under construction, with a total capacity of about 3.8 GW_e; it is anticipated that by the end of 2010, 26 units with a total generating capacity of about 21.4 GW_e will be in service.

According to the long-term power development programme (1999-2015) set in 2000, nuclear capacity will be increased to 26 050 MW_e, or 33% of total generating capacity, by 2015.

The Ministry of Commerce, Industry and Energy announced in October 2000 that the development of a next-generation Korean-standard 1 400 MW_e NPP would be concluded by the end of 2001.

LITHUANIA

Two LWGR's (each of 1 185 MW_e net capacity) were built at Ignalina, north-east of Vilnius, in the mid-1980's. The two units accounted for 73% of Lithuania's electricity generation in 1999.

In February 2000 the Lithuanian Nuclear Power Safety Inspectorate began preparations for extending Ignalina-2's licence for ten years from 2002. Later in the year (November), the new Lithuanian prime minister said that his government would "fight" to save Ignalina from closure, and reiterated his support for building a third unit at the site.

In May 2000 the Lithuanian Parliament enacted legislation to bring about the decommissioning of Ignalina-1 by 2005. This move reflected international disquiet over the safety of its Chernobyl-type reactors and Lithuania's ambition to become a member of the European Union in due course. The EU is pressing for the closure of Ignalina-2 by 2009.

MEXICO

There is a single nuclear power station with two BWR units, each of 654 MW_e net capacity, at Laguna Verde in the eastern state of Veracruz. The first unit was brought into operation in April 1989 and the second in November 1994. Laguna Verde's electricity output accounted for 5.5% of Mexico's total net generation in 1999.

During 1999 the installed capacity of both reactors at Laguna Verde was increased by approximately 5% through a power up-rate programme.

MOROCCO

There is a long-term possibility of the construction of two 1 000 MW_e LWR's, for completion post 2014.

NETHERLANDS

Two nuclear power plants have been constructed in the Netherlands: a 55 MW_e BWR at Dodewaard (connected to the grid in 1968) and a 449 MW_e PWR at Borssele (on-line from 1973). The BWR was taken out of service in 1997 and the PWR will be shut down by the end of 2003. Borssele's output accounted for 3.9% of Dutch electricity generation in 1999.

PAKISTAN

A small (125 MW_e) PHWR plant was commissioned in 1971. Known as Kanupp (Karachi Nuclear Power Plant), this facility makes a minor contribution (less than 1%) to the national electricity supply.

A second plant (Chasnupp 1), a 300 MW_e PWR, has been constructed at Chasma; it was connected to the grid in June 2000. Plans are reported for a second unit at Chasma, to be operational in about 2009: negotiations with China on its construction were under way in May 2001.

PHILIPPINES

The construction of a 650 MW_e PWR at Napot Point, near Bataan, was begun in 1976 but halted ten years later, with the plant still incomplete. It was reported in March 2000 that the Philippines was again seriously considering the use of nuclear power.

POLAND

Two 440 MW_e WWERs were ordered in 1974 and three more (1 x 950 MW_e and 2 x 440 MW_e) in 1981-1982. Although construction work had started at two 440 MW_e reactors at Zarnowiec, all five units were cancelled during 1990.

Construction of a nuclear power plant is contemplated for the period 2015-2020 but no decision has been taken so far.

ROMANIA

Romania's first nuclear plant – a 648 MW_e PHWR supplied by AECL of Canada – came on-line in 1996 at Cernavoda in the east of the republic. In September 2000, The Romanian Minister of Industry and Trade announced that financing for Cernavoda-2 would proceed. The Cernavoda station is the first nuclear generating plant in Eastern Europe to utilise safe technology, similar to that employed in the West. Cernavoda-2 is expected to be completed by 2005. A partnership contract with Italy for continuing construction of Cernavoda-2 was approved in May 2001.

The Romanian WEC Member Committee reports that four nuclear units, totalling 2 592 MW_e, were under construction at end-1999, but anticipates that only a total of two units will be in operation by end-2010.

RUSSIAN FEDERATION

There were 29 nuclear units installed at nine different sites at the end of 1999, with an aggregate net generating capacity of 19 843 MW_e. The reactor types represented consisted of eleven 925 MW_e LWGR's, seven 950 MW_e WWER's, four 411 MW_e WWER's, four 11 MW_e LWGR's, two 385 MW_e WWER's and one 560 MW_e FBR. In all, nuclear power plants provided 14.4% of the Russian Federation's electricity output in 1999.

Three reactor units, with an aggregate capacity of 2 825 MW_e, were under construction at the end of 1999. One of these units (a 950 MW_e WWER, Rostov-1) was completed in early 2001. The anticipated aggregated nuclear generating capacity in service at the end of 2010 is 21.3 GW_e.

In October 2000, Russia was reported to be planning a tripling of its nuclear output, from 110 billion kWh in 1999 to 330 billion kWh by 2020. An intention to build six new NPPs by 2010 was announced in May 2001.

SLOVAKIA

Four 408 MW_e WWER's were brought into service at Bohunice between 1978 and 1985; a slightly smaller (388 MW_e net) WWER came into operation at Mochovce in 1998. Mochovce-2 (also 388 MW_e) was connected to the grid just before the end of 1999 and went commercial in March 2000. Together, these reactors provided 47% of the republic's electricity output in 1999. Two more blocks are reported to be under construction, but completion is probably a long way off.

In September 1999, the European Union demanded a clear timetable from Slovakia for the decommissioning of the first block of the Bohunice station, before negotiations for eventual membership of the EU could begin.

SLOVENIA

A 632 MW_e PWR has been in operation at Krsko, near the border with Croatia, since 1981. Its output is shared 50/50 with Croatia. Slovenia's share provided about 36% of its electricity generation in 1999.

The long-term aim is to abandon electricity generation based on nuclear power in a safe and ecologically, as well as economically, acceptable way. It is not foreseen that any new nuclear power plants will be constructed.

The objective is to maintain a high operational safety level of the nuclear power plant at Krsko, both during its operation and after shutdown, as well as to gradually establish conditions for its safe decommissioning.

SOUTH AFRICA

There is a single nuclear power station at Koeberg in Cape Province, with two 900 MW_e PWR units, which came on-line in 1984-1985. The plant, which is owned and operated by the South African utility Eskom, provided 7% of the country's electricity generation in 1999.

No expansion of the PWR reactors is planned. However, there is a possibility that a pebble-bed modular reactor (PBMR) could be built in South Africa in the next five years, depending on the outcome of an environmental impact study currently being performed. BNFL of the UK became the first foreign investor in the PBMR project in June 2000.

The PBMR concept envisages a number of small (100 MW_e) nuclear reactors of modular design, operating in tandem to produce the required amount of electrical power.

SPAIN

Nine nuclear reactors were brought into commission between 1968 and 1988: at the end of 1999, they had an aggregate net capacity of 7 459 MW_e and in 1999 provided about 28% of Spain's electricity generation. Two of the units are BWR's (total capacity 1 437 MW_e), the rest being PWR's. Planned uprating of capacity brought the total up to 7 508 MW_e by mid-2000 and a further increase (to 7 798 MW_e by end-2010) is foreseen.

Upgrading programmes to increase the capacity of the Spanish nuclear power plants have resulted in a total increase of 476 MW_e since 1990.

At present, the construction of new nuclear power plants is not foreseen. The present policy concerning the existing NPP's is to continue their operation as long as they are safe, economical and reliable. The current life management programme will allow them to exceed the usual 40-year mark by a substantial number of years, in line with the trends prevailing in various leading countries.

SWEDEN

Between 1971 and 1985 a total of 12 nuclear reactors (nine BWR's and three PWR's) commenced operation. The 11 units remaining in service at end-1999 had an aggregate net capacity of 9 452 MW_e. Nuclear power provided 46.5% of Sweden's net output of electricity in 1999.

In June 1997 the Swedish Parliament took a decision to start the phasing-out of nuclear power. The decision specified that the two units, 600 MW_e each, at the Barsebäck nuclear station were to be closed by end-June 1998 and end-June 2001, respectively; an earlier decision with regard to a final date for total nuclear phase-out by 2010 was explicitly removed, without specifying an alternative final date.

The execution of the first closure was delayed by legal conflicts between the owner, Sydkraft, and the Government. During November 1999 an agreement was reached concerning the level of compensation, and Barsebäck-1 was permanently taken out of operation at the end of the month, without the closure being enforced by law. The phasing-out of Barsebäck-2 is, however, conditional upon its replacement by sufficient capacity from renewable sources and/or proven results from electricity conservation. Recently official spokesmen have stated that these conditions cannot be fulfilled in time for phase-out during 2001. The Government now estimates that the relevant conditions are unlikely to be met before 2003; the phase-out of the second unit at Barsebäck is to be postponed to a yet-undecided date.

SWITZERLAND

There are three PWR's and two BWR's in operation, with a total net generating capacity of 3 127 MW_e. All five reactors were commissioned between 1969 and 1984. Their output in 1999 represented about 35% of Switzerland's total power generation.

No new nuclear power stations are planned. The existing plants will continue in operation through 2010, possibly with some uprating of their current capacity levels.

In October 2000, the Swiss Government rejected a proposal to set limits to the operating lifetimes of the country's NPP's.

TAIWAN, CHINA

There are six reactors in service at three locations, with an aggregate net generating capacity of 4 884 MW_e; the four BWR's and two PWR's were all brought on line between 1977 and 1985. In 1999 nuclear plants provided just over a quarter of Taiwan's electricity generation. Two more BWR's, with a total net capacity of 2 630 MW_e, are under construction at a fourth location (Lungmen), with completion scheduled for 2004-2005.

The Lungmen project has become highly controversial within Taiwan, especially since a change of government in April 2000. The new Prime Minister stated in July that construction of the fourth NPP would continue even if controversies regarding the project could not be resolved. However, antagonism towards the scheme was still very evident and in October the Government had a change of mind, and suspended all construction work at the Lungmen site. The pendulum swung back again in January 2001, when Taiwan's Council of Grand Justices ruled that the Government had acted improperly in stopping the building of the fourth NPP.

The Taiwan, China WEC Member Committee considers that construction of the Lungmen nuclear project will proceed, but that delays caused by prior controversy may make the originally-estimated completion in 2004 or 2005 unrealistic.

THAILAND

A 950 MW_e LWR is planned for construction by around 2012.

TURKEY

Plans exist for the construction of two nuclear reactors at Akkuyu, one with a net generating capacity of 650 MW_e and a possible completion date within the present decade, and another (1 200 MW_e) not expected to be operating until some years after 2010.

UKRAINE

At end-1999 there were 14 nuclear reactors (with a total net generating capacity of 12 115 MW_e) in service at five sites: they had come into operation between 1980 and 1995. Nuclear plants accounted for almost 44% of Ukraine's power output in 1999.

Four 925 MW_e RBMK reactors were installed at Chernobyl between 1977 and 1983. In April 1986 the last unit to be completed, Chernobyl-4, was destroyed in the world's worst nuclear accident. Chernobyl-2 was closed down in 1991, Chernobyl-1 in 1996 and Chernobyl-3 in December 2000.

The EBRD has granted a loan to Ukraine to finance the completion of two nuclear reactors (Khmelnitski-2 and Rovno-4 (also known as K2R4)) to replace the electricity output lost as a result of the shut-down of Chernobyl-3.

UNITED KINGDOM

The UK had 33 nuclear reactor units in service at the end of 1999, with an aggregate net generating capacity of 12 742 MW_e. In 1999, nuclear power accounted for 26% of net electricity generation. No new plants are under construction, on order or planned: by the end of 2010 it is predicted that nuclear generating capacity will be 7 750 MW_e, with 13 reactors in service.

The Government's main energy policy objective is to ensure secure, diverse and sustainable supplies of energy at competitive prices. Nuclear power is playing an important role in meeting that objective. The Government believes that existing nuclear power stations should continue to contribute both to electricity supply and to the reduction of emissions, as long as they can do so to the high safety and environmental standards which are currently observed.

As with other forms of generation in the UK, it is for the generating companies to make proposals for any new nuclear plant. There are currently no such plans. Nuclear power has to demonstrate that it is economically competitive and that it can secure acceptance by the public. It is not UK Government policy to support or subsidise nuclear power in a deregulated market.

British Nuclear Fuels (BNFL) announced in May 2000 that most of the older magnox reactors will close before 2010.

UNITED STATES OF AMERICA

At the end of 1999, there were 104 nuclear reactor units connected to the grid, with an aggregate net generating capacity of some 97.5 GW_e (equivalent to about 28% of total world nuclear capacity). The totals include Brown's Ferry-1 (1 065 MW_e), which has been shut-down since March 1985 but is still fully licensed to operate. Nuclear plants accounted for about 20% of US electricity output in 1999.

Only two reactors have come on line since 1990: Comanche-2 (1 110 MW_e) in 1993, and Watts Bar-1 (1 177 MW_e) in 1996. No commercial reactors are under construction in the United States. Although construction permits have been issued for three units (total capacity 3.36 MW_e), these are not expected to come on line.

No new commercial reactors are currently projected by the Energy Information Administration to be constructed prior to 2020. However, one US utility has discussed participation in South Africa's Pebble Bed project and has indicated that it plans to purchase a reactor of this type.

By the end of 2010 there are expected to be 98 reactors connected to the grid, with an overall net generating capacity of 93.7 GW_e.

Nuclear power plants in the United States are largely owned and operated by private sector entities, although there are several plants owned by a Federal Government agency, the Tennessee Valley Authority. If the owners of nuclear plants are regulated electric utilities (which is usually the case), they are generally subject to economic regulation by state or local public utilities commissions.

The construction, operation, and decommissioning of nuclear power plants is closely regulated to ensure public health and safety by a Federal Government agency, the Nuclear Regulatory Commission (NRC). The NRC also regulates the handling and transportation of nuclear materials, including nuclear fuels.

The NRC will generally grant a completed plant an operating licence for a period of years consistent with the expected operating life of the plant. It is now undertaking research to determine the conditions under which existing nuclear plants may be modified to safely extend their operating lives and permit the NRC to re-licence these plants.

The US Department of Energy funds research and development of various aspects of nuclear power and continues to work on developing facilities for the long-term storage of spent nuclear fuel.

VIETNAM

The Vietnamese Government is planning to construct a 1 000 MW_e LWR, with completion in about 2020. The Ministry of Industry expects to complete a pre-feasibility study by end-2001.

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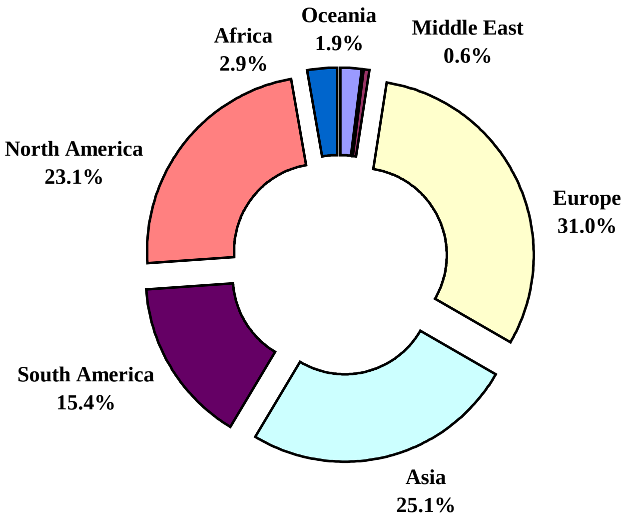
Chapter 7

HYDROPOWER

Although hydropower currently provides about one fifth of the world's electricity supply, development of the world's remaining technical potential could, by no means, cover the growth in future demand. However, carefully planned hydropower development can, and does, make a great contribution to improving electrical system reliability and stability throughout the world. Also, future development will play an important role in the improvement of living standards in the developing world, where the greatest hydropower potential still exists.

This development, together with the existing installed hydropower capacity (some 700 GW), will make a substantial contribution to the avoidance of greenhouse gas emissions and the related climate change issues.

Figure 7.1: Installed hydropower capacity (all schemes) at end-1999 - regional distribution



Hydroelectricity, at present the most important of the clean, economically feasible, renewable energy options, can be a major benefit of a water resources development project; however, it is seldom the only benefit. Hydropower stations integrated within multipurpose schemes generally subsidise other vital functions of a project, such as irrigation, water supply, improved navigation, flood mitigation, recreational facilities, and so on.

It is clear, therefore, that hydropower has an important role to play in the future, both in terms of energy supply and water resources development. As with all options, there is a need to develop the resources according to the highest social, environmental, economic and technical standards.

The inevitable increase in energy consumption

It is easy to predict that world energy demand, and especially that for electricity, will increase greatly during this 21st century, not only because of demographic pressures, but also through an improvement in living standards in the less developed countries, which will represent 7 billion inhabitants in 2050 (78% of the total).

Consumption of primary energy will increase up to threefold by the middle of this century, and the increase will be even greater for electricity. In view of this situation, many sources of energy will be necessary, but for environmental reasons, a high priority should be the development of all technically feasible potential from clean renewable sources, especially hydropower.

Characteristics of hydropower

The most important characteristics of hydropower can be summarised as follows:

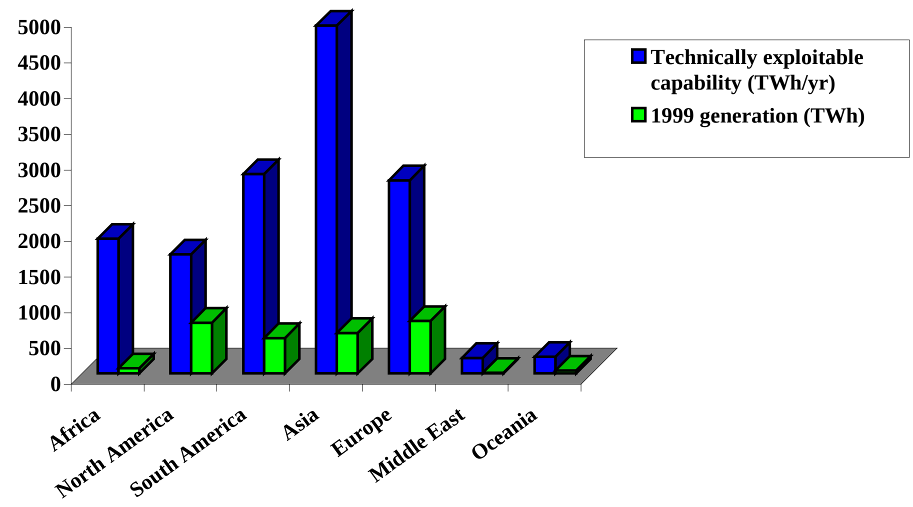
- its resources are widely spread around the world. Potential exists in about 150 countries, and approximately two-thirds of the economically feasible potential remains to be developed. This is mostly in developing countries, where the capacity is most urgently required;
- it is a proven and well advanced technology, with more than a century of experience. Modern power plants provide extremely efficient energy conversion;
- it plays a major role in reducing greenhouse gas emissions in terms of avoided generation by fossil fuels. Hydro is a relatively small source of atmospheric emissions compared with fossil-fired generating options;
- the production of peak load energy from hydropower allows for the best use to be made of base load power from other less flexible electricity sources. Its fast response time can add substantially to the reliability and quality of the electrical system;
- it has the lowest operating costs and longest plant life, compared with other large-scale generating options. Once the initial investment has been made in the necessary civil works, the plant life can be extended economically by relatively cheap maintenance and periodic replacement of the electromechanical equipment;
- as hydro plants are often integrated within multipurpose developments, the projects can help to meet other fundamental human needs (for example, irrigation for food supply, domestic and industrial water supply, flood protection). The reservoir water may also be used for other functions such as fisheries, discharge regulation downstream for navigation improvements, and recreation. Hydropower plants can help to finance these multipurpose benefits, as well as some environmental improvements in the area, such as the creation of wildlife habitats;
- the ‘fuel’ (water) is renewable, and is not subject to fluctuations in market conditions. Hydro can also represent energy independence for many countries.

Hydro potential

Today, hydropower provides about 19% (2 650 TWh/yr) of the world's electricity supply.

Information received from WEC Member Committees, supplemented by data published by *The International Journal on Hydropower & Dams*, indicates that the world's total technically feasible hydro potential is about 14 400 TWh/yr, of which just over 8 000 TWh/yr is currently considered to be economically feasible for development. Installed hydro-electric generating capacity is some 692 GW, with a further 110 GW under construction (see Tables 7.1 and 7.2).

Figure 7.2: Hydropower - technically exploitable capability and 1999 generation (all schemes) - regional distribution



The remaining economically exploitable potential is about 5 400 TWh/yr: assuming the same average annual utilisation as for the totality of existing hydro power plants, the exploitation of this potential would entail the construction of some 1 400 GW of hydro capacity (twice the present installed capacity).

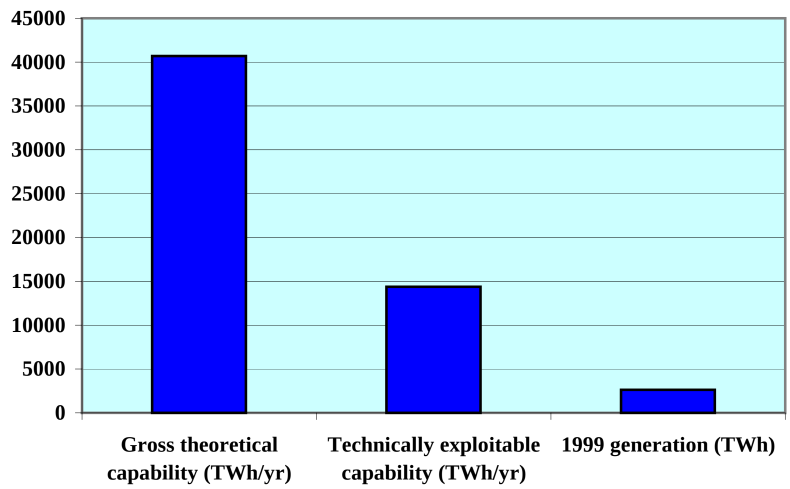
An investment of at least US$ 1 500 billion would be necessary to realise such a programme. Assuming a mean level of hydro power plant capacity in the range of 50 MW to 100 MW, some 20 000 plants would need to be built (very large schemes such as Three Gorges and Itaipú will not be the norm, and it can be anticipated that future development of hydropower will generally follow the pattern observed in the western countries up to the present).

In order to implement a plant construction programme of this magnitude, a great deal of work (technical, financial and political) would need to be accomplished by all the players involved, particularly in Asia, South America and Africa.

Avoided emissions

There is international consensus that greenhouse gas (GHG) emissions will lead to major climatic changes, and will therefore have consequences on the hydrological system (and thus on water supply and agriculture) as well as on the sea level. Measures accommodating such changes will need to be taken into account when planning the utilisation of the hydropower resource.

Figure 7.3: Hydropower - world gross theoretical/technically exploitable capability and 1999 generation (all schemes)



The challenge is clear: an inevitable increase in energy consumption in the world, with the risk of a major environmental impact, and climate change, as a result of the combustion of fossil fuels. Hydropower thus has a very important role to play in the future.

Continued international research confirms that the GHG emission factor for hydro plants is substantially less than the factors for fossil fuel generation, taking into account net emissions from reservoirs. Current initiatives involve the validation and standardisation of various measuring techniques, and efforts to obtain greater consensus on the processes determining the river-basin carbon budget (Rosa, 2001).

According to current figures, development of even half of the world's economically feasible hydropower potential could reduce GHG emissions by about 13% (by avoided fossil fuel-based generation), and the impact on avoided sulphur dioxide (the main cause of acid rain) and nitrous oxide emissions is even greater.

Hydropower also avoids the substantial impact of particulate emissions (fly-ash, for example): the costs to human health in the form of respiratory disease is a very tangible impact of this problem. A recent estimate of the environmental cost of this form of pollution is put at US$ 100-500 per t/year (Oud, 1999).

Social aspects

As with other forms of economic activity, hydro projects bring about changes to the project area. Social changes are mainly associated with transformation of land use in the project area, and displacement of people living in the reservoir area.

The social effects of hydro schemes are variable and project-specific. However, if anticipated and tackled early in the planning stage of a project, the negative impacts can be addressed efficiently, and in some cases avoided altogether. Positive aspects can include substantial infrastructure and community services development.

It is increasingly common for an effective public participation programme to be implemented from the early stages of a project. When the project is considered as an opportunity for the community, the people affected will be able to enjoy a higher standard of living through associated infrastructural developments such as the provision of water and sanitation services. Sincere and concerted efforts are being made to demonstrate this aspect. Recent examples include projects in Laos, Uganda, India, China, Japan and Brazil.

Environmental changes

Although the majority of hydropower reservoirs are valued as environmental enhancements by the societies they serve, it is clear that not every hydro plant in the world is without environmental challenges. Often, however, projected reservoirs can in fact focus attention on existing problems in a watershed.

Today, the multi-disciplinary hydropower profession is well aware of the problems to be addressed. The expertise exists to mitigate the known impacts, in order to achieve an acceptable balance, and research continues.

Changes relating to sedimentation, fauna, flora and water quality, for example, are predicted with increasing precision by the profession. If considered by experts early in the planning process, these changes can be managed or even turned to social and/or environmental advantage.

All modern hydropower projects include a comprehensive environmental impact assessment at the early stages of investigation. Environmental management programmes ensure that mitigation and enhancement measures continue throughout the operating life of the project.

Small versus large

Conventionally a distinction is drawn between small and large hydro plants but it is impossible for many governments and other authorities to keep national records on very small (often privately-owned) schemes.

There is a growing misconception relating to renewable technology and ‘green’ energy, whereby small projects are perceived as having lower impacts.

Recent legislation has differentiated between projects with capacities above or below 10 MW, favouring smaller projects. There is no scientific or technical justification for this, and it may lead to greater environmental impacts.

Research has been conducted on this subject by a number of organisations, including the World Bank, and a paper was recently presented by a member of the IHA Environment Committee (Egré, 1999) pointing out that valid comparisons compare impacts per unit of output. The impacts of a single large project and its distribution system should be compared with the cumulative impacts of several small projects yielding the same power output and level of service.

In the case of hydropower, small projects generally require a far greater total reservoir area than a single large project, to provide the same stored water volume. This is not to say that either end of the capacity scale has the advantage.

In the case of multipurpose development, where the reservoir water will have several uses in addition to passing through a powerplant of a certain size, the dimensions of the reservoir will not be purely dependent on the use for power.

The most fundamental influences on the total costs and benefits of hydropower projects are the site-specific conditions, and not the scale of the project.

Economic aspects

From the point of view of economics, it is clear that hydropower requires a substantial initial investment cost, which can be a deterrent to potential developers. However this should always be balanced against the long life and low operating costs of hydro plants, and the fact that there is no consumption of fuel for energy production. Globally, in comparison with other plants, and considering the quality of the energy produced, the balance shows a clear advantage for hydropower.

For some years, the idea has been developing to take into consideration the external benefits and costs. On the basis of the full costs throughout the lifetime of the various electricity generation options, hydropower (if available) appears to have the greatest advantage.

Conclusions

It was concluded at the 17th Congress of the World Energy Council in Houston in 1998 that clear priority should be given to the development and use of appropriate renewable energies with the aim of limiting emissions resulting from the use of fossil fuels.

This declaration supports the following recommendations of the International Hydropower Association:

- the remaining hydro potential should be developed to the maximum possible extent, provided it is implemented in a technically, economically, environmentally and socially acceptable way;

- hydropower development should go hand-in-hand (rather than in competition) with further development of other renewable sources of energy;
- the cost of the kWh produced by a hydro plant is competitive. The initial investment is substantial but the life of the plant is long (about 100 years). This is part of the sustainable character of hydropower. The operating cost is low. Financial solutions will have to be found to facilitate the initial investment in hydropower in developing countries without requiring the owners to give guarantees that they cannot afford;
- the state cannot totally entrust hydropower development to a private organisation (as is the case for a thermal plant). It should be involved in the planning and development process;
- it has been demonstrated in many countries that hydroelectric potential is a form of potential wealth and sustainable development. Its implementation, with a strong backing of the state, contributes to the well-being of society.

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DEFINITIONS

This chapter is restricted to that form of hydraulic energy that results in the production of electrical energy as a result of the natural accumulation of water in streams or reservoirs being channelled through water turbines. Energy from tides, waves and marine energy is reported in Chapters 14, 15 and 17.

Annual generation and capacity attributable to pumped storage is excluded. Where such installations produce significant energy from natural run-off, the amount is included in the total for annual generation.

It must be recognised that for some countries it is not possible to obtain comprehensive data corresponding exactly to the definitions. This particularly applies to small hydro schemes, many of which are owned by small private generators. Also, not all countries use the same criteria for the distinction between small and large hydro. In this Survey, small hydro mainly applies to schemes of less than 10 MW. However, some countries and other sources of data make the distinction between small and large schemes at other levels.

In the tables, the following definitions apply:

Gross theoretical capability is the annual energy potentially available in the country if all natural flows were turbined down to sea level or to the water level of the border of the country (if the water course extends into another country) with 100% efficiency from the machinery and driving water-works. Unless otherwise stated in the notes, the figures have been estimated on the basis of atmospheric precipitation and water run-off.

Gross theoretical capability is often difficult to obtain strictly in accordance with the definition, especially where the data are obtained from sources outside the WEC. Considerable caution should therefore be exercised when using these data.

Where the gross theoretical capability has not been reported, it has been estimated on the basis of the technically exploitable capability, assuming a capacity factor of 0.40. Where the technically exploitable capability is not reported, the value for economically exploitable capability has been adopted, preceded by a ">" sign.

Technically exploitable capability is the amount of the gross theoretical capability that can be exploited within the limits of current technology.

Economically exploitable capability is the amount of the gross theoretical capability that can be exploited within the limits of current technology under present and expected local economic conditions. The figures may or may not exclude economic potential that would be unacceptable for social or environmental reasons.

Capacity in operation is the total of the rated capacities of the electric generating units that are installed at all sites which are generating, or are capable of generating, hydro-electricity.

Actual generation is the net output (excluding pumped-storage output) in the specified year.

Probable annual generation is the total probable net output of electricity at the project sites, based on the historical average flows reaching them (modified flows), net heads, and the plant capacities reported, making allowance for plant and system availability.

Capacity planned refers to all sites for which projects have been proposed and plans have been drawn up for eventual development, usually within the next 10 years.

Capacity under construction and planned relates to all units not operational but which were under construction, ordered or about to be ordered at the end of 1999.

Table 7.1 Hydropower: capability at end-1999

[Excel files]	Gross theoretical capability	Technically exploitable capability	Economically exploitable capability
		TWh/yr	
Algeria	12	5	
Angola	150	90	65
Benin	2	1	
Burkina Faso	1	N	N
Burundi	> 6	> 1	1
Cameroon	294	115	103
Central African Republic	7	3	
Chad	N	N	
Comoros			
Congo (Brazzaville)	> 125	> 50	
Congo (Democratic Rep.)	1 397	774	< 419
Côte d'Ivoire	46	> 12	12
Egypt (Arab Rep.)	> 125	> 50	50
Equatorial Guinea			
Ethiopia	650	> 260	260
Gabon	200	80	33
Ghana	17	11	7
Guinea	26	19	15
Guinea-Bissau	1	N	N
Kenya	> 30	9	
Lesotho	5	2	
Liberia	28	11	
Madagascar	321	180	49
Malawi	15	6	
Mali	> 12	> 5	
Mauritania			
Mauritius	N	N	
Morocco	12	5	4
Mozambique	50	38	32
Namibia	9	9	9
Niger	> 3	> 1	1
Nigeria	43	32	30
Réunion			
Rwanda	1	N	
São Tomé & Príncipe			
Senegal	11	4	2
Sierra Leone	17	7	
Somalia	2	1	
South Africa	73	11	5
Sudan	48	19	2
Swaziland	4	1	N
Tanzania	39	20	2
Togo	4	2	
Tunisia	1	N	N
Uganda	> 18	> 7	
Zambia	52	29	11
Zimbabwe	19	18	
Total Africa	**> 3 876**	**> 1 888**	
Belize	1	N	N
Canada	1 289	951	523
Costa Rica	223	43	
Cuba	5	2	
Dominica	N	N	N
Dominican Republic	50	9	6
El Salvador	7	5	2

Table 7.1 Hydropower: capability at end-1999 contd.

	Gross theoretical capability	Technically exploitable capability	Economically exploitable capability
		TWh/yr	
Greenland	470	14	
Grenada	N	N	N
Guadeloupe			
Guatemala	55	22	
Haiti	4	1	N
Honduras	16	6	
Jamaica	N	N	N
Mexico	154	64	38
Nicaragua	33	10	7
Panama	26	> 12	12
Puerto Rico			
St Vincent & the Grenadines			
United States of America	4 485	529	376
Total North America	**6 818**	**> 1 668**	
Argentina	172	130	
Bolivia	178	126	50
Brazil	3 040	1 488	811
Chile	227	162	
Colombia	1 000	200	140
Ecuador	115	32	16
French Guiana			
Guyana	61	> 25	25
Paraguay	111	85	68
Peru	1 578	> 260	260
Surinam	32	13	
Uruguay	32	10	
Venezuela	345	261	130
Total South America	**6 891**	**> 2 792**	
Afghanistan			
Armenia	22	8	6
Azerbaijan	44	16	7
Bangladesh	5	2	
Bhutan	263	70	56
Cambodia	208	83	24
China	5 920	1 920	1 260
Cyprus	59	24	
Georgia	139	68	32
India	2 638	660	
Indonesia	2 147	402	40
Japan	718	136	114
Kazakhstan	163	62	27
Korea (Democratic People's Rep.)			
Korea (Republic)	52	26	19
Kyrgyzstan	163	99	55
Laos	233	63	42
Malaysia	230	123	
Mongolia	56	22	
Myanmar (Burma)	877	130	
Nepal	727	158	147
Pakistan	210	130	130
Philippines	47	20	18
Sri Lanka	11	8	7
Taiwan, China	103	14	12

Table 7.1 Hydropower: capability at end-1999 contd.

	Gross theoretical capability	Technically exploitable capability	Economically exploitable capability
		TWh/yr	
Tajikistan	527	> 264	264
Thailand	56	19	18
Turkey	413	216	122
Turkmenistan	24	5	2
Uzbekistan	88	27	15
Vietnam	300	100	80
Total Asia	**16 443**	**> 4 875**	
Albania	40	15	6
Austria	75	> 56	56
Belarus	7	3	2
Belgium	1	N	N
Bosnia-Herzogovina	69	24	19
Bulgaria	26	15	12
Croatia	10	9	8
Czech Republic	12	4	
Denmark	N	N	N
Estonia	2	N	N
Faroe Islands	1	N	N
Finland	47	> 20	20
FYR Macedonia	9	6	
France	200	72	70
Germany	120	26	20
Greece	80	15	12
Hungary	7	5	
Iceland	184	64	40
Ireland	1	1	1
Italy	340	105	65
Latvia	7	6	5
Lithuania	5	3	2
Luxembourg	N	N	N
Moldova	2	1	1
Netherlands	1	N	N
Norway	600	200	180
Poland	23	14	7
Portugal	33	25	20
Romania	56	36	17
Russian Federation	2 800	1 670	852
Serbia, Montenegro	68	> 27	27
Slovakia	10	> 7	6
Slovenia	13	9	8
Spain	138	70	41
Sweden	176	130	90
Switzerland	144	41	35
Ukraine	45	24	19
United Kingdom	40	3	1
Total Europe	**5 392**	**> 2 706**	
Iran (Islamic Rep.)	368	88	48
Iraq	225	90	67
Israel	88	< 35	
Jordan	N	N	N
Lebanon	2	1	
Syria (Arab Rep.)	5	4	4
Total Middle East	**688**	**< 218**	

Table 7.1 Hydropower: capability at end-1999 contd.

	Gross theoretical capability	Technically exploitable capability	Economically exploitable capability
		TWh/yr	
Australia	264	> 30	30
Fiji	3	1	
French Polynesia	N	N	N
New Caledonia			
New Zealand	152	77	40
Palau			
Papua New Guinea	175	123	37
Solomon Islands	2	> 1	
Western Samoa	N	N	
Total Oceania	**596**	**> 232**	
TOTAL WORLD	**> 40 704**	**> 14 379**	

Notes:
1. A quantification of hydropower capability is not available for Comoros, Equatorial Guinea, Mauritania, Réunion, São Tomé & Principe, Guadeloupe, Puerto Rico, St Vincent & the Grenadines, French Guiana, Afghanistan, Korea (Democratic People's Republic), New Caledonia and Palau
2. As the data available on economically exploitable capability do not cover all countries, regional And global totals are not shown for this category
3. Sources: WEC Member Committees, 2000/2001; *Hydropower & Dams World Atlas 2001*, supplement to The International Journal on Hydropower & Dams, Aqua~Media International; estimates by the editors

Table 7.2 Hydropower: status of development at end-1999 (all schemes)

Excel files

	In operation		Under construction		Planned	
	Capacity	Actual generation in 1999	Capacity	Probable annual generation	Capacity	Probable annual generation
	MW	GWh	MW	GWh	MW	GWh
Algeria	275	203				
Angola	290	1 000	780			
Benin	67	170				
Burkina Faso	32	125				
Burundi	43	98				
Cameroon	725	2 423				
Central African Republic	19	81				
Chad						
Comoros	1	2				
Congo (Brazzaville)	89	352				
Congo (Democratic Rep.)	2 440	5 350	4			
Côte d'Ivoire	614	1 800				
Egypt (Arab Rep.)	2 810	11 450	65			
Equatorial Guinea	1	2				
Ethiopia	398	1 600	297			
Gabon	168	830				
Ghana	1 072	5 169			400	1 000
Guinea	127	414				
Guinea-Bissau						
Kenya	600	3 294	140			
Lesotho	79	200				
Liberia						
Madagascar	105	510	42			
Malawi	283	800	64			
Mali	50	243	104			
Mauritania	61	26	30			
Mauritius	59	30				
Morocco	1 175	817	98			
Mozambique	2 180	11 548				
Namibia	240	854				
Niger						
Nigeria	1 938	6 986	64			
Réunion	125	486				
Rwanda	27	110				
São Tomé & Príncipe	6	20				
Senegal			66			
Sierra Leone	4	24	70			
Somalia	5					
South Africa	653	726				
Sudan	303	1 000				
Swaziland	41	190			19	
Tanzania	377	1 748	180			
Togo	4	6				
Tunisia	64	90	2			
Uganda	276	1 600	320			
Zambia	1 674	7 782	60			
Zimbabwe	670	3 000	85			
Total Africa	**20 170**	**73 159**	**2 471**			
Belize	25	80				
Canada	66 954	341 312	1 566	8 057	2 600	13 376
Costa Rica	1 233	5 085	163			
Cuba	60	110				
Dominica	8	32				

Table 7.2 Hydropower: status of development at end-1999 (all schemes) contd.

	In operation		Under construction		Planned	
	Capacity	Actual generation in 1999	Capacity	Probable annual generation	Capacity	Probable annual generation
	MW	GWh	MW	GWh	MW	GWh
Dominican Republic	402	1 380				
El Salvador	388	1 759				
Greenland	30	165				
Grenada						
Guadeloupe	5	15				
Guatemala	827	3 500				
Haiti	70	280				
Honduras	433	2 142	55			
Jamaica	24	120				
Mexico	9 390	32 005			2 517	7 748
Nicaragua	111	409	1			
Panama	551	3 062	135			
Puerto Rico	85	260				
St Vincent & the Grenadines	6	25				
United States of America	79 511	319 484	17		434	
Total North America	**160 113**	**711 225**	**1 937**			
Argentina	8 981	21 598	960	5 060	216	1 390
Bolivia	330	1 688	126			
Brazil	57 517	285 603	10 845	53 201	16 475	80 820
Chile	3 900	13 379	688			
Colombia	8 556	33 165	800			
Ecuador	1 707	7 156				
French Guiana	116	280				
Guyana	1	3				
Paraguay	7 390	51 910			3 400	16 630
Peru	2 900	13 700	294			
Surinam	180	1 435				
Uruguay	1 534	5 499				
Venezuela	13 165	60 600	2 160	11 900	11 260	41 400
Total South America	**106 277**	**496 016**	**15 873**			
Afghanistan	292	478				
Armenia	1 000	1 500				
Azerbaijan	953	2 050				
Bangladesh	230	750				
Bhutan	345	1 836	1 102			
Cambodia	1	5	12			
China	65 000	204 300	35 000			
Cyprus	1	N				
Georgia	2 800	6 800	700			
India	22 083	82 237	15 400			
Indonesia	4 196	13 000	565			
Japan	27 229	84 500	997	1 851		
Kazakhstan	2 200	7 200				
Korea (Dem. People's Rep.)	5 000	22 500				
Korea (Republic)	1 515	2 814				
Kyrgyzstan	2 949	12 138	2 260			
Laos	415	1 000	210			
Malaysia	2 050	7 400	55			
Mongolia	3	5	12			
Myanmar (Burma)	340	742	665			
Nepal	389	1 475	289	937		
Pakistan	4 826	21 500	1 634	7 631		

Table 7.2 Hydropower: status of development at end-1999 (all schemes) contd.

	In operation		Under construction		Planned	
	Capacity	Actual generation in 1999	Capacity	Probable annual generation	Capacity	Probable annual generation
	MW	GWh	MW	GWh	MW	GWh
Philippines	2 304	5 048	855		650	
Sri Lanka	1 142	4 500	88			
Taiwan, China	4 422	8 917	150	541	1 720	3 509
Tajikistan	4 054	16 120	4 600			
Thailand	2 923	3 534	1 011	437	1 743	1 729
Turkey	10 820	34 678	4 057	13 368	19 715	69 809
Turkmenistan						
Uzbekistan	1 710	6 538	244			
Vietnam	2 884	13 936	1 265			
Total Asia	**174 076**	**567 501**	**71 171**			
Albania	1 440	5 283	100			
Austria	11 647	41 727	34	194		
Belarus	7	20				
Belgium	97	338				
Bosnia-Herzogovina	1 624	8 900				
Bulgaria	1 803	3 300	160			
Croatia	2 045	6 487			80	300
Czech Republic	907	1 892				
Denmark	11	31				
Estonia	N	5				
Faroe Islands	31	77				
Finland	2 980	12 500			85	532
FYR Macedonia	434	1 300	80			
France	25 335	77 500			50	85
Germany	4 897	21 539				
Greece	3 080	5 000	477			
Hungary	48	181				
Iceland	1 000	6 043	90	430	800	5 300
Ireland	230	839	2	7		
Italy	16 546	47 054	86			
Latvia	1 517	2 750	22	50		
Lithuania	101	413				
Luxembourg	33	106				
Moldova	56	300				
Netherlands	37	90			9	47
Norway	27 528	121 824	10	53	2 334	6 993
Poland	785	2 166				
Portugal	4 298	13 000	240	343		
Romania	5 795	17 857	1 027	2 829	257	1 059
Russian Federation	44 000	160 500	5 115			
Serbia, Montenegro	2 864	12 000	50			
Slovakia	1 375	4 857				
Slovenia	855	3 740	114	182	283	925
Spain	15 580	28 240	60	180	1 000	2 750
Sweden	16 192	70 823				
Switzerland	13 230	37 377	1 250	319	42	68
Ukraine	4 483	14 244				
United Kingdom	1 477	5 352			58	187
Total Europe	**214 368**	**735 655**	**8 917**			
Iran (Islamic Rep.)	2 007	5 000	9 045	3 917	1 714	7 505
Iraq	910	600				
Israel	7	10			2	2
Jordan	7	14				

Table 7.2 Hydropower: status of development at end-1999 (all schemes) contd.

	In operation		Under construction		Planned	
	Capacity	Actual generation in 1999	Capacity	Probable annual generation	Capacity	Probable annual generation
	MW	GWh	MW	GWh	MW	GWh
Lebanon	274	750	76			
Syria (Arab Rep.)	980	2 060	630			
Total Middle East	**4 185**	**8 434**	**9 751**			
Australia	7 609	16 797				
Fiji	79	418				
French Polynesia	47	188				
New Caledonia	78	393				
New Zealand	5 176	23 287	62	220	175	1 045
Palau	10	30				
Papua New Guinea	219	746				
Solomon Islands	N	1				
Vanuatu	1	4	1			
Western Samoa	12	54				
Total Oceania	**13 231**	**41 918**	**63**			
TOTAL WORLD	**692 420**	**2 633 908**	**110 183**			

Notes:
1. A quantification of the status of hydropower development is not available for Chad, Guinea-Bissau, Liberia, Niger, Grenada and Turkmenistan
2. As the data available on the probable annual generation of capacity under construction, and on planned capacity and generation, do not cover all countries, regional and global totals are not shown for these categories
3. Data on planned capacity and generation are as reported by WEC Member Committees
4. Sources: WEC Member Committees, 2000/2001; H*ydropower & Dams World Atlas 2001*, supplement to The International Journal on Hydropower & Dams, Aqua~Media International; *Energy Statistics Yearbook 1997*, United Nations; national and international published sources; estimates by the editors

Table 7.3 Hydropower: status of development at end-1999 for small-scale schemes (<10MW)

[Excel files]

	Economically exploitable capability	In operation		Under construction and planned	
		Capacity	Actual generation in 1999	Capacity	Probable annual generation
	GWh/yr	MW	GWh	MW	GWh
Africa					
Ghana	1				
South Africa	350	15	53		
Swaziland		7			
North America					
Canada	41 157	865	4 410	100	570
Mexico		296	1 068		
United States of America		2 537	7 456	52	
South America					
Argentina		82	278		
Brazil		1 484	7 280	1 639	7 897
Chile			5		
Asia					
Japan		3 449		87	393
Nepal		13		1	
Pakistan	1 400	6	34	67	382
Taiwan, China	552	61	398	15	29
Thailand	80	55	123	73	344
Turkey	555	138	331	436	2 091
Europe					
Belgium		66	210		
Croatia	60	31	105		
Czech Republic		283	705		
Denmark		11	31		
Estonia		N	5		
Finland	300	324	978		
France		2 016	7 584		
Hungary		9	64		
Iceland		43	231		
Ireland		53	203	2	7
Italy		2 200	8 602		
Latvia	150	2	15	1	3
Lithuania		9	25		
Netherlands		N			
Norway	14 000	945		58	257
Poland	1 600	32	121		
Portugal	1 850	280	1 100	30	90
Romania	600	273	433		
Slovakia		55	202		
Slovenia	1 115	80	338	1	4
Spain	7 000	1 300	3 790	720	2 230
Sweden		890			
Ukraine		78	260		
Middle East					
Iran (Islamic Rep.)		15	37	5	24
Israel		7	10	2	
Jordan	87	7	14		
Oceania					
New Zealand		78	370		

Notes:

1. The data on small-scale schemes are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Sources: WEC Member Committees, 2000/2001

COUNTRY NOTES

The Country Notes on hydro have been compiled by the editors, drawing principally upon the 2000 and 2001 editions of the *Hydropower & Dams World Atlas*, supplement to *The International Journal on Hydropower & Dams*, Aqua~Media International, together with information provided by WEC Member Committees in 2000/2001 and various national published sources.

ARGENTINA

Hydropower & Dams World Atlas quotes Argentina's gross theoretical hydropower potential as 172 000 GWh/year; its technically feasible potential is put at 130 000 GWh/year, of which about 23% has so far been exploited.

Hydro output in 1999 was 21.6 TWh, but this was an exceptionally depressed level, owing to a severe drought in the regions of Comahue and Patagonia during 1998/1999. With an installed capacity of nearly 9 000 MW at end-1999, normal hydro output would be around 30 TWh/year.

A substantial portion of Argentina's hydro capacity is accounted for by its 50% share in two bi-national schemes: Salto Grande (installed capacity 1 890 MW), shared with Uruguay, and Yacyretá (3 100 MW), shared with Paraguay. The latter plant is currently operating at a reduced head, with its capacity restricted to 1 800 MW.

The total amount of hydro capacity under construction at the end of 1999 was 960 MW, with a further 216 MW at the planning stage.

BOLIVIA

Bolivia has a considerable hydro potential, its technically feasible potential being assessed at 126 TWh/year, of which 50 TWh/year is considered to be economically exploitable. Only a minute proportion of the potential has been harnessed so far – 1999 hydro capacity was 330 MW, with an output of about 1.7 TWh.

A 126 MW expansion of a privately-owned plant at Corani was nearing completion in 1999, whilst the approximately 700 MW of hydro capacity planned includes major plants at San José (126 MW), Misicuni (120 MW) and Palillada (80 MW).

BRAZIL

Hydro-electric power is one of Brazil's principal energy assets: the republic has by far the largest hydropower resources on the continent, with an economically exploitable capability of over 800 TWh/year. Hydro output in 1999 was over 285 TWh, implying that about 35% of this potential has been harnessed so far. Hydro provides most of Brazil's electricity: 88% of 1999 generation.

Hydro generating capacity more than doubled between 1980 and 1999, partly through gradual commissioning of the huge Itaipú scheme (total capacity 12 600 MW), which came into operation between 1984 and 1991. Brazil shares Itaipú's output with its neighbour Paraguay, which sells back to Brazil the surplus power remaining after its own electricity needs have been satisfied.

At the end of 1999, Brazil had nearly 11 GW of hydro capacity under construction: the projects include a major (4 125 MW) extension of capacity at Tucuruí, new plants at Porto Primavera (1 814 MW), Itá (1 450 MW), Machadinho (1 140 MW) and Lajeado (850 MW), plus two additional 700 MW units at Itaipú. A further 16 GW of capacity is planned for future development.

Within the overall picture outlined above, small-scale hydro (since 1998, defined in Brazil as plants with a capacity of 1 to 30 MW) has a technically exploitable capability of about 25 TWh/year, nearly 30% of which had been exploited by capacity installed as at end-1999. The 1 500 MW of small-scale hydro currently in place will be augmented by 1 600 MW additional capacity which is under construction or planned. The Federal Government provides a number of financial incentives to owners/developers of small-scale hydro schemes.

CAMEROON

The technically exploitable hydro capability is the fourth largest in Africa but the current level of utilisation of this potential is, like that in other hydro-rich countries in the continent, very low. Within a total hydro capacity of 725 MW, Cameroon's major stations are Song Loulou (398 MW) and Edéa (265 MW). New hydro plants are planned for a number of other sites but no schemes are presently under construction.

CANADA

Canada possesses enormous hydropower potential, with an economically exploitable capability second only to that of Brazil in the whole of the Western Hemisphere. Hydro-electricity generation in 1999 represented 65% of the assessed economic potential of 523 TWh/year. About 61% of Canada's electricity generation in 1999 was furnished by hydro plants, which produced some 341 TWh.

At the end of 1999, 1 566 MW of hydro-electric generating capacity was under construction and 2.6 GW additional capacity was planned for future development. Included in the latter figure are hydro projects at Gull Island, Labrador (1 700 MW, completion scheduled for 2008), in Manitoba (860 MW), and in Alberta (40 MW, due 2003).

Installed capacity of hydro plants of less than 10 MW capacity totalled 865 MW at end-1999; 100 MW is planned for future installation. Under the Renewable Energy Strategy released by the Department of Natural Resources in October 1996, an accelerated tax write-off is provided for certain classes of equipment, including hydro-electric installations with a planned average annual generating capacity not exceeding 15 MW.

CHILE

There is substantial hydropower potential, with the technically exploitable capability estimated at about 162 TWh/year, of which about 12% has so far been exploited. Hydro output in 1999 was 13.4 TWh, equivalent to about 35% of Chile's total electricity generation. Although hydro's share has been falling in recent years (in 1994 it was 69%), the 1999 level was to some extent distorted by an exceptionally severe drought.

The largest hydro scheme currently in hand is the 570 MW Ralco project, which was originally scheduled for completion in 2002. However, construction was halted in 1999 by a court order on behalf of local inhabitants. A relocation scheme for the Pehuenche Indians affected was agreed in early 2000 and construction got under way again.

CHINA

China’s hydro-electric resources are vast, however measured: its gross theoretical potential approached 6 000 TWh/year, while its economically feasible potential has been assessed as some 290 000 MW (1 260 TWh/year) – in both instances, far larger than that of any other country in the world. Current hydro output exceeds 200 TWh/year, contributing about 17% to the republic’s electricity generation.

The total amount of hydro capacity under construction is about 35 000 MW: as large as the combined current building programme of the next three largest hydro developers (Brazil, India and Iran). By far the largest hydro scheme under way is the Three Gorges Project (18 200 MW), scheduled for commissioning between 2003 and 2009. Ertan (3 300MW), Xiaolangdi (1 800 MW) and several other hydro schemes with individual capacities exceeding 1 000 MW have been brought into operation recently or are approaching completion.

More than 50 GW of pure hydro-electric capacity is planned for construction, including five very large schemes: Xiluodu (14 400 MW) and Xiangjiaba (6 000 MW) in the Yangtze river basin, Nuozadu (5 000 MW) and Xiaowan (4 200 MW) in the Lancang basin and Longtan (4 200 MW) in the Hongshui basin.

China has about 4 100 MW of pumped-storage capacity, with 1 900 MW under construction and 7-8 GW planned.

COLOMBIA

The theoretical potential for hydropower is very large, being estimated to be in the order of 1 000 TWh/year, of which 20% is classed as technically feasible. The economically exploitable capability has been evaluated as 140 TWh/year: hydro output in 1999 represented about 25% of this potential, and accounted for around 70% of Colombia’s electricity generation.

Two large hydro schemes are under construction – Porce II (392 MW) and La Miel I (400 MW). The former was originally scheduled for completion during 1999 but was delayed by two years owing to a change in the main contractor. La Miel I is due to come into service in 2002-2003.

CONGO (DEMOCRATIC REP.)

The assessed potential for hydropower is by far the highest in Africa, and one of the highest in the world. The gross theoretical potential is almost 1 400 TWh/year, of which about 55% is regarded as technically feasible. The current level of hydro-electric output is equivalent to less than 1% of this latter potential. Hydro provides virtually the whole of the country’s electricity.

The national power authority SNEL has 16 hydro plants, with a total rated capacity of 2 426 MW; its largest stations are Inga 1 (1 424 MW) and Inga 2 (351 MW). The effective capacity at SNEL’s hydro plants has recently been less than half their rated level, owing to problems in maintenance and refurbishment.

A huge scheme (Grand Inga or Inga 4) exists for the installation of up to 52 generators of 750 MW each, to supply electricity to Egypt and South Africa via new long-distance transmission lines. The construction of a first-stage plant of around 8 000 MW is envisaged by 2010, but implementation would depend upon success in arranging finance, together with a favourable national and international political climate.

COSTA RICA

For a country with a surface area of only 51 100 km^2, Costa Rica has a surprisingly large hydro-electric potential. Its gross theoretical potential is estimated at 223 TWh/year, within which 43 100 GWh/year has been assessed as technically feasible. Hydro output in 1999 was 5 085 GWh, only about 12% of the technical potential.

Aggregate hydro capacity was 1 233 MW at end-1999, equivalent to about 75% of Costa Rica's generating capacity. Several new hydro plants are under construction or planned: Angostura (177 MW) was completed during 2000, whilst Pirris (128 MW) is scheduled to come on line in 2003. Guayabo (234 MW) is at the design stage, with completion envisaged for 2006.

CZECH REPUBLIC

The overall potential for all sizes of hydropower is quite modest (technically exploitable capability: 3 978 GWh/year). Total hydro-electricity output in 1999 was 1 892 GWh, representing 48% of the technical potential. Hydropower furnishes about 3% of the republic's electricity generation.

A relatively high proportion (nearly 40%) of the technically exploitable capability is classified as suitable for small-scale schemes; installed capacity in this category at the end of 1999 was 283 MW, equivalent to about 31% of the Czech Republic's hydro capacity. Actual generation from small-scale schemes in 1999 accounted for 37% of hydro output.

Small hydro schemes are covered by a state programme for the promotion of better utilisation of renewable energy resources and cogeneration. Under this programme, projects seeking state support must have a payback period of less than 12 years, the efficiency of newly-installed turbines in small hydropower plants must be at least 80% and they should be used in through-flow plants under automatic operation. In addition to the state support programme, a free consulting service on small-scale hydro plants has been organised by the Czech Power Company (CEZ) and the Association of Entrepreneurs for Energy Fuels Utilisation.

ETHIOPIA

There are enormous resources for hydro generation, the gross theoretical potential (650 TWh/year) being the second largest in Africa. The technically feasible potential is stated to be 260 TWh/year, of which 10% represents the potential for small-scale hydro installations. Hydro output in 1999 was about 1.6 TWh, a minute fraction of the assessed potential. Currently, hydro-electricity provides around 97% of Ethiopia's electricity.

At the end of 1999, 398 MW of hydro capacity was in place and a further 297 MW was under construction: the principal sites were Gilgel Gibe (184 MW) and Tis Abbay II (70 MW).

FRANCE

France is Western Europe's second largest producer of hydro-electricity, after Norway (and excluding Russia). The country's technically feasible capacity has already been exploited: no hydro plants are under construction and only about 50 MW of new capacity is planned.

At the end of 1999, the total installed capacity of small-scale (<10 MW) plants was just over 2 000 MW. There were, on the other hand some 280 hydro plants of greater than 10 MW, with an aggregate installed capacity of about 23 000 MW.

GHANA

There are 17 potential hydro sites, of which only Akosombo (912 MW) and Kpong (160 MW) have so far been developed. The next most attractive hydro project is the 400 MW Bui dam on the Black Volta river, which is at a preparatory stage.

Electricity generation in Ghana is a responsibility of the Volta River Authority, established in 1961. The average annual output of its two existing hydro stations (6 000 GWh) is equivalent to about 54% of Ghana's technically exploitable hydro capability.

After many years of low rainfall, the Volta Reservoir received substantially above-average inflows during 1999, enabling output from Akosombo and Kpong to be raised from 3 830 GWh in 1998 to 5 169 GWh in 1999.

ICELAND

Together with its geothermal resources, Iceland's hydropower potential represents virtually its only indigenous source of commercial primary energy. Gross theoretical potential of 184 TWh/year includes 40 TWh of economically harnessable output. Hydro-electricity production in 1999 was just over 6 TWh, implying that about 15% of this economic potential has been developed. Hydro capacity at present under construction will add 90 MW to the existing installed capacity of 1 000 MW. A further 800 MW of hydro capacity is planned.

The technically exploitable capability of small-scale hydro plants is reported to be 12.3 TWh/year, equivalent to about 19% of the level for total hydro. Installed capacity of small hydro at end-1999 was 43 MW, or 4.3% of total hydro capacity.

Hydropower provides 18% of Iceland's primary energy supply and 84% of its electricity generation.

INDIA

India's gross theoretical hydropower potential (2 638 TWh/yr) and theoretically feasible potential (660 TWh/yr) are amongst the highest in the world. The public utilities' total installed hydro-electric capacity exceeded 22 000 MW by the end of 1999 and rose by 1 100 MW during 2000. Hydro output in 1999 was 82.2 TWh, equivalent to 17.5% of India's public sector electricity generation. According to the 1997 Energy Statistics Yearbook published by the United Nations Statistics Division, non-utility (self-producers) generation of hydro-electricity has so far been on a very small scale; however, several IPP hydro plants are now under construction.

Hydropower & Dams World Atlas 2001 reports that a total of some 15 GW of hydro capacity is under construction and a further 25 GW is planned. There are at least 17 plants of over 300 MW capacity being built, of which the largest are Nathpa Jhakri (1 500 MW), Sardar Sarovar (1 200 MW), Tehri Stage I (1 000 MW) and Narmada Sagar (1 000 MW).

Over 1 500 small-scale hydro plants are in operation, with an aggregate installed capacity of about 400 MW; a further 365 MW of small-scale capacity is under construction in more than 80 schemes. Over 1 000 schemes, totalling around 500 MW in capacity, are at the planning stage.

INDONESIA

At some 2 150 TWh/year, Indonesia's gross theoretical hydro potential is the third largest in Asia. Its technically exploitable capability is just over 400 TWh/year, of which about 10% is considered to be economically exploitable. Hydro output in 1999 was about 13 TWh, indicating the possible scope for further development within the feasible potential. Hydro provides approximately 11% of Indonesia's electricity supplies.

Hydropower & Dams World Atlas 2001 reports that about 565 MW of hydro-electric generating capacity is under construction and that another six hydro projects (all in the range of 330-400 MW) are planned for early implementation.

ITALY

Italy's theoretical resource base for hydropower is one of the largest in Western Europe, and its economically exploitable capability is virtually the same as that of France. Hydro-electric power has not, however, been developed to the same degree as in the case of its neighbour: about 72% of the assessed economic potential of 65 000 GWh/year has so far been harnessed. At the end of 1999, 86 MW of hydro generating plant was reported to be under construction.

The installed capacity of small-scale plants at end-1999 was some 2 200 MW, representing about 13% of the overall hydro capacity of 16 546 MW.

JAPAN

Japan has a vast potential for hydro generation: its gross theoretical capability is about 718 TWh/year, of which 136 TWh is regarded as technically exploitable. Hydro generation (excluding output from pumped-storage schemes) in 1999 was approximately 85 TWh, equivalent to 62% of the technical potential and providing about 9% of Japan's electricity.

At end-1999, just under 1 000 MW of hydro capacity was under construction. Most of the sites suitable for the installation of large-scale conventional hydro-electric plants have now been developed. The great majority of the larger hydro projects presently under construction or planned in Japan are pumped-storage schemes.

The technically exploitable capability for small-scale hydro developments is assessed at 47 TWh/year, a relatively high proportion (34%) of the total hydro level. Developed small-hydro capacity at end-1999 was about 3.4 GW, equivalent to 12.7% of total hydro capacity.

LATVIA

Although its hydro potential is quite modest – a gross theoretical capability of only about 7 TWh/year – Latvia is of interest for its rapid development of small-scale hydro plants in recent years. In 1996 there were only 16 small hydro-stations, which generated 4.5 GWh. By 1999, the number in service had grown to 53 and annual generation to 15 GWh, while a further 15 plants were under construction.

MADAGASCAR

Madagascar has a considerable land area (greater than that of France, for example) and heavy annual rainfall (up to 3 600 mm). Consequently the potential for hydropower is correspondingly large: gross theoretical potential is put at 321 TWh/year, within which the technically feasible potential is 180 TWh/year. With current installed capacity standing at

105 MW and annual hydro output about 510 GWh, the island's hydro capability has scarcely begun to be utilised. A small amount of hydro capacity (42 MW) is under construction.

MALAYSIA

There is a substantial potential for hydro development, with a total technically feasible potential of about 123 TWh/year, most of which is located in Sarawak (87 TWh/year) and Sabah (20 TWh/year); a considerable proportion of Peninsular Malaysia's technically feasible potential of 16 TWh/year has already been developed. At end-1999, Malaysia possessed 2 050 MW of hydro capacity: according to *Hydropower & Dams World Atlas 2001*, 55 MW of capacity was under construction and 625 MW was planned.

Construction of the 2 400 MW Bakun hydro project in Sarawak was halted by the Government in 1997 as an austerity measure, but the Government began inviting bids for the project in December 2000.

MEXICO

With a gross theoretical hydro capability of around 155 TWh/yr and a technically exploitable capability of 64 TWh/yr, Mexico possesses a considerable hydro-electric potential. Its economically exploitable capability – defined in the case of Mexico as covering projects with approved feasibility studies, plus present installed capacity, with an assumed availability factor of 35% - is currently assessed as 38.5 TWh/yr. Using the same availability assumption, the end-1999 installed hydro capacity of 9 390 MW would have an electricity output equivalent to about 75% of the economically feasible potential.

Mexico's 1999 hydro-electric output of 32 TWh accounted for about 19% of total net generation of electricity.

There was no additional hydro capacity reported to be under construction at end-1999, but just over 2 500 MW is planned for future development. The principal plants involved are:

- El Cajon (680 MW), scheduled for completion in 2007;
- La Parota (765 MW), planned for 2008;
- Copainalá (210 MW), also due in 2008.

A major extension of the Manuel Moreño Torres (Chicoasén) hydro plant is planned for completion in 2003; this will add three units, with a total incremental capacity of 900 MW.

At end-1999, installed capacity of small-scale hydropower (Comisión Federal de Electricidad only) totalled 296 MW; output during the year was 1 068 GWh. The use of small hydro plants is being promoted among private investors; a study carried out by the National Energy Savings Commission in the states of Veracruz and Puebla identified about 100 sites for mini-hydro installations.

MYANMAR (BURMA)

The country is well-endowed with hydro resources: its technically feasible potential is put at 37 000 MW. At an assumed annual capacity factor of 0.40, this level would imply an annual output capability of approximately 130 TWh; recently, annual hydro output has been about 1.6 TWh. Severe water shortages in 1999 brought about a drastic reduction in hydro-electric output, the year's total falling to less than half the normal level. Given a return to historical amounts of precipitation, there appears to be ample scope for substantial development of hydropower in the long term.

Current hydro capacity is about 340 MW; plants under construction will virtually treble this total within a few years. A 280 MW plant is scheduled to be completed at Paung Laung in 2002, whilst Nan Kok (200 MW) and two other stations are expected to enter service not long afterwards.

NEPAL

There is a huge theoretical potential for hydropower, estimated to be in the region of 83 000 MW, but the economically feasible potential is assessed at 42 000 MW or about 147 TWh (at an assumed average capacity factor of 0.40). Output of hydro-electricity in 1999 was about 1.5 TWh, only 1% of the estimated economic potential. Hydro currently provides almost all of Nepal's electric power.

Total hydro capacity at end-1999 was 389 MW; a further 289 MW of capacity was reported to be under construction at that time. This increment includes Khimti I (60 MW), which was completed in July 2000, and Kali Gandaki A (144 MW) which was due for completion in mid-2001. A number of other, smaller hydro plants are in various stages of construction, with completion expected during the next four years.

Nepal's topography gives it enormous scope for the development of hydro-electricity, which probably provides the only realistic basis for its further economic development. Small-scale hydro plants are the most viable option for rural electrification. Large projects, however, in view of Nepal's limited financial resources, would probably require power export contracts with India as a prerequisite.

NORWAY

Norway possesses Western Europe's largest hydro resources, both in terms of its current installed capacity and of its economically feasible potential. Its gross theoretical capability is put at 600 TWh/year, of which about 180 TWh is economically exploitable. The hydro generating capacity installed by the end of 1999 had an output capability equivalent to around 63% of the economic potential. Actual hydro output was 121.8 TWh, providing virtually all of Norway's electric power.

Hydro capacity under construction at the end of 1999 amounted to only 10 MW, while a further 2 334 MW of capacity was approved for development, under licencing or under planning.

The economically exploitable capability applicable to small-scale hydro schemes is reported to be 14 TWh/year, equivalent to 7.8% of the overall level. Installed capacity of small hydro plants totalled 945 MW at end-1999, with an average annual output capability of 4.5 TWh. A further 58 MW of small-scale capacity was under construction or approved for development (development licence granted).

PAKISTAN

Pakistan's reported level of technically exploitable hydro capability (130 TWh/year) places it in the middle ranks of Asian countries in this respect, alongside Japan, Malaysia, Myanmar and Nepal. The degree of utilisation of its potential is relatively high. Hydro capacity in operation at the end of 1999 totalled 4 826 MW (including Tarbela, 3 478 MW and Mangla, 1 000 MW); output during the year was 21.5 TWh, accounting for almost 37% of Pakistan's electricity generation.

Capacity under construction at end-1999 amounted to 1 634 MW, comprising the Ghazi Barotha hydro station, with 5 units totalling 1 450 MW, and Chashma (184 MW). The planned development of hydro capacity includes several large/very large projects, including Kalabagh (2 400 MW) and Basha (3 360 MW).

The Power Policy Framework 1998, announced by the Government of Pakistan, promotes the use of hydro-electric resources for power generation and is based on setting a minimum, levelised tariff as a result of competitive process through international bidding. For small hydel projects, however, the Government would allow concessional procedures and attractive tariffs to promote private investment.

PARAGUAY

In the context of energy supply, Paraguay's outstanding natural asset is its hydro-electric potential, which is mainly derived from the river Paraná and its tributaries. The country's gross theoretical capability for hydro-electricity is about 111 TWh/year, of which 68 TWh is estimated to economically exploitable. Two huge hydro-electric schemes currently utilise the flow of the Paraná: Itaipú, which Paraguay shares with Brazil, and Yacyretá, which it shares with Argentina.

Itaipú is the world's largest hydro-electric plant, with a total generating capacity of 12 600 MW, of which Paraguay's share is 6 300 MW. This share is far in excess of its present or foreseeable needs and consequently the greater part of the output accruing to Paraguay is sold back to Brazil.

The bi-national plant at Yacyretá, downstream from Itaipú, has an installed capacity of 3 100 MW. The first unit came into operation in September 1994; all 20 units have now been installed, but are operating at a reduced head, pending the reservoir's final operating level being attained.

Paraguay has a wholly-owned hydro plant (Acaray), which has been recently uprated from 200 MW to 256 MW.

With its wealth of hydropower, Paraguay can virtually dispense with fossil-fuelled power plants.

Total installed hydro-electric generating capacity was just under 7.4 GW at the end of 1999, with no new capacity reported to be under construction. Planned capacity was 3 400 MW, consisting mainly of a new bi-national project on the Paraná (Corpus, 2 880 MW). This plant would be jointly owned by Paraguay and Argentina. There are also plans for additional capacity to be installed at Itaipú and Yacyretá.

PERU

Peru's topography, with the Andes running the length of the country, and many fast-flowing rivers, endows the republic with an enormous hydro-electric potential. Its hydro capability is assessed as one of the largest in the whole of South America: its economically exploitable capability is some 260 TWh/year. Current utilisation of this capability is very low – about 5% in 1999. Hydro provides about 75% of Peru's electric power.

Plants under construction at end-1999 were San Gabán (110 MW), Yanango (42 MW) and Chimay (142 MW), all of which were completed during 2000. Other schemes (including the 525 MW Cheves project on the Huaura river and a 134 MW plant at Yúncan) have faced delays as a result of a temporary moratorium on hydropower development, but work at Yúncan is now going ahead.

RUSSIAN FEDERATION

Russia's hydro resource base is enormous – the gross theoretical potential is some 2 800 TWh/year, of which 852 TWh is regarded as economically feasible. The bulk of the Federation's potential is in its Asian regions (Siberia and the Far East). Hydro output in 1999 (161 TWh) represented 19% of the economic potential and accounted for 19% of total electricity generation.

At the end of 1999 installed hydro-electric generating capacity was some 44 GW; according to *Hydropower & Dams World Atlas 2001*, 5.1 GW of additional capacity was under construction and about 17 GW of further capacity was planned for installation in the period up to 2020.

The largest plants under construction are Bureya (2 000 MW) on the river Bureya in the Far East and Iganai (800 MW) in the Caucasus.

SWEDEN

Sweden has one of the highest hydro potentials in Western Europe: its gross theoretical capability is reported to be 176 TWh/year, of which 90 TWh is economically exploitable. The average annual capability of the hydro capacity installed at the end of 1999 was 64 TWh, about 71% of the economic potential. Actual hydro output in 1999 was 70.8 TWh: hydropower provides nearly half of Sweden's electricity generation.

The construction of new hydro plants has virtually stopped, on account of environmental and political considerations. Future activity is likely to be very largely confined to the modernisation and refurbishment of existing capacity.

TAJIKISTAN

The terrain and climate are highly favourable to the development of hydropower. Apart from the Russian Federation, Tajikistan has the highest potential hydro generation of any of the FSU republics. Its economically feasible potential is estimated to be 263.5 TWh/year, of which only about 6% has been harnessed so far. Hydropower provides over 95% of Tajikistan's electricity generation.

There is just over 4 GW of hydro capacity installed: the plants under construction will add another 4.6 GW. *Hydropower & Dams World Atlas 2001* reports that plans exist for installing a further 11.8 GW, which would eventually bring Tajikistan's total hydro capacity to over 20 GW, assuming that all the plans come to fruition. The largest hydro plant presently under construction is the huge Rogun scheme (3 600 MW) on the river Vakhsh.

TURKEY

Turkey has a gross theoretical hydropower potential of 413 TWh/year, a technically feasible potential of 216 TWh/year and an economically feasible potential of 122 TWh/year. About 32% of the economically feasible potential has been developed, based on average annual generation.

At end-1999 there was 10.8 GW of hydro capacity in operation (out of 24 GW total electric capacity), capable of generating about 39 TWh in an average year. A further 4.1 GW hydro capacity was under construction at end-1999. The largest plants involved were Birecik (672 MW), Deriner (670 MW) and Berke (510 MW). By 2010, the Government aims to develop 60% of the economically feasible potential, with installed capacity reaching 22 GW. In all, a total of 19 715 MW of hydro capacity is planned for development over the next 25 years, in addition to the projects currently being built.

UNITED STATES OF AMERICA

The hydro resource base is huge: the gross theoretical potential has been assessed as 512 GW, equivalent to 4 485 TWh/yr. The economically feasible potential output is put at 376 TWh; the end-1999 US hydro capacity of 79.5 GW had an average annual capability of about 300 TWh, equivalent to 80% of this potential. Hydro-electric output of 319.5 GWh in 1999 accounted for 8.6% of US electricity generation. Only 17 MW of additional hydro-electric generating capacity was reported to be under construction at the end of 1999, while 434 MW was at the planning stage.

The installed generating capacity of small-scale hydro plants totalled just over 2.5 GW at end-1999; an additional 52 MW was reported to be planned for implementation during the period up to 2004.

The levels reported as installed capacity are net summer capacity; those specified as under construction or planned relate to generator nameplate capacity.

Most large-scale hydro-electric plants in the United States were built and are operated by various Federal Government bodies. The projects are usually intended to serve multiple purposes, including irrigation and public water supply, flood control, and recreation as well as power generation. Depending on the dominant purpose, dam construction and operation may have been undertaken by the Bureau of Reclamation, Department of the Interior (for irrigation projects) or the US Army Corps of Engineers (for flood control projects). Sales of electric power from Federal dams are usually managed by one of four Federal Power Marketing Administrations, with power being sold preferentially to public bodies.

The licensing of the construction and operation of new hydro-electric plants is conducted by the Federal Energy Regulatory Commission (FERC), which is responsible for taking into consideration safety and environmental aspects of dam construction. New private-sector projects (when constructed by regulated electric utilities) are subject to economic regulation by state and local bodies, and to state and local regulation with respect to land use, water rights and environmental impacts.

URUGUAY

Hydropower is Uruguay’s only indigenous source of commercial primary energy, but even this is on a relatively limited scale. The technically exploitable potential is 10 TWh/year and 1999 output was 5.5 TWh, leaving a fairly small amount of incremental capacity available (in principle) for exploitation in the future.

During the 1980’s almost all of Uruguay’s incremental generating capacity was in the form of hydropower, with the commissioning of the bi-national Salto Grande (1 890 MW) plant on the river Uruguay; the republic shares its output with Argentina.

Hydro provided 70% of Uruguay’s electricity generation in 1999. No hydro plants are under construction or planned: future increases in generating capacity are likely to be fuelled by natural gas.

VENEZUELA

Venezuela's gross theoretical capability is estimated to be 345 TWh/year, of which 130 TWh/year is considered as economically exploitable. Hydro-electric output in 1999 was 60.6 TWh, indicating that nearly half the realistic potential has already been harnessed. About three-quarters of the republic's electricity requirements are normally met by hydropower.

A large increase in hydro-electric capacity occurred during the 1980's, the major new plant being Guri (Raúl Leoni), on the river Caroní in eastern Venezuela – its capacity of 10 300 MW makes it currently the world's second largest hydro station, after Itaipú.

At the end of 1999, total hydro-electric generating capacity was 13.2 GW; 2.2 GW was under construction and a further 11.3 GW of hydro capacity was planned for future development.

The 2 160 MW Caruachi project, sited 59 km downstream from Guri, is scheduled for phased entry into operation between 2003 and 2006. Two major projects at the planning stage are Tocoma (1 160 MW) and La Vueltosa (480 MW).

VIETNAM

Vietnam has abundant hydro resources, particularly in its central and northern regions. Its gross theoretical potential is put at 300 000 GWh/yr, with an economically feasible potential of some 80 000 GWh/yr. There are more than 50 hydro stations in operation, with a total installed capacity of nearly 2 900 MW at end-1999. Hydro-electricity provides over half of Vietnam's power supplies.

The principal areas of hydro potential are the rivers Da in the north, Sesan in central Vietnam and Dongmai in the south. *Hydropower & Dams World Atlas 2000* reported that at end-1999, 1 265 MW of hydro capacity was under construction, the largest of which - Yali (720 MW) - was completed in 2000. According to the 2001 *Atlas*, more than 8 000 MW of capacity is planned for installation at some 20 sites; the principal project is Son La, with up to 3 600 MW envisaged as coming into operation between 2007 and 2012.

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Chapter 8

PEAT

Background

Since World War II there has been a big change in attitudes towards the use of peat as an energy source and the role of peatlands as a natural resource. In the 1950´s peat was still regarded as an important fuel in many countries in Europe, and large development programmes were being undertaken in Ireland, Sweden, Germany, Denmark, Finland and in the member states of the then Soviet Union.

A good example of the importance of peat in energy production at that time was a decision made during the World Power Conference held in London in 1950 to maintain permanent contacts among peatmen interested in international co-operation. Through the initiative of this group and the generous support of the Irish state-owned peat company Bord na Móna, it was decided to hold an International Peat Congress in Dublin, Ireland in 1954. This plan was realised and later another International Peat Congress was organised in the then Leningrad in 1963. As a result of this development the International Peat Society was inaugurated in 1968 in Quebec, Canada in connection with the 3rd International Peat Congress.

In the 1960´s the availability of cheap oil and coal started to affect the competitiveness of peat as fuel and the role of energy peat began to decrease in these countries, except for Ireland and the Soviet Union, where peat continued to play an important role as a fuel in power generation and also in small local consumption. Numerous peat briquette factories were in operation in Ireland, Belarus, Russia, Ukraine and Estonia.

At the end of the 1960´s and at the beginning of the 1970´s fuel prices started to increase, on the basis of which the first national energy peat development programme was adopted in Finland in 1971. The Government of Finland approved a peatland reclamation policy according to which production of energy peat was planned to be raised to 10 million cubic metres till 1980. This target was doubled in 1974 after the Middle East war, as a result of which oil prices increased in the world market. The Finnish Parliament allocated the required financial resources for the purchase of peatlands and for the hiring of a labour force. As a result of intensive work, the target was met for the first time in 1986, when 20.4 million cubic metres of energy peat (1.7 mtoe) was produced in Finland.

The 1970´s meant a turning point in peat usage. In Western Europe large mire areas had been reclaimed during past generations for agricultural use, as a result of which the number of pristine mires was decreasing with ever-increasing speed. In some countries large areas of peatlands were drained after World War II for growing forests. Peatlands were particularly effectively drained in Finland, where during the 1950´s to 1980´s almost 50% of the country´s original 10.4 million hectares of pristine mires were drained for forestry purposes. Simultaneously with this development the use of peat as a growing medium was gradually increasing, which added to the pressure, especially on large pristine ombrotrophic type of bogs, the number of which was getting scarce in Central European countries.

In Canada and in the USA some studies were made in the 1970´s and 1980´s to evaluate the use of peat as fuel. The outcome of these studies was that peat is not competitive, owing to the availability of cheap oil, coal and natural gas in those countries. Only in some areas in the midlands of Canada is peat used today on a minor scale as a local fuel. In Canada and the USA peat is used as growing media and today Canada is the leading country in the world in terms of volume of horticultural peat produced. This has led to the fact that Canada is also one of the major players in the world community as far as environmental issues related to the use of peat and peatlands are concerned.

There have also been some attempts to develop the use of peat as fuel in Central Africa and South-East Asia. In Burundi, for example, minor peat operations have been established with the aid of West European countries. In Indonesia and Malaysia, where there are huge peat resources, fuel peat operations were developed in the 1980´s and 1990´s. Owing to economic difficulties in that area these operations have been closed for the present and no major peat development programmes are being conducted for the time being.

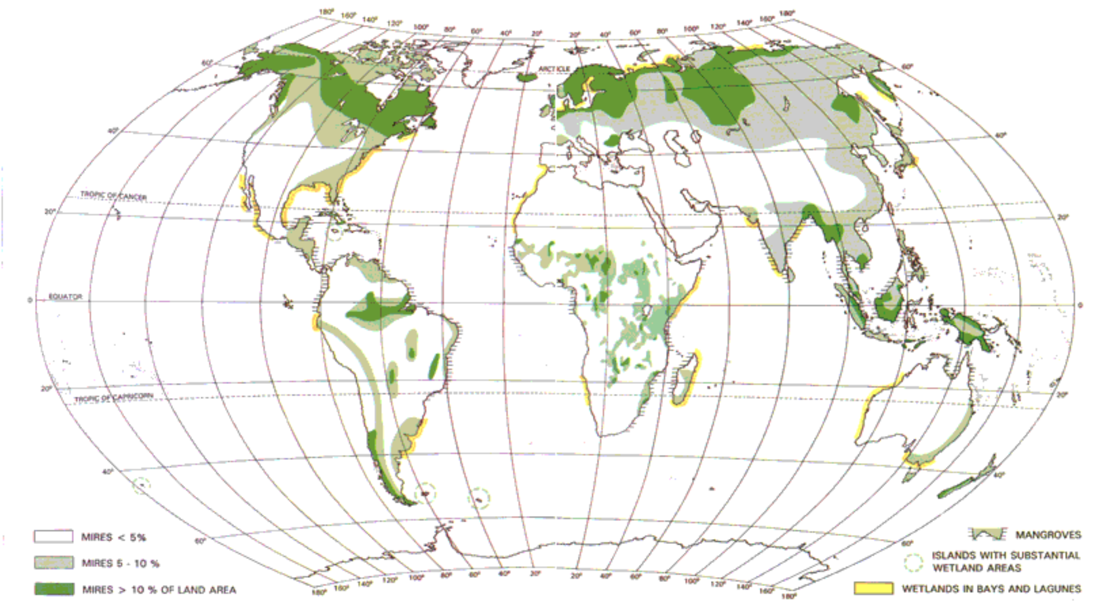

Figure 8.1: Distribution of Mires (Source: International Peat Society)

The existence of the South-East Asian peat resources has come to the attention of the world community, owing to immigration programmes for which purpose huge areas of peatlands have been drained for agricultural purposes. One example is the famous "Mega-Rice" land conversion programme, commenced in 1996 in Central Kalimantan, which covers about one million hectares of peatlands drained and cleared from forestry for rice cultivation. Immigration programmes with drainage of peatlands and cutting of timber from peatland forests, followed by slash burning, have caused huge fires in that area, as a result of which thick layers of peat swamps have been burnt to ash from top to bottom.

Environmental considerations

Although more than half of the mires within the European Union are still pristine, the development mentioned above has led to strong anti-peat campaigns, especially in the United Kingdom, Ireland and Germany. For instance in Switzerland all remaining peatlands have been protected and no peat harvesting is possible any more. Also in the North European countries, nature conservation organisations and environmental authorities carefully monitor the environmental impacts of peat production and use, and new restrictions are imposed almost annually, as a result of ever-tightening environmental legislation. The role of the European Commission in environmental issues concerning peat has increased, especially after Finland and Sweden joined the EU in 1995, with repercussions in both countries.

Major environmental concerns regarding the use of energy peat are principally the same as those for other fuels. Worry about the adequacy of peat resources and the sustainability of their use has activated nature conservation bodies to increase the number of protected mires, and special mire conservation programmes have been developed in different countries. In Finland, for instance, this discussion was most intensive in the 1970´s, when national peat development programmes were started and the peat industry was branded as the destroyer of Finnish peatlands. This fear was gradually overcome, as people started to realise that less than one percent of the total peatland area was needed for the peat industry during the future decades, at the same time as the protected mire area was in practice increasing to over one million hectares. In Central Europe the situation is worse because peatlands have been an object of human impact for hundreds or even thousands of years and certain types of pristine mires may be relatively scarce compared with Northern and Eastern Europe - to say nothing of Canada, where there is the largest concentration of pristine mires in the western world, or of Siberia in the east, where huge land areas are covered with thick and untouched peat deposits.

Drainage is a specific feature of peat usage because over 90% of the weight of natural peat mass is water. Especially at the initial stage of ditching, a lot of water is released and directed by the force of gravitation to streamlets, rivers and lakes, carrying along solid substances and nutrients. Sophisticated mechanical and chemical techniques have been developed to reduce emissions from the drainage network and an acceptable purification level has been achieved under normal working conditions. Water legislation varies from country to country, but the new EU Framework Directive in the Field of Water Policy (No 2000/60/EC) will no doubt in the long run lead to harmonisation of water quality requirements, including within the peat industry.

Emissions from the combustion of peat are for the present well controlled owing to the relatively low natural SO_2 content of peat and the use of new boiler techniques, as a result of which NO_x emissions have been kept at a reasonable level. Changing over from oil and coal to peat has significantly reduced the SO_2 load in towns where there are large CHP plants using peat as major fuel. According to the present emission limits there has not been a need to use chemical purification systems. Early in 2001, a proposal was being discussed in the European Commission to adopt a Council directive on the limitation of emissions of certain pollutants into the air from large combustion plants (11070/1/2000 – C5-0562/2000 – 1998/0225(COD)), which may bring with it a need for changes to the present peat fired-plants.

During the past decade the Greenhouse Gas (GHG) problem has become a major issue in discussions concerning the environmental impacts of energy production. In this debate the peat industry has been the loser, because peat is classified as a fossil fuel and CO_2 emissions released during its combustion are taken into account in full in the calculations of the International Panel for Climate Change (IPCC). This classification and calculation model has been strongly criticised, especially by the peat industry of Finland and Sweden, because it does not take into account annual growth of peat and the possibility of producing biomass on cut-over peatlands. Thanks to the report “The Role of Peat in Finnish Greenhouse Gas Balances”, commissioned by the Finnish Ministry of Trade and Industry and produced by three internationally-recognised peatlands and climate change experts from the USA, the UK and Finland, the attitude towards peat has changed and approaches that of the peat industry. In the report it is stated that peat could be classified as a biomass fuel, so as to distinguish it from biofuels (such as wood) and from fossil fuels (such as coal). According to the report, peat can be regarded as a slowly renewable natural resource. In November 2000 the European Parliament amended Article 21 of the Council Directive on the promotion of electricity from renewable energy sources in the international electricity market, adding peat to the list of renewable energy sources. The fate of the amendment is unknown for the present, because at the time of writing the decision-making process is unfinished. In the countries where peat still plays an important role as a local energy source, great attention is nowadays being paid to the process of peat classification and to how greenhouse gas emissions from peat combustion are taken into account in the calculations of the IPCC.

Peat as an energy source

Although environmental aspects nowadays play a central role in social and commercial decision-making processes, they are only a part of the totality, which includes many other aspects. In the White Book on “An Energy Policy for the European Union” the Commission emphasises that in the energy policy of the European Community market integration, sustainable economic growth, job creation and prosperity for its citizens have to be taken into account. An especially important principle of the EU’s energy policy is security of supply, as well as social and economic cohesion.

Peat as a local “biomass” fuel meets most of the demands the Commission has set for the energy policy of the European Community. Peat is produced mostly in remote areas where there is a chronic lack of industrial jobs. Powerful tractors typical in peat harvesting can be used outside the production season in agriculture, road maintenance and in wood transportation. New methods have been developed to establish “biomass terminals” on peat production sites, where wood is collected from the surrounding forests, crushed into chips, mixed with peat and transported to CHP plants. There have been experiments in drying wood chips with the aid of solar energy during the summer on the surface of the peat bog and collecting the air-dried wood chips from the peat fields with the same machines as for peat.

Especially in Finland, attention has been paid to co-combustion of peat and wood. It has been found that the chemical properties of wood fuel alone may cause certain problems in boilers. Burning peat together with wood helps to control the combustion process and reduce corrosion in the superheater tubes. This is mainly due to the mineral components of peat, which are proportionally higher than those of wood. Some advantage is gained with respect to SO_2 emissions when peat is used simultaneously with wood. Many boilers which have been originally dimensioned for combustion of peat cannot meet full capacity with wood only. Thus, a successful increase in the use of wood as fuel in CHP plants depends on the use of peat as well. There are also good reasons to have alternative fuels available on commercial grounds and for security of supplies.

According to statistical data collected by the International Peat Society, energy peat production in Europe in 1999 was 21.5 million tonnes of air-dried peat. Finland was a leading energy peat producer in terms of volume, with some 7.5 million tonnes of production. The second in rank was Ireland with 4.7 million tonnes and the third the Russian Federation with 3.7 million tonnes of production. Belarus, Sweden and Estonia followed as the next largest producers. Compared with the situation in 1990, the use of energy peat has slightly decreased, but the same countries are involved as in 1990. Energy peat is mainly used locally, but small amounts of peat briquettes have been exported from Estonia to Sweden and Finland, sod peat from Estonia, Scotland and Finland to Sweden and milled peat from Finland to Sweden. There have also been experiments in importing a few parcels of milled fuel peat from Russia into Finland. The total production area of energy peat in Europe was 113 000 ha. Including the USA, Canada and South Africa, horticultural peat was produced on an area of 100 000 ha. IPS data show that there were over 800 companies producing peat in 1999, with a labour force contributing an average of about 32 000 man-years.

Raimo Sopo
Secretary General
International Peat Society
Finland

Editors' note: The production data in Table 8.3, which are based as far as possible on questionnaires returned by WEC Member Committees, are broadly compatible with the IPS data, after allowing for differences in reporting conventions (e.g. for Ireland).

DEFINITIONS

Peat is a soft organic material consisting of partly decayed plant matter together with deposited minerals.

For the purposes of Table 8.1, **Peatland** is defined as follows: for land to be designated as peatland, the depth of the peat layer, excluding the thickness of the plant layer, must be at least 20 cm on drained, and 30 cm on undrained land.

Peatland reserves are most frequently quoted on an area basis because initial quantification normally arises through soil survey programmes or via remotely-sensed data. Even where deposit depths and total peat volumes are known, it is still not possible to quantify the reserves in energy terms because the energy content of in-situ peat depends on its moisture and ash contents. However, the organic component of peat deposits has a fairly constant anhydrous, ash-free calorific value of 20-22 MJ/kg, and if the total quantity of organic material is known, together with the average moisture and ash contents, then the peat reserve may be equated with standard energy units.

The definitions applicable to Table 8.2 are as follows:

Proved amount in place is the tonnage that has been carefully measured and assessed as exploitable under present and expected local economic conditions, with existing available technology.

Proved recoverable reserves is the tonnage within the proved amount in place that is recoverable under present and expected local economic conditions, with existing available technology.

Estimated additional amount in place is the indicated and inferred tonnage additional to the proved amount in place which is thought likely to exist in unexplored extensions of known deposits or has been inferred from geological evidence. Speculative amounts are not included.

Estimated additional amount recoverable is the tonnage within the estimated additional amount in place which geological and engineering information indicates with reasonable certainty might be recovered in the future.

Types of Peat Fuel

There are three main forms in which peat is used as a fuel:

- **Sod peat -** slabs of peat, cut by hand or by machine, and dried in the air; mostly used as a household fuel;
- **Milled peat -** granulated peat, produced on a large scale by special machines; used either as a power station fuel or as raw material for briquettes;
- **Peat briquettes -** small blocks of dried, highly compressed peat; used mainly as a household fuel.

Table 8.1 Peat: areas of peatland at end-1999

Excel files	thousand hectares
Algeria	22
Angola	10
Burundi	14
Congo (Brazzaville)	290
Congo (Democratic Rep.)	40
Côte d'Ivoire	32
Egypt (Arab Rep.)	46
Guinea	525
Kenya	160
Liberia	40
Madagascar	197
Malawi	91
Mozambique	10
Nigeria	700
Rwanda	80
Senegal	7
South Africa	950
Sudan	100
Tunisia	1
Uganda	1 420
Zambia	1 106
Total Africa	**5 841**
Belize	90
Canada	111 328
Costa Rica	37
Cuba	658
El Salvador	9
Haiti	48
Honduras	453
Jamaica	12
Mexico	1 000
Nicaragua	371
Panama	5
Puerto Rico	10
Trinidad & Tobago	1
United States of America	21 400
Total North America	**135 422**
Argentina	50
Bolivia	1
Brazil	1 500
Chile	1 047
Colombia	339
Falkland Islands	1 151
French Guiana	162
Guyana	814
Paraguay	50
Peru	10
Surinam	113
Uruguay	3
Venezuela	1 000
Total South America	**6 240**
Afghanistan	12
Armenia	3
Bangladesh	60
Brunei	10
China	1 044
Georgia	25
India	100
Indonesia	27 000

Table 8.1 Peat: areas of peatland at end-1999 contd.

	thousand hectares
Japan	200
Korea (Democratic People's Rep.)	136
Korea (Republic)	630
Malaysia	2 536
Myanmar (Burma)	965
Pakistan	2
Philippines	240
Sri Lanka	5
Thailand	64
Turkey	56
Vietnam	100
Total Asia	**33 188**
Albania	10
Austria	22
Belarus	2 397
Belgium	20
Bulgaria	3
Czech Republic	27
Denmark	142
Estonia	902
Finland	8 900
France	100
Germany	1 420
Greece	10
Hungary	100
Iceland	1 000
Ireland	1 180
Italy	120
Latvia	640
Lithuania	483
Netherlands	280
Norway	2 370
Poland	1 200
Portugal	20
Romania	7
Russian Federation	56 800
Slovakia	4
Slovenia	100
Spain	38
Sweden	6 400
Switzerland	22
Ukraine	1 008
United Kingdom	1 926
Total Europe	**87 651**
Iran (Islamic Rep.)	290
Iraq	1 790
Israel	5
Total Middle East	**2 085**
Australia	15
Fiji	4
New Zealand	260
Papua New Guinea	685
Total Oceania	**964**
TOTAL WORLD	**271 391**

Notes:
1, Data for African countries are as given in *Global Peat Resources* and relate to total mire areas, which “include coastal mangroves and other wetlands without any information about the thickness of peat or other organic soils”
2. The peatland area shown for Slovenia also includes those In Bosnia-Herzogovina, Croatia and Serbia, Montenegro

3. The peatland area shown for Australia is as reported by the Australian WEC Member Committee for the 1995 *Survey of Energy Resources*; mangrove swamps, tidal marshes, and salt flats are excluded

4. Sources: WEC Member Committees, 2000/2001; Lappalainen, E. (editor), 1996, *Global Peat Resources*, International Peat Society, Finland

Table 8.2 Peat: resources and reserves at end-1999

Excel files	Proved amount in place	Proved recoverable reserves	Estimated additional amount in place	Estimated additional amount recoverable
	million tonnes			
Africa				
Senegal	17			
North America				
Canada	1 092		336 908	
United States of America	6 400	15	103 600	
South America				
Argentina	90	80	50	15
Asia				
Turkey	53			
Europe				
Estonia	2 370	1 520		
Finland	850	420	2 200	1 000
Germany	157	36		
Hungary	28	24	159	121
Ireland	138	98	140	120
Latvia	473	190	324	194
Netherlands		120		
Poland	40		5 400	
Romania	25	13	10	10
Sweden	700	70		

Notes:
1. The data on resources are those reported by WEC Member Committees in 2000/2001. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
2. Tonnages are generally expressed in terms of air-dried peat (35%-55% moisture content), except those for Ireland, Which are reported on a 0% moisture content basis

Table 8.3 Peat: 1999 production and consumption for fuel

Excel files	production	consumption
	thousand tonnes	
Burundi	12	12
Total Africa	**12**	**12**
Argentina	N	N
Falkland Islands	15	15
Total South America	**15**	**15**
China	600	600
Indonesia	536	520
Total Asia	**1 136**	**1 120**
Austria	1	1
Belarus	3 090	2 157
Denmark	N	N
Estonia	575	345
Finland	7 927	6 849
France	N	N
Germany	20	8
Ireland	2 927	2 232
Latvia	383	139
Lithuania	98	87
Norway	N	N
Poland	N	N
Romania	11	11
Russian Federation	3 220	2 847
Sweden	1 117	1 100
Ukraine	716	502
United Kingdom	20	10
Total Europe	**20 105**	**16 288**
TOTAL WORLD	**21 268**	**17 435**

Notes:

1. Data on production relate to peat produced for energy purposes; data on consumption (including imported peat) similarly relate only to fuel use

2. Annual production of peat in individual countries tends to vary considerably from year-to-year; the peat drying process is highly dependent on the weather, with below-average sunshine and/or wind, or above-average rainfall, depressing output (and vice versa). Demand for peat is generally much more stable than production: the resulting surpluses or deficits are borne by buffer stocks of dried peat

3. Data for Burundi and the Falkland Islands relate to 1998; those for China relate to 1990 and for Indonesia to 1996

4. Tonnages are generally expressed in terms of air-dried peat (35%-55% moisture content), except those for Ireland which are reported on a 0% moisture content basis

5. Sources: WEC Member Committees, 2000/2001; *Energy Statistics Yearbook,* 1998; United Nations; *Survey of Energy Resources* 1992 and 1998; direct communications from International Energy Agency and International Peat Society

COUNTRY NOTES

The Country Notes on peat have been compiled by the editors, drawing principally upon the following publications:

- Lappalainen, E. (editor); 1996; *Global Peat Resources*; International Peat Society, Finland
- Couch, G.R.; 1993; *Fuel peat - world resources and utilisation*; IEA Coal Research, London

Information provided by WEC Member Committees and from other sources has been incorporated when available.

ARGENTINA

There are some 500 km^2 of peat bogs on the Isla Grande de Tierra del Fuego at the southern tip of the republic. These deposits constitute some 95% of Argentina's peatlands: other peat bogs exist in the highland valleys of the Andean Cordillera and in other areas. However, economic exploitation of peat is almost entirely confined to Tierra del Fuego, where relatively small amounts (circa 3 000 m^3 per annum) are extracted, almost entirely for use as a soil-improvement agent. Consumption of peat for fuel is currently negligible.

Proved recoverable reserves of peat are reported by the Argentinian Member Committee to be 80 million tonnes, within a total proved amount in place of some 90 million tonnes. A further 50 million tonnes of (unproved) resources is estimated to be present, of which some 15 million tonnes is deemed to be recoverable.

BELARUS

The peatlands of Belarus are by far the most extensive in Eastern Europe (excluding the Russian Federation), amounting to 24 000 km^2. The largest areas of peat formation are in the Pripyat Marshes in the south and in the central area around Minsk. Peat has been used as a fuel for many years, with the highest consumption during the 1970's and 1980's. The use of peat as a power station fuel ceased in 1986; fuel output in recent years has been largely confined to the production of peat briquettes, mainly for household use.

Out of a total fuel peat production of around 3 million tonnes per annum, deliveries to briquetting plants account for about 2 million tonnes. Consumption of peat by heat plants amounts to about 300 000 tpa, with the balance of peat supply either being exported or consumed by a variety of small-scale consumers. Current annual output of peat briquettes is approximately 1.7 million tonnes, of which about 78% is consumed by residential users.

BRAZIL

The area of peatland has not been precisely established but it is believed to be at least 15 000 km^2, which makes it the largest in any South American country. There are extensive deposits in the Middle Amazon and in a large marshy plain (Pantanal) near the Bolivian border. Smaller areas of peatland exist in some coastal locations; those in the industrialised south-east of Brazil (in the states of Espírito Santo, Rio de Janeiro and São Paulo), and further north in Bahia state, have attracted interest as potential sites for the production of peat for energy purposes. The Irish peat authority Bord na Móna carried out preliminary surveys in Brazil in the early 1980's but no production of peat for fuel has yet been developed.

The total amount of peat in situ has been estimated as 25 billion tonnes. According to the Ministry of Mines and Energy, measured/indicated/inventoried resources of peat amounted to just over 129 million tonnes at end-1999, with an inferred/estimated additional amount of almost 358 million tonnes.

BURUNDI

There are appreciable areas of peatland, totalling about 140 km^2. The principal known deposits lie beneath the Akanyaru swamp complex in northern Burundi: these cover about 123 km^2 and are estimated to contain 1.42 billion cubic metres of peat in situ. The proved amount in place (expressed in terms of recoverable dry peat) was reported in 1992 to be 56 million tonnes.

Peat has been proposed as an alternative fuel to wood, in order to reduce deforestation, and a number of surveys have been conducted. Fuel peat is currently produced by semi-manual methods at four locations, but usage of the resource remains predominantly for agricultural purposes. The United Nations estimates annual production and consumption of fuel peat as 12 000 tonnes.

CANADA

The total area of peatland, reported by the Canadian WEC Member Committee to be more than 1.1 million km^2, is greater than that of any other country. Deposits of peat are widely distributed, with the largest areas in the Northwest Territories (23% of the Canadian total), Ontario (20%) and Manitoba (19%). The reported amounts of peat in place are enormous, with over a billion tonnes classified as proved and an additional 300+ billion tonnes as indicated or inferred.

There have been a number of assessments of the potential for using peat as a fuel (including for power generation) but at present there is virtually no use of peat for energy purposes and none is likely in the immediate future. Canada is, however, a major producer (and exporter) of peat for horticultural applications.

CHINA

Peatlands are quite widely distributed but do not have a high overall significance in China's topography, accounting for only about 0.1% of the country's land area. The principal peat areas are located in the region of the Qingzang Plateau in the south-west, in the north-east mountains and in the lower Yangtze plain in the east.

Peat has been harvested for a variety of purposes, including fuel use, since the 1970's. Some is used in industry (e.g. brick-making), but the major part of consumption is as a household fuel. Peat has been reported to be sometimes mixed with animal dung as input to biogas plants. No information is available on the current level of peat consumption for fuel. The Chinese WEC Member Committee reported production and consumption of 600 000 tonnes in 1990 for an earlier Survey.

DENMARK

Human activities, chiefly cultivation and drainage operations, have reduced Denmark's originally extensive areas of peatland from some 20-25% of its land area to not much more than 3%. Out of a total existing mire area of some 1 420 km^2, freshwater peatland accounts for about 1 000 km^2, the remainder consisting of salt marsh and coastal meadow. Commercial exploitation of peat resources is at a low level: in 1995 the area utilised was some 1 200 hectares, producing about 100 000 tonnes per annum. Almost all the peat produced is used in horticulture; fuel use is negligible.

ESTONIA

Peatlands are a major feature of the topography of Estonia, occupying about 22% of its territory. They are distributed throughout the country, with the largest mires being located on the plains. The Estonian WEC Member Committee reports a proved amount of peat in place of 2.37 billion tonnes, of which just over 1.5 billion tonnes is classed as proved recoverable reserves.

Out of a total peatland area of over 9 000 km^2, commercial extraction of peat takes place on about 160 km^2. More than half of the output is used for horticultural purposes: the use of peat for fuel is currently in the order of 350 000 tonnes per annum, cut from about 60 km^2 of peat bogs. Most of the peat is consumed in the form of briquettes – there are three briquetting plants, each with an output capacity of 120 000 tonnes/year. In 1999 briquette production totaled 106 000 tonnes, down from 162 000 tonnes in 1996; 64 000 tonnes of briquettes were exported, the balance being very largely consumed in the residential sector. Most of the consumption of un-briquetted peat is accounted for by district heating and electricity generation. Some sod peat (31 000 tonnes in 1999) is exported.

FINLAND

With their total area of some 89 000 km^2, the Finnish peatlands are some of the most important in Europe and indeed globally – Finland has the highest proportion of wetlands of any nation in the world. Peat deposits are found throughout Finland, with a greater density to the west and north of the country.

The Finnish WEC Member Committee reports that as at end-1999 the proved amount in place was 850 million tonnes, of which 420 million tonnes is regarded as proved recoverable reserves. Additional amounts of 2.2 billion tonnes in place, with 1.0 billion tonnes recoverable, are also reported for the present Survey.

The area of peat potentially suitable for commercial extraction is 6 220 km^2, of which about 22% contains high-grade peat suitable for horticulture and soil improvement. The remaining 78% (together with other deposits from which the surface layers have been harvested for horticultural use) is suitable for fuel peat production. In 1995, the total area used for peat production was only 530 km^2, from which 25.8 million m^3 were extracted for fuel use and 2.1 million m^3 for non-energy uses.

In 1998, CHP plants accounted for 48%, and power stations 22%, of the total national consumption of fuel peat; industrial users consumed 25%, the balance being used in heat plants (4%), and directly in the residential and agricultural sector (1%).

GERMANY

The majority of the peatlands are in the northern länder of Lower Saxony, Mecklenburg-West Pomerania and Brandenburg. Most of Germany's fens have been drained, the land being used for agriculture, mainly grassland farming. The German WEC Member Committee reports that in a total peatland area of some 14 000 km^2 the proved amount of peat in place is 157 million tonnes, of which about 23% is considered to be recoverable.

Out of the total area covered by raised bogs, approximately 60% is farmed, with only a small proportion (less than 10%) exploited for peat production. Energy use of peat is reported to be very limited at present, virtually all production being destined for agricultural/horticultural uses or for the manufacture of activated carbon. A small amount of energy-grade peat is exported.

GREECE

Despite the drainage of large stretches of former fenland, and the loss of much peat through oxidation and self-ignition, peat resources in Greece are still quite considerable. The largest deposits are in the north of the country, at Philippi in eastern Macedonia and Nissi in western Macedonia. The Philippi peatland covers about 55 km^2 and is nearly 190 metres deep – the thickest known peat deposit in the world.

Fuel Peat: World Resources and Utilisation quotes total reserves as 4 billion tonnes: the proportion of this amount that might be suitable for fuel use is indeterminate.

Peat resources in Greece have not so far been commercially exploited, either for use as fuel or for agricultural, horticultural or other purposes. Schemes for peat-fired electricity generation at Philippi and Nissi have been proposed in the past, but have subsequently been abandoned.

ICELAND

Peatlands cover some 10 000 km^2 or about 10% of Iceland's surface area; the ash content of the peat is usually high (10-35%), owing to the frequent deposition of volcanic ash. Although peat has traditionally been used as a fuel in Iceland, present-day consumption is reported as zero. In the past, an important non-energy application of peat consisted of the use of "peat bricks" in the construction of buildings.

INDONESIA

The peatlands are by far the most extensive in the tropical zone and rank as the fourth largest in the world: they are located largely in the sub-coastal lowlands of Irian Jaya, Kalimantan and Sumatra. A feasibility study was carried out in 1985-1989 regarding the use of peat for electricity generation in central Kalimantan; no project resulted, but a small peat-fired power plant has operated in southern Sumatra. For the 1998 Survey, the Indonesian WEC Member Committee reported a proved amount in place of 49 billion tonnes and that 1996 consumption of peat for energy purposes was 520 000 tonnes.

IRELAND

More than 17% of the republic's land surface is classified as peatland. Peat deposits are widely distributed, being especially prominent along the western seaboard and across the

Midland Plain in the centre of the island. Domestic consumption of peat for energy purposes in Ireland dates back to prehistoric times, with documentary evidence of its use existing from as early as the 8th century. After large stretches of the island's forests were cleared in the 17th century, peat became the only fuel available to the majority of households.

Mechanical methods of extraction were adopted on a large scale following World War II, both for the production of milled peat (used as a power-plant fuel and in the manufacture of peat briquettes) and to replace manual cutting of sod peat for household use. Out of current annual consumption of peat for energy purposes, about 60% is used in power stations, 15% is briquetted and 25% consists of sod peat, used predominantly as a residential fuel. Peat briquettes are also almost all used as household fuel.

Since its foundation in 1946, the Irish Peat Development Authority (Bord na Móna) has promoted the economic development of Ireland's peat resources. A number of power stations and briquetting plants have been built near peat deposits; the five main peat-fired power plants have an aggregate capacity of 550 MW. A programme is under way to replace these stations with three more efficient and more environmentally-friendly peat-fired power plants. The first of the new stations, built by Edenderry Power Ltd. near Clonbulloge, County Offaly, with a net output capacity of 118 MW, was commissioned in November 2000. It will consume 1 million tonnes of milled peat per annum. The other new stations will be constructed at Shannonbridge and Lanesboro.

The Irish WEC Member Committee reports the proved amount of peat in place at end-1999 as 138 million tonnes, with proved recoverable reserves standing at 98 million tonnes. An additional 140 million tonnes is estimated to be in place, of which 120 million tonnes is deemed to be recoverable. Production of fuel peat in 1999 was about 2.9 million tonnes, with consumption just over 2.2 million tonnes. (Note: Irish peat data are reported on a 0% moisture content basis).

ITALY

There are significant resources of peat in Italy, mostly in Piedmont, Lombardia and Venezia in the north of the country. *Fuel Peat: World Resources and Utilisation* gives the estimated reserves as 2.5 billion tonnes: the proportion of this amount that might be suitable for fuel use is indeterminate.

Although peat has been used for fuel during the past, notably in the context of wartime shortages of other sources of energy, no present-day usage has been reported.

LATVIA

Peatlands cover about 6 400 km^2, or almost 10% of Latvia's territory, with the major deposits being located in the eastern plains and in the vicinity of Riga. "Explored deposits" of peat (reported by the Latvian WEC Member Committee as the proved amount in place) are 473 million tonnes, of which 190 million tonnes are classed as proved recoverable reserves. "Evaluated deposits" provide an additional amount in place of 324 million tonnes, of which 194 million tonnes is regarded as recoverable.

Peat has been used in agriculture and as a fuel for several hundred years: output peaked in 1973, when fuel use amounted to 2 million tonnes. By 1990, the tonnage of peat extracted had fallen by 45% and fuel use was down to only about 300 000 tonnes. Consumption has tended to decline in recent years, with deliveries to CHP plants accounting for about two-thirds of the total. Relatively small tonnages of peat are consumed by heat plants and in the production of peat briquettes (mostly for household use).

LITHUANIA

Peatlands are widespread, with the larger accumulations tending to be in the west and south-east of the country. Fuel use of peat fell from 1.5 million tonnes in 1960 to 1 million tonnes in 1975 and to only about 0.1 million tonnes in 1985, since when consumption has remained at approximately the same level. The principal peat consumers are heat plants, briquetting plants and households; the last-named also account for virtually all Lithuania's consumption of peat briquettes.

NORWAY

Although there are extensive areas of essentially undisturbed peatland, amounting to nearly 24 000 km^2, peat extraction (almost all for horticultural purposes) has been at a relatively low level in recent years.

Peat had traditionally been used as a fuel in coastal parts of the country; unrestrained cutting led to considerable damage to the peatland, which in 1949 resulted in legislation to control extraction.

POLAND

The area of peatland is some 12 000 km^2, with most deposits in the northern and eastern parts of the country. For the present Survey, the Polish WEC Member Committee has reported the proved amount of peat in place as 40 million tonnes, with 17 billion m^3 (approximately 5.4 billion tonnes) as the estimated additional amount in place. No recoverable tonnages are given.

Much use was made of peat as a fuel in the years immediately after World War II, with some production of peat briquettes and peat coke; by the mid-1960's fuel use had, however, considerably diminished. Current consumption of peat is virtually all for agricultural or horticultural purposes.

ROMANIA

There are just over 70 km^2 of peatlands: the proved amount of peat in place is reported by the Romanian WEC Member Committee to be 25 million tonnes, of which just over half is deemed to be economically recoverable. An additional 10 million tonnes of recoverable peat is estimated to be in place. Peat production for energy purposes has been only a few thousand tonnes per annum in recent years, with consumption confined to the residential and agricultural sectors.

RUSSIAN FEDERATION

According to *Global Peat Resources*, the total area of peatlands is some 568 000 km^2: the deposits are widely but unevenly distributed throughout the Federation. The principal peat areas are located in the north-western parts of European Russian, in West Siberia, near the western coast of Kamchatka and in several other far-eastern regions. The Siberian peatlands account for nearly 75% of the Federation total.

Total peat resources are quoted in *Global Peat Resources* as 186 billion tonnes, second only to Canada's in world terms. Of the total, 11.5 billion tonnes have been the subject of detailed surveys and a further 6.1 billion tonnes have been preliminarily surveyed.

The bulk of current peat production is used for agricultural/horticultural purposes. Peat deposits have been exploited in Russia as a source of industrial fuel for well over a hundred years. During the 1920's the use of peat for power generation expanded rapidly, such that by 1928 over 40% of Soviet electric power was derived from peat. Peat's share of power generation has been in long-term decline, and since 1980 has amounted to less than 1%.

Approximately 5% of the exploitable peat deposits are used for fuel production, which currently amounts to around 3 million tonnes per annum.

SWEDEN

In Western Europe, the extent of Sweden's peatlands (64 000 km^2 with a peat layer thicker than 30 cm) is second only to that of Finland's: the deposits are distributed throughout the country, being particularly extensive in the far north. The Swedish WEC Member Committee reports a proved amount of peat in place of 700 million tonnes, of which 10% is deemed to be recoverable.

According to data reported to the IEA, peat production in recent years has averaged about 1 million tonnes per annum, with relatively little annual variation. In 1998, CHP plants accounted for 61% of total consumption, heat plants for 37% and industrial users for the remaining 2%.

The largest peat-production unit is located at Sveg, central Sweden, at an altitude of over 400 metres; it supplies a nearby briquetting plant, the only one in the country. This plant has an output capacity of about 300 000 tonnes per annum: production of briquettes (made from a mixture of peat, sawdust and wood chips) is currently about 220 000 tpa.

The use of peat as a household fuel has never been of much significance. Production of peat for industrial energy use began during the 19^{th} century and, after reaching a peak level during World War II, declined to virtually zero by 1970. Use of peat as a fuel for power stations and district heating plants started in the mid-1980's and now constitutes by far the greater part of consumption.

Sweden has imported small tonnages of peat in recent years, in the form of briquettes from Estonia and sod peat from the U.K.

UKRAINE

There are over 10 000 km^2 of peatlands, more than half of which are located in Polesie, in the north of the country, where they account for 6.4% of the surface area. The other main area for peat deposits is the valley of the Dnieper, in particular on the east side of the river. Peat production rose during the period of the communist regime, reaching 7.5 million tonnes in 1970, when 73% was used in agriculture and 27% for fuel. In recent years consumption of peat for fuel purposes has fallen to well under a million tonnes per annum, most of which is briquetted for use as a household fuel.

UNITED KINGDOM

The peatlands of Great Britain cover an area of some 17 500 km^2, most deposits being in the northern and western regions; Scotland accounts for about 68% of the total area of peat, England for 23% and Wales 9%.

There are about 1 700 km^2 of peatland in Northern Ireland, mostly located in the western half of the province.

The total UK peatland area is nearly twice that of Ireland, but the extraction of peat is on a very much smaller scale: in Great Britain, commercialised peat extraction takes place on only some 5 400 ha (equivalent to about 0.3% of total peatland). Almost all peat industry output is for the horticultural market; there is however still quite extensive (but unquantified) use of peat as a domestic fuel in the rural parts of Scotland and Northern Ireland. About 20 000 tonnes per annum of air-dried sod peat is reported by the International Peat Society to be produced for energy purposes, part of which is exported to Sweden.

UNITED STATES OF AMERICA

In 1995 the total area covered by peat soils (known as histosols) was some 214 000 km^2, of which Alaska accounted for just over 50%. In the contiguous United States, the major areas of peat deposits are in the northern states of Minnesota, Michigan and Wisconsin, along the eastern seaboard from Maine to Florida and along the Gulf coastal region as far as Louisiana.

The US WEC Member Committee reports a proved amount of peat in place of 6.4 billion tonnes, of which only 15 million tonnes is considered to economically recoverable. These assessments are based on “demonstrated” resource estimates. The large disparity between proved recoverable reserves and proved amount in place is due to a combination of environmental restrictions on commercial activities in wetlands and the fact that much of the proved amount in place is in Alaska where virtually no reserves are currently reported.

An enormous additional amount (103.6 billion tonnes) is stated to be in place, but no estimate of the tonnage eventually recoverable is available, owing to the uncertainties involved.

The potential uses of peat as fuel were evaluated during the 1970’s; a Department of Energy study published in 1980 covered – in addition to direct combustion uses – the potential for producing liquid fuels from peat.

Interest in developing the use of peat for energy purposes has diminished since 1980. A small (23 MW) power plant was constructed in 1990 in Maine, to be fuelled by local peat. Initial problems associated with the use of inappropriate harvesting equipment were overcome but it was then difficult to obtain further permits to exploit the larger bog area required; the boilers are now mainly fuelled by wood chips. There were proposals for three or four small peat-burning power stations (aggregate capacity 360 MW) to be built in Florida. However, the natural gas companies set a low enough price for the supply of gas that once again the planned use of peat did not come to fruition.

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Chapter 9

WOOD (INCLUDING CHARCOAL)

Woodfuels consist of three main commodities: fuelwood, charcoal and black liquor. Fuelwood and charcoal are traditional forest products derived from the forest, trees outside forests, wood-processing industries and recycled wooden products from society. Black liquors are by-products of the pulp and paper industry.

Figure 9.1 shows regional production of fuelwood (including wood for direct use as fuel and for conversion into charcoal) in 1999. The data reflect as far as possible those reported by WEC Member Committees; where information was not available from this source, estimates have been derived from information provided by FAO, Rome. Wood residues recycled to energy use are not included, nor is the production of black liquor. Insofar as these items have been quantified by Member Committees for this Survey, they are included in the Country Notes to Chapter 10: Biomass (other than Wood).

In 1999, about 1.4 billion tonnes of fuelwood were produced worldwide, which is about 470 mtoe or about 5% of the world total energy requirement.

Quantification of the production and consumption of all forms of biofuel is invariably difficult, and woodfuels are no exception. FAO is making strenuous efforts to improve the quality and quantity of wood energy data, in particular by ensuring that as far as possible production and consumption statistics cover all sources of fuelwood - not only established forests, but also other wooded land, farms and gardens, roadside trees, etc. Black liquor supplied about 72 mtoe of energy in 1997. Thus, it can be roughly estimated that woodfuels in total contribute about 540 mtoe annually to the world energy requirement.

This amount is smaller than that of nuclear energy, which provided 650 mtoe in 1999, but substantially larger than the output from hydro and other renewable sources of energy. On average, the annual per-capita consumption of woodfuels is estimated to be 0.3-0.4 m^3 or around 0.1 toe, but with considerable regional variances.

Figure 9.1. Total fuelwood production in 1999

	mtoe	**%**
Africa	141.1	29.9
North America	38.5	8.1
South America	37.7	8.0
Asia	216.1	45.8
Europe	34.9	7.4
Middle East	0.2	0.0
Oceania	3.8	0.8
TOTAL WORLD	**472.3**	**100.0**

The amount of woodfuel use varies considerably among regions, mainly owing to differences in stages of development. Fuelwood use is especially common in the rural areas of developing countries as the main source of household energy, while charcoal is mainly used by urban and peri-urban dwellers. In general terms, fuelwood production can be assumed to be more or less equal to fuelwood consumption within a region. However, the same rule cannot be applied to the amount of fuelwood used for charcoal making. In fact, the production of 1 tonne of charcoal requires approximately 6 m^3 of wood.

Asia is by far the largest producer and consumer of fuelwood, accounting for 46% of world production. Africa has the second highest share at 30%, followed by South America and North America, both at around 8%. On the other hand, the production and consumption of black liquor are concentrated in developed countries with large pulp and paper industries. Therefore, about 50% of black liquor consumption is in North America, followed by Europe with 19% and Asia with 12%.

Africa is the most intensive user of woodfuels in per-capita terms, with an average annual per-capita consumption of 0.77 m^3, or 0.18 toe. In Africa, almost all countries rely on wood to meet basic energy needs. The share of woodfuels in African primary energy consumption is estimated at 60% to 86%, with the exception of North African countries and South Africa. On average, about 40% of the total energy requirement in Africa is met by fuelwood.

In Asia, about 7% of the total energy requirement is met by fuelwood and the per-capita consumption level is not very high; however, the situation varies from country to country. Many countries in South and South East Asia, such as Nepal, Cambodia, Thailand and Indonesia, rely heavily on fuelwood, consuming more than 0.5 m^3 per-capita annually. In Latin America, about 10% of the total energy requirement is met by fuelwood.

In Europe and North America, the share of fuelwood in the total energy requirement is low, at 1.2% and 1.4% respectively. However, for countries such as Finland, Sweden, the USA and Canada, per-capita consumption is quite high if black liquor is included. In Austria, Finland and Sweden, wood energy provides about 12% to 18% of the country's total primary energy supply.

Households

Woodfuels, as well as other traditional sources of energy such as agricultural residues and animal dung, have an important role in the lives of the rural populations in developing countries. Fuelwood and charcoal, the commonest forms of woodfuel, are used widely as household power sources in poor rural neighbourhoods in developing countries. In Pakistan and the Philippines, for example, fuelwood supplied 58% and 82% respectively, of rural household energy consumption in the late 1980's to early 1990's. The major energy end-use is cooking in households: about 86% of fuelwood consumed in urban households in India is for this purpose, while the rest is used mainly for water heating. In Africa, in 1994, more than 86% of total woodfuel consumption was attributed to the household sector. Dependence on woodfuels to meet household energy needs is especially high in most of sub-Saharan Africa, where 90% to 98% of residential energy consumption is met by woodfuels. In the European

Union, most woodfuels are used by households, which account for around 60% of the total wood energy consumed.

Industry

Most of the non-household fuelwood consumption occurs in agro-based rural industries such as crop drying, tea processing and tobacco curing, as well as in the brick and ceramic industries. Woodfuel consumption by such users is smaller than that of households; nevertheless, it should not be overlooked as it can constitute 10% to 20% of fuelwood use in some Asian countries. In Africa, in 1994, it was estimated that traditional industries accounted for about 9.5% of woodfuel consumption.
Woodfuels are also used in larger-scale industries, mostly in the form of charcoal. For example, in Brazil some 6 million tonnes of charcoal are produced every year for use in heavy industry, such as steel and alloy production.

The widespread use of fuelwood and charcoal is attributable to various reasons. Fuelwood is often the cheapest and most accessible form of energy supply in the rural areas of developing countries. In many cases, it is harvested at no monetary cost as a common property resource from forests and from scattered pockets or belts of trees along field margins or roadsides and on waste or common ground. Both fuelwood and charcoal are traded, mainly in and around urban areas or beside transportation routes. Charcoal is the favoured commodity for trading, as it burns more efficiently than fuelwood and is easier to transport and store.

Rising income levels and expanding urbanisation usually make it possible for people to have access to more modern forms of energy. The rapid expansion of conventional energy capacity to meet the energy needs of industries and modern lifestyles results in a reduced share of woodfuels in the total energy mix, as well as lower per-capita consumption of woodfuels.

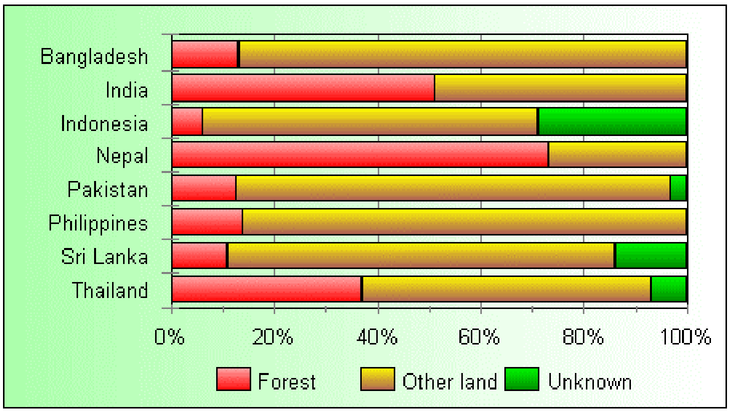
In developed countries, biofuels (including woodfuels) are mostly used for electricity and heat generation in cogeneration systems (combined heat and power production) on industrial sites or in municipal district heating facilities. In Oceania, North America and Europe, black liquors are widely used for fuelling the heat and power plants of the large pulp and paper industries. Almost all of their energy needs are met by black liquors and, in some cases, surplus electricity is sold to the public grid.

Recent trends in both energy and environmental policies, mainly in developed countries, promote the use of woodfuels. In many countries, deregulation, liberalisation and privatisation of energy markets over the past two decades have stimulated competition among energy suppliers and have presented new opportunities for non-fossil energy sources. Technological developments in woodfuel production, transportation, combustion, etc. are helping to make woodfuels more cost-competitive. In addition, woodfuels are increasingly receiving more attention for the environmental benefits they provide. Some countries have raised the taxes on fossil fuels, thus encouraging a decrease in the use of these fuels and, in some cases, increased use of other energy sources. Moreover, several countries and regions, for instance, Canada, Finland and the European Community, have adopted energy policies aimed at an expanded use of woodfuels.

Supply of woodfuels

Woodfuels come from a variety of supply sources, such as forests, non-forest lands and forest industry by-products. In 1998, 3.2 billion m^3 of wood were harvested worldwide, more than 50% of which was used for woodfuel. It has often been said that most woodfuels are obtained from forests, contributing to deforestation in a major way. However, it is now estimated that considerable amounts of woodfuels come from non-forest areas, such as village lands, agricultural land, agricultural crop plantations (rubber, coconut, etc.), homesteads and trees along roadsides. In some Asian countries, the proportion of woodfuels originating from non-forested areas exceeds 50%, as is shown in Figure 9.2. In some areas, nevertheless, woodfuel consumption exceeds the sustainable production from available and accessible supply sources. In Haiti, the Andean highlands and the Sahelian countries, as well as around large cities such as Khartoum, Dakar and Tegucigalpa, the obvious pressure on forest resources is causing concern.

Figure 9.2: Sources of woodfuels in some Asian countries



Source: **www.rwedp.org/sources.html**

Social aspects: gender and health

Such social aspects as gender and health are strongly related to the use of woodfuels, especially with the traditional use of fuelwood in the rural areas of developing countries. Fuelwood collection for household consumption, usually a task for women and children, is becoming more burdensome as fuelwood becomes scarcer. It is estimated that the proportion of rural women affected by fuelwood scarcity is 60% in Africa, nearly 80% in Asia and nearly 40% in Latin America. Moreover, gathering fuelwood can consume one to five hours per day for these women.

The direct burning of fuelwood in poor-quality cooking stoves can result in incomplete combustion, emitting pollutants such as carbon monoxide, methane and particulates in the kitchen. In most cases, women are responsible for cooking, spending many hours in the kitchen and thus being more exposed to these pollutants than men are. In addition, the daily hauling of the fuelwood collected imposes a huge physical strain on women.

Historical and new trends of wood use and projections

Woodfuel consumption in developing countries has increased steadily in parallel with the growth in population, although the share of woodfuels in the national energy balance of these countries has progressively diminished as a result of the increased use of such fossil fuels as oil, coal and gas.

Projections of future energy scenarios present various possibilities in terms of the magnitude of woodfuel use in the future. The *World Energy Outlook 2000*, prepared by the International Energy Agency, projects an increase in the consumption of combustible renewables and waste (CRW; including fuelwood, charcoal, crop residues and animal wastes) between 1997 and 2020 in absolute terms in every region of the world. In developing countries, the primary energy supply through CRW will grow from 886 mtoe in 1997 to 1 103 mtoe in 2020, at an annual growth rate of 1%. However, the share of CRW in the total primary energy supply in developing countries will drop from about 24% in 1997 to 15% in 2020, owing to a more rapid expansion of commercial energy use as a result of rising income levels. However, in Africa the share would still remain high, at around 43% in 2020, based on a projection of relatively modest increases in income levels within the region.

In the recently published Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios, it is estimated that the largest renewable energy potentials in the medium term (to 2025) lie in the development of modern biomass (70 to 140 EJ), followed by solar (16 to 22 EJ) and wind energy (7 to 10 EJ). In the longer term, the maximum technical energy supply potential of biofuels is estimated to be 1 300 EJ, second to solar with a potential of around 2 600 EJ. However, the report points out some constraining factors, such as competition with agriculture for land for food production, productivity in biomass production, etc.

Important factors for the future of woodfuels

Recent developments that are likely to influence the future of woodfuels include further changes in energy and environmental policies that aim to promote the use of non-fossil fuels and the efforts to mitigate global warming. The changes in energy and environmental policies, as mentioned above, have already started, mainly in developed countries in Europe and North America, and are likely to evolve in the future, especially with the pressure to reduce carbon emissions to mitigate climate change. Climate change might provide an opportunity for developing countries to develop less carbon-intensive energy systems, which could involve the greater use of woodfuels.

In developing countries, owing to the decentralised nature of wood energy systems and the lack of adequate national capabilities, energy and forestry statistics seldom include the same level of woodfuel consumption detail as is available for other conventional energy sources, or for forest products. More accurate information on woodfuels needs to be collected and analysed in order to carry out effective policy planning and implementation, on both the energy and the forestry aspects.

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DEFINITIONS

In Table 9.1, the following definitions apply:

Land area is defined as the total area of a country, excluding areas under inland water bodies.

Forest area denotes the estimated total forest cover provided by natural forest and plantations.

Fuelwood production is the tonnage of wood in the rough produced for direct use as a fuel or for conversion into charcoal. Wood residues recycled to energy use are excluded.

TABLE NOTES

In Table 9.1, **Total land area** and **Forest area** have been derived from the FAO's *Global Forest Resources Assessment 2000* (FRA 2000), using Table 3: Forest cover 2000, based on FRA 2000 findings as of 19 January 2001.

The data shown on **Fuelwood production** reflect as far as possible those reported by WEC Member Committees in 2000/2001; if information was not available from this source, estimates for 1999 were projected from FAO time-series of fuelwood production (WEIS database).

Bearing in mind the uncertainty associated with virtually all wood energy statistics, the levels of fuelwood production shown in Table 9.1 should not be taken as definitive, precise measurements but as, in general, no more than indicative of the magnitude involved.

Where necessary, fuelwood volumes in cubic metres have been converted into tonnes by using an average density of 0.725.

Table 9.1 Wood: land area, forest area and fuelwood production in 1999

Excel File	Total land area	Forest area	Fuelwood production
	thousand square km		million tonnes
Algeria	2 382	21	1.6
Angola	1 247	698	4.6
Benin	111	27	2.5
Botswana	567	124	1.5
Burkina Faso	274	71	9.2
Burundi	26	1	5.0
Cameroon	465	239	11.2
Cape Verde	4	1	0.1
Central African Republic	623	229	2.4
Chad	1 259	127	1.7
Comoros	2	N	0.2
Congo (Brazzaville)	341	221	2.1
Congo (Democratic Rep.)	2 267	1 352	36.5
Côte d'Ivoire	318	71	6.9
Djibouti	23	N	0.1
Egypt (Arab Rep.)	995	1	1.8
Equatorial Guinea	28	18	0.3
Eritrea	101	16	2.9
Ethiopia	1 000	46	48.0
Gabon	258	218	0.8
Gambia	10	5	0.7
Ghana	228	63	6.5
Guinea	246	69	5.7
Guinea-Bissau	28	22	0.3
Kenya	569	171	29.3
Lesotho	30	N	1.2
Liberia	96	35	1.3
Libya/GSPLAJ	1 760	4	0.4
Madagascar	582	117	8.1
Malawi	94	26	8.2
Mali	1 220	132	5.7
Mauritania	1 025	3	0.2
Mauritius	2	N	N
Morocco	446	30	7.6
Mozambique	784	306	15.8
Namibia	823	80	1.5
Niger	1 267	13	3.1
Nigeria	911	135	91.6
Réunion	3	1	N
Rwanda	25	3	4.2
São Tome and Principe	1	N	0.1
Senegal	193	62	3.3
Seychelles	N	N	N
Sierra Leone	72	11	2.3
Somalia	627	75	2.7
South Africa	1 221	89	8.2
Sudan	2 376	616	6.4
Swaziland	17	5	0.5
Tanzania	884	388	34.5
Togo	54	5	2.4
Tunisia	155	5	2.1
Uganda	200	42	16.2
Western Sahara	266	2	
Zambia	743	313	8.0
Zimbabwe	387	190	10.8
Total Africa	**29 636**	**6 499**	**428.3**

Table 9.1 Wood: land area, forest area and fuelwood production in 1999 contd.

	Total land area	Forest area	Fuelwood production
	thousand square km		million tonnes
Bahamas	10	8	
Belize	23	13	0.1
Canada	9 221	2 446	2.2
Costa Rica	51	20	2.5
Cuba	110	23	1.6
Dominica	1	N	N
Dominican Republic	48	14	3.2
El Salvador	21	1	5.0
Greenland	342		
Guadeloupe	2	1	N
Guatemala	108	29	9.3
Haiti	28	1	5.2
Honduras	112	54	6.6
Jamaica	11	3	0.8
Martinique	1	N	N
Mexico	1 909	552	17.2
Nicaragua	121	33	2.9
Panama	74	29	1.2
Puerto Rico	9	2	
Trinidad & Tobago	5	3	N
United States of America	9 159	2 260	59.0
Other	4	1	N
Total North America	**21 370**	**5 493**	**116.8**
Argentina	2 737	346	2.6
Bolivia	1 084	531	1.4
Brazil	8 457	5 325	69.5
Chile	749	155	11.6
Colombia	1 039	496	12.0
Ecuador	277	106	3.2
French Guiana	88	79	N
Guyana	197	169	0.6
Paraguay	397	234	5.5
Peru	1 280	652	5.8
Surinam	156	141	0.1
Uruguay	175	13	1.5
Venezuela	882	495	0.6
Other	12		
Total South America	**17 530**	**8 742**	**114.4**
Afghanistan	652	14	4.7
Armenia	28	4	N
Azerbaijan	87	11	N
Bangladesh	130	13	24.1
Bhutan	47	30	1.3
Brunei	5	4	N
Cambodia	177	93	5.1
China	9 327	1 635	129.6
Cyprus	9	1	N
Georgia	70	30	0.1
India	2 973	641	203.5
Indonesia	1 826	1 055	115.4
Japan	377	241	0.5
Kazakhstan	2 671	122	0.2
Korea (Democratic People's Rep.)	120	82	3.5
Korea (Republic)	99	63	3.3
Kyrgyzstan	192	10	N
Laos	231	126	3.0
Malaysia	329	193	5.6
Mongolia	1 566	106	0.2

Table 9.1 Wood: land area, forest area and fuelwood production in 1999 contd.

	Total land area	Forest area	Fuelwood production
	thousand square km		million tonnes
Myanmar (Burma)	658	344	14.1
Nepal	143	39	15.3
Pakistan	771	25	24.3
Philippines	298	58	29.2
Singapore	1	N	
Sri Lanka	65	19	7.0
Tajikistan	141	4	N
Thailand	511	148	25.1
Turkey	770	102	17.6
Turkmenistan	470	38	N
Uzbekistan	414	20	N
Vietnam	325	98	23.3
Other	N	N	N
Total Asia	**25 483**	**5 369**	**656.0**
Albania	27	10	0.3
Austria	83	39	5.3
Belarus	207	94	0.6
Belgium & Luxembourg	33	7	0.4
Bosnia-Herzogovina	51	23	
Bulgaria	111	37	0.9
Croatia	56	18	1.3
Czech Republic	77	26	1.6
Denmark	42	5	0.7
Estonia	42	21	1.2
Finland	305	219	3.4
FYR Macedonia	25	9	0.4
France	550	153	20.0
Germany	349	107	10.6
Greece	129	36	0.8
Hungary	92	18	1.1
Iceland	100	N	
Ireland	69	7	0.1
Italy	294	100	3.7
Latvia	62	29	3.7
Lithuania	65	20	1.9
Moldova	33	3	0.3
Netherlands	34	4	0.1
Norway	307	89	0.6
Poland	304	93	7.0
Portugal	92	37	0.4
Romania	230	65	11.0
Russian Federation	16 889	8 514	14.0
Serbia, Montenegro	102	29	N
Slovakia	48	20	0.3
Slovenia	20	11	0.9
Spain	499	144	2.3
Sweden	412	271	8.0
Switzerland	40	12	1.4
Ukraine	579	96	1.3
United Kingdom	242	26	0.3
Other	1	N	N
Total Europe	**22 601**	**10 392**	**105.9**
Bahrain	1	N	
Iran (Islamic Rep.)	1 622	73	0.3
Iraq	437	8	0.1
Israel	21	1	N
Jordan	89	1	N
Kuwait	18	N	
Lebanon	10	N	0.3

Table 9.1 Wood: land area, forest area and fuelwood production in 1999 contd.

	Total land area	Forest area	Fuelwood production
	thousand square km		million tonnes
Oman	212	N	
Qatar	11	N	
Saudi Arabia	2 150	15	
Syria (Arab Rep.)	184	5	
United Arab Emirates	84	3	
Yemen	528	4	
Other	6		
Total Middle East	**5 373**	**110**	**0.7**
Australia	7 682	1 581	6.9
Fiji	18	8	N
French Polynesia	4	1	N
New Caledonia	18	4	N
New Zealand	268	79	0.5
Papua New Guinea	453	306	4.0
Samoa	3	1	0.1
Solomon Islands	28	25	0.1
Vanuatu	12	4	N
Other	5	2	N
Total Oceania	**8 491**	**2 011**	**11.6**
TOTAL WORLD	**130 484**	**38 616**	**1 433.7**

COUNTRY NOTES

The Country Notes on wood are based upon material supplied by WEC Member Committees in 2000/2001, supplemented by information culled by the editors from national and international sources, in particular:

- publications of the FAO's Regional Wood Energy Development Programme in Asia (RWEDP) – *Wood Energy News*, country reviews, etc.;
- *Energy Balances of Non-OECD Countries 1997-1998*; 2000; International Energy Agency.

BANGLADESH

Bangladesh has relatively little forest cover, accounting for only 10% of its land area. Reflecting its status as one of the world's least developed countries, it has a very low per-capita consumption of energy, of which at least half is supplied from biomass fuels. Within this category, agricultural residues (mainly from rice production) are the principal component, with fuelwood, animal dung and tree residues having smaller shares.

An estimated 63% of fuelwood is used in domestic cooking, with the balance consumed in industrial or commercial applications.

The bulk of Bangladesh's fuelwood supplies are obtained not from natural forest, plantations or unclassified state forest, but from non-forest lands. Homestead lands have been estimated to supply about two-thirds of total fuelwood, with much smaller contributions provided by other types of non-forest lands, such as village land, cropland, roads, canal embankments, marginal and waste land.

BRAZIL

Based on FAO data, Brazil's forest area of some 5.3 million square km is the second largest in the world, after that of the Russian Federation. About 63% of the land area of Brazil is presently under forest.

The production of fuelwood has been on a declining trend during the present decade: the 1999 total of 69.5 million tonnes was only 65% of the level in 1989 (106.3 million tonnes), mainly owing to a fall in the demand for charcoal. Within the 1999 figure, 25 million tonnes were transformed into charcoal and a relatively minor amount (less than 0.5 million tonnes) used for electricity generation. The sectoral breakdown of the 44 million tonnes of final consumption was: residential sector 47%, industry 39%, agriculture 13% and commerce 1%. Major industrial markets for wood included food and beverages, building material/ceramics and paper/pulp.

Charcoal consumption was 6.25 million tonnes in 1999, of which some 89% was consumed in the industrial sector (mostly by the iron and steel industry); the residential sector accounted for about 9% of consumption.

CANADA

Canada has the world's third largest forest area – over 2.4 million square km – which supports a massive forest-based sector: timber, pulp and paper and a host of associated products. These industries generate very large amounts of residues – chiefly bark, sawdust and shavings from the timber industry and black liquor (sulphite lyes) from the paper industry. Wood-based production of electrical or mechanical energy in Canada uses these residues (and not wood as such) as fuel – see Chapter 10: Biomass (other than Wood).

If the availability of surplus residues declines in the future as a result of, for instance, improved mill technologies or increased utilisation rates, there is a possibility of wood fibre being grown specifically for use as fuel. The Canadian Forest Service has supported research on energy plantations for many years through the Energy from the Forest (ENFOR) Project. The main purpose of this research is to develop fast-growing poplars and willows for the production of forest biomass for energy.

CHINA

The density of forest cover in China's vast land area is only moderate overall, at under 18%, but the physical extent of forest land is still enormous – over 1.6 million km^2, the fifth largest national total in the world. Biomass fuels provided 20% of China's inland primary energy supplies in 1998; fuelwood probably accounts for about 45% of total biomass, and therefore contributed around 9% of primary energy. Annual production of fuelwood, based on FAO estimates, is currently in the order of 130 million tonnes.

Biomass energy (principally fuelwood and crop residues) plays an important role in the energy economy of rural China, where some 70% of its population resides. Fuelwood's share of rural energy consumption is probably 15%-20%; it has been on a declining trend over the long term, as (inter alia) the penetration of fuel-saving stoves has risen and alternative fuels (e.g. coal) have increased their share. Overall, urban consumers account for only a small fraction of total fuelwood use – probably between 5% and 10%.

An appreciable proportion of China's fuelwood supply is obtained from non-forest sources: in 1993, for example, a survey found that nearly 47% of usable fuelwood yield emanated from sources such as cash forests (trees grown for their leaves, seeds, etc.), "four-sides" trees (planted around fields, alongside roads, etc.), brush and sparsely-wooded land.

CZECH REPUBLIC

There are currently no tree-planting programmes for energy production purposes. Several small firms produce equipment for burning biofuels, with capacities ranging from 7 kW (stoves) to 50 kW (boilers for family houses); there are also three producers of larger equipment (100-500 kW) for blocks of buildings, and three producers of equipment with a capacity of 2-3 MW and higher, for large plants and local cogeneration stations.

A fluid pressure gasification method for processing wood residues has been developed in the Czech Republic. A cogeneration unit for power and heat production from wood chips has been built in Skotnice: it has an electrical capacity of 32 kW_e and a heat capacity of 97 kW_t.

DENMARK

Three areas have been planted with different species of trees at varying densities, in order to explore the incremental availability of fuel as a function of species and density.

Several large-scale research and development programmes on the combined production of electricity and heat from wood fuels are being undertaken. Seven plants of various sizes are in operation.

Production of dry wooden pellets for fuel amounts to about 250 000 tonnes per annum. There are numerous projects for heat production using wood-based fuels: 48 district heating plants to burn forest chips, 21 fired with wooden pellets and 8 forest chip-fired CHP stations.

FINLAND

Leaving aside Russia, as being of a totally different order of magnitude, Finland possesses the second largest forest area in Europe; moreover the forested proportion of Finland's total land area is, at 72%, the highest of any European country.

Fuelwood production in 1999 is reported as some 3.4 million tonnes. The target of Finland's Wood Energy Research Programme is to increase small-scale use of wood by 45% between

1995 and 2010, and by 70% by 2025. Research in the area of wood-based liquid biofuels is mainly concentrated on flash-pyrolysis oil.

FRANCE

France has one of the largest areas of forest land (more than 150 000 square km) in Europe. Production of fuelwood in 1999 is reported to have been about 20 million tonnes. By far the greater part of this quantity is consumed in the residential sector.

A household survey by Ceren (Centre d'études et de recherches économiques sur l'énergie) indicates that French households consumed a total of 8.3 million toe of fuelwood in 1996, equivalent to around 25 million tonnes of wood. Wood was the primary space-heating fuel in some 3 million houses and 140 000 apartments; 2.2 million houses and 100 000 apartments regularly used wood as a supplementary fuel.

GERMANY

Forests cover almost one-third of Germany's surface area; public and privately-owned productive forests account for 92% of the total forest area. Production and consumption of fuelwood are not registered in official statistics: the figure shown in Table 9.1 is estimated, and refers to private households only. Other consumers of fuelwood are small industries and the agriculture sector. Some local and regional schemes are trying to promote the use of fuelwood, e.g. in small district-heating plants.

INDIA

Within a total land area of nearly 3 million km^2, India's forest land covers some 640 000 km^2, or 21.6%. Biomass fuels contributed 41% of total inland primary energy supplies in 1998; in India's rural areas, the percentage supplied by biomass (wood, animal dung and agricultural residues) rises to about 95. Whereas the use of dried dung and waste as fuel is widespread in agriculturally prosperous regions, wood is still the principal domestic fuel in poorer and less well-endowed regions. Overall, fuelwood is estimated to provide almost 60% of energy in rural areas and around 35% in urban areas.

Current annual consumption of fuelwood is estimated at 217 million tonnes, of which only about 18 million tonnes constitutes sustainable availability from forests: approximately half of fuelwood supplies is derived from TOF (trees outside forests) sources, such as farms, village woodlots, small plantations on private or government land, and trees or shrubs alongside roads, railways, canals, ponds etc. The balance of fuelwood supply represents non-sustainable drawings from forest areas plus miscellaneous gathering of woody material.

Besides its primary use as the almost universal rural fuel for domestic cooking and heating, fuelwood is also used in bakeries, hotels, brick and tile manufacture, and numerous small cottage industries.

It is to be noted that estimates of Indian fuelwood production/consumption, and especially of the breakdown by source or sector, are extremely conjectural, varying widely from agency to agency and from one estimate to another. Consequently any levels quoted above should be regarded as, at best, indicative.

INDONESIA

The Indonesian archipelago has a surface area of 1.83 million km^2, of which 1.05 million km^2 (or 58%) is forested. Biomass fuels (chiefly fuelwood) accounted for 37% of total primary energy supply in 1998.

Fuelwood is used by almost all rural households, principally for cooking, whilst many urban households meet part of their energy requirements from wood or charcoal. Wood fuels are also used by small-scale industries such as lime-burners and makers of bricks, ceramics and tiles.

Notwithstanding its wealth of forest resources, much of Indonesia's fuelwood is derived from non-forest sources. Java has been reported to derive about two-thirds of its fuelwood supplies from village lands.

JAPAN

Notwithstanding forest cover equivalent to 64% of its total land area, Japan uses a relatively modest amount of fuelwood – in the order of 0.5 million tonnes per annum. There are reported to be no special plans or projects to utilise wood as a fuel.

KENYA

About 30% of Kenya is forested, and wood is of great importance as a fuel, currently providing around 70% of primary energy supply. Wood fuel meets over 93% of rural household energy needs, whilst charcoal is the dominant fuel in urban households.

Besides being the standard cooking fuel for the majority of Kenyan households, fuelwood is also an important energy source for small-scale rural industries and for crop-drying (especially tobacco-curing).

Since the rate of fuelwood consumption exceeds that of replenishment, a number of measures have been adopted to rectify the supply-demand imbalance, in order to enhance environmental preservation. To achieve this objective, programmes aimed at promoting energy conservation through the use of technically efficient but cost-effective end-use technologies have been adopted. By means of programmes of public information and education, farmers are being encouraged to plant more trees, to increase the supply of tree seedlings and to engage in agro-forestry.

MALAYSIA

Well over half of Malaysia's land area is forested, but owing to (inter alia) the existence of substantial resources of crude oil, natural gas and hydropower, biomass fuels play a relatively small role in energy supply, accounting for only 5.5% of total inland primary energy in 1998. Within the biomass category, annual production of fuelwood is estimated to be some 7.5-8 million m^3, or circa 5.6 million tonnes. A substantial proportion of this amount is converted into charcoal, the annual consumption of which is approaching 500 000 tonnes.

Although industrial users account for a small part of the final consumption of fuelwood/charcoal, households take by far the major share (around 95%), with cooking as the main end-use.

MEXICO

Forests cover about 29% of Mexico's land area. Wood holds a modest place in the Mexican energy economy, currently accounting for just over 4% of total inland primary energy supply. All fuelwood consumption takes place in the residential sector, where its significance is markedly greater: in 1999 wood accounted for almost 36% of residential energy use, compared with just over 40% ten years previously.

The National Programme for Dendro-energy (a joint project of the Secretariat of Environment, Natural Resources and Fisheries (SEMARNAP) and FAO) is currently at a planning stage. It contemplates promoting the development of considerable amounts of land for multiple uses, including wood production from appropriate species.

MYANMAR

Although Myanmar is quite well-endowed with energy resources, both fossil-fuel and renewable, the consumption of oil, gas, coal and hydropower remains low: the bulk of primary energy supplies (77% in 1998) is furnished by biomass fuels, principally fuelwood.

Forest lands account for just over 50% of Myanmar's surface area, but the remaining major forests are in the north of the country, far from the main areas of fuel demand in the central and southern provinces. About 24% of total fuelwood supply comes from non-forest lands – homesteads, gardens, farms and wastelands. Total fuelwood production is in the region of 14 million tonnes per annum, according to FAO estimates, although other assessments indicate a substantially higher level of around 24 million tonnes.

PAKISTAN

Pakistan has a very small proportion of its total land area under forest – only some 25 000 km^2, or 3.2% of the total. In 1998, 39% of its inland primary energy supply was furnished by biomass fuels, of which more than one-third consisted of fuelwood. FAO estimates point to a 1999 level of fuelwood production of around 24 million tonnes.

Reflecting Pakistan's relative paucity of natural forest, almost all its fuelwood supplies come from trees grown on agricultural land. An agroforestry campaign over the past twenty years has greatly improved the supply of wood, both for fuel and for non-energy purposes.

PHILIPPINES

The Philippines' remaining forest resources are fairly moderate, with cover equivalent to just under 20% of its total land area.

According to the Philippines' Department of Energy data quoted in *The Woodfuel Scenario and Policy Issues in the Philippines*, FAO, Bangkok, June 2000, biomass fuels (within which fuelwood constituted about 62%) supplied 29.4% of total primary energy in 1997. Fuelwood consumption in that year is quoted as 42.2 million barrels of fuel oil equivalent, which corresponds to 6.1 million toe or about 19 million tonnes of wood. This last figure appears to be in line with the 1990 Philippine *Master Plan for Forestry Development*, which quotes total fuelwood supply (excluding wastewood) as equating to approximately 16 million tonnes in 1990 and a forecast of 18.5 million tonnes for 2000. In each year the major sources of fuelwood were given as farmlands and brushlands, with a share falling from 79% in 1990 to a forecast 63% in 2000.

By way of illustrating the uncertainties inherent in any discussion of fuelwood supply and demand, it may be noted that FAO Rome quote fuelwood production in 1997 as 37 858 000

m^3, equivalent to about 27.4 million tonnes (as compared with the figure of 19 million tonnes quoted above).

Fuelwood in the Philippines is primarily a household fuel, but other users include small-scale industries such as bakeries, furniture manufacturers and potteries, as well as certain larger industries such as sugar mills, where wood is used to supplement bagasse for steam-raising and electricity generation.

POLAND

The proportion of Poland's land area that is covered by forest is gradually increasing, and is now in the vicinity of 30%. Total annual production of wood is about 25 million m^3, of which about 13 million m^3 is used for energy purposes.

RUSSIAN FEDERATION

The Russian Federation has by far the largest area of forest land of any country in the world: more than 8.5 million km^2, an area greater than the sum of the next two largest forest lands – Brazil (5.3 million km^2) and Canada (2.4 million km^2). Russia's forests cover just over half of its land area.

Solid biomass, most of which is derived from wood, is estimated to have accounted for 0.7% of Russia's inland primary energy supply in 1998.

SOUTH AFRICA

Out of a total land area of more than 1.2 million km^2, South Africa's forests account for less than 90 000 km^2 – equivalent to 7.3% of the total.

Wood is the basic fuel for 3.2 million rural households, providing approximately 65% of their energy needs. Although South Africa's programme of electrification is reaching an increasing proportion of such households, fuelwood is expected to remain the dominant domestic energy source in rural areas for many years to come. Current consumption is estimated to be in excess of 8 million tonnes per annum.

The South African Government launched a rural forestry campaign with the slogan "Trees for the People" in 1992 in an effort to provide fuelwood to rural and informal communities.

SWEDEN

Apart from Russia, Sweden possesses the largest forested area in Europe, accounting for nearly two-thirds of its total land area. About 85% of its forest land is considered to be accessible and capable of sustaining wood production. Current annual production of fuelwood is about 8 million tonnes.

There are 14 000 ha of tree plantings (mainly salix) specifically for energy production, on the basis of short-rotation forestry.

Since 1998, governmental R&D programmes for energy have concentrated on cost-reduction measures and the introduction of new technology based on renewable energy sources. Support for R&D in industries and universities has increased, and it has been guided in a new direction. In 1999, the Swedish National Energy Administration contributed US$ 65 million to R&D and the private sector another US$ 45 million, most of it directed towards bioenergy.

Besides R&D, the state subsidises investments in biofuel-based CHP; US$ 45 million has been assigned for investment subsidies during the five-year period ending in 2002.

The research programmes managed by the Swedish National Energy Administration cover fuel-based energy systems, transportation, electricity generation, industry, buildings and energy system studies. The technical and agricultural universities carry out the bulk of Swedish bioenergy research; applied research is conducted through special programmes for which the various private sectors provide most of the finance, although substantial support is given via the Energy Technology Fund.

THAILAND

The supply and usage of wood fuels has been re-assessed since the 1998 Survey.

Of the 25 million tonnes of fuelwood consumed in 1999, 16 million tonnes were transformed into charcoal. Within direct use, about 78% was consumed by the residential/commercial sector (mostly in the rural areas), the balance by industrial users. In the residential/commercial sector, wood accounted for 25% of energy use, charcoal for 22%. A minor quantity of wood (142 000 tonnes) was used to generate electricity. Approximately 3.3 million tonnes of charcoal was produced, all of which was consumed in the residential/commercial sector.

UNITED KINGDOM

The United Kingdom's remaining forested land constitutes a relatively low proportion of its total land area – only slightly over 10% in 1999. The area of forest has, however, been gradually increasing in recent years. It is estimated that 85% of the total forest area can be regarded as productive forest, capable of sustaining wood production.

Total fuelwood production is of the order of 300 000 tonnes per annum, of which most is used directly as a household fuel in open fires, cooker boilers and other wood-burning stoves. Charcoal consumption for fuel is at a very modest level in the UK, estimated at around 5 000 tonnes per annum.

VIETNAM

There are almost 100 000 km^2 of forests, covering about 30% of the total land area. Biomass fuels provided two-third of Vietnam's primary energy supplies in 1998. Fuelwood probably accounted for about one-third of all biomass energy or around 22% of total primary energy: these levels are based on indications derived from FAO, which suggest that fuelwood production in 1999 was some 32 million m^3 (or 23 million tonnes). Other assessments have placed the level appreciable higher: as is usually the case, especially in developing countries, the true magnitude of fuelwood production/consumption remains imponderable.

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Chapter 10

BIOMASS
(OTHER THAN WOOD)

Previous Commentaries (e.g. Hall & House 1995; Hall & Rosillo-Calle, 1998), offered an overview of biomass energy potential which is still largely valid today. For this reason this commentary takes a slightly different approach, paying particular attention to the use of residues and efforts to modernise and upgrade biomass energy. It also briefly indicates the potential role of bio-energy in the mitigation of climate change.

This chapter deals with “Biomass other than wood”. This definition includes agricultural and wood/forestry residues and herbaceous crops grown specifically for energy but excludes forest plantations grown specifically for energy. Currently there are a number of dedicated energy plantations, e.g. Brazil, where there are about 3 million ha of eucalyptus plantations used for charcoal making; China, which has a plantation programme for 13.5 million ha of fuelwood by 2010; Sweden, where there are about 16 000 ha of willow plantations used for the generation of heat and power; and the USA, where some 50 000 ha of agricultural land has been converted to woody plantations, possibly rising to as much as 4 million ha (10 million acres) by 2020. But all current plantations have tended to follow traditional agricultural and forestry practices.

Municipal solid waste (MSW) is potentially a major source of energy. However, there are a number of reasons why this source of biomass will not be considered in this commentary (although data are included in the country notes): i) the nature of MSW, which comprises many different organic and non-organic materials; ii) difficulties and high costs associated with sorting such material, which make it an unlikely candidate for renewable energy except for disposal purposes; iii) re-used MSW is mostly for recycling, e.g. paper; iv) MSW disposal would be done in landfills or incineration plants.

It is well known that biomass is a very poorly documented energy source. Indeed lack of data has hampered sound decision-making when it comes to biomass energy. For example, a close examination of this chapter’s Country Notes illustrates the variations and discrepancies between the biomass resources reported by the WEC Member Committees quite well. The inability to fully address the indigenous biomass resource capability and its likely contribution to energy and development is still a serious constraint to the full realisation of this energy potential, despite a number of efforts to improve biomass energy statistics.

Previous commentaries estimated, roughly, that biomass consumption in rural areas of developing countries (including all types of biomass and end-uses) was about 1 tonne (15% moisture, 15GJ/t) per person/year and about 0.5 tonne in semi-urban and urban areas. This assumption is still generally valid today. It seems that while in relative terms traditional biomass energy consumption may be declining in some parts of the world, in absolute terms the total amount of biomass energy is increasing. There are many variations due to the large numbers of factors involved, such as availability of supply, climatic differences, population growth, socio-economic development, cultural factors, etc.

This commentary highlights some of the changes that have occurred since the previous Commentary in 1998. The growing interest in biomass energy in the late 1990's is the result of a combination of underlying factors, including:

i. rapid changes in the energy market worldwide, driven by privatisation, deregulation and decentralisation;
ii. greater recognition of the current role and future potential contribution of biomass as a modern energy carrier, combined with a general interest in other renewables (RE);
iii. its availability, versatility and sustainability;
iv. better understanding of its global and local environmental benefits and perceived potential role in climate stabilisation;
v. existing and potential development and entrepreneurial opportunities;
vi. technological advances and knowledge which have recently evolved on many aspects of biomass energy and other RE.

In addition, there are other more specific factors that are favouring the development of biomass energy:

i. growing concern with global climate change that may eventually drive a global policy on pollution abatement. For example, The Hague meeting (COP6), despite its failure, firmly established support for RE which could provide the basis for a global market;
ii. growing recognition among established conventional institutions of the importance of biomass energy, e.g. a World Bank 1996 report concluded that "energy policies will need to be as concerned about the supply and use of biofuels as they are about modern fuels…. (and)…. they must support ways to use biofuels more efficiently and sustainably";
iii. expected increases in energy demand, combined with current rapid growth of RE. The Global Environmental Facility (GEF) predicts that developing countries alone will need as much as five million MW of new electrical generation capacity in the next 40 years, most of which could be supplied by RE. For the two billion people who lack reliable energy, most of them in remote areas with little prospect of connecting to an electrical grid, RE remains one of the best options (GEF, 2001);
iv. a growing number of countries are introducing specific policies in support of RE, with biomass energy playing a central role;
v. environmental pressures will increase the price of fossil fuels as the cheaper sources are depleted. Also, as the external costs are

progressively incorporated into the final costs of energy, RE will be put onto a more equal footing with fossil fuels;

vi. despite the fact that some technologies have failed to live up to commercial expectations, technology is evolving rapidly and the time-span is being reduced. Significant advances have been made in gasification, co-firing, biogas production, etc. This is reflected in the growing number of modern applications, e.g. electricity generation, ethanol fuels blended with gasoline, biodiesel, etc. (See Rosillo-Calle, 2001).

A major challenge still remaining is how best to tackle the problems posed by the traditional uses of bio-energy e.g. low combustion efficiency and health hazards. For biomass energy to have a future, it must provide people with what they want, e.g. cheap and convenient fuels, lighting, power, etc. at an affordable price.

Current and potential future uses of bio-energy.

The increasing interest in biomass for energy since the early 1990's is well illustrated by the large number of energy scenarios showing biomass as a potential major source of energy in the 21st century. Hoogwijk et al (2001) have analysed 17 such scenarios, classified into two categories: i) Research Focus (RF) and ii) Demand Driven (DD). The estimated potential of the RF varies from 67 EJ to 450 EJ for the period 2025-2050, and that of the DD from 28 EJ to 220 EJ during the same period. The share of biomass in the total final energy demand lies between 7% and 27%. For comparison, current use of biomass energy is about 55 EJ.

Biomass resources are potentially the world's largest and most sustainable energy source - a renewable resource comprising 220 billion oven-dry tonnes (about 4 500 EJ) of annual primary production (Hall & Rao, 1999). The annual bio-energy potential is about 2900 EJ, though only 270 EJ could be considered available on a sustainable basis and at competitive prices. The problem is not availability but the sustainable management and delivery of energy to those who need it.

Residues are currently the main sources of bio-energy and this will continue to be the case in the short to medium term, with dedicated energy forestry/crops playing an increasing role in the longer term. The expected increase of biomass energy, particularly in its modern forms, could have a significant impact not only in the energy sector, but also in the drive to modernise agriculture, and on rural development.

Utilisation of residues.

Residues are a large and under-exploited potential energy resource, and present many opportunities for better utilisation. There have been many attempts to estimate global production and use of residues, but with large variations, e.g. Woods & Hall (1994) estimated these residues at 93 EJ. However, there are a number of important factors that need to be addressed when considering the use of residues for energy. Firstly, there are many other alternative uses, e.g. animal feed, erosion control, use as animal bedding, use as fertilisers (dung), etc. Secondly, there is the problem of agreeing on a common methodology for determining what is and what is not a recoverable residue, e.g. estimates often vary by a factor of five. This is due, among other things, to variations in the amount of residue assumed necessary for maintaining soil organic matter, soil erosion control, efficiency in harvesting, losses, non-energy uses, disagreement about animal manure production, etc. Nonetheless, many of these residues are readily available and represent a good opportunity at low cost.

Agricultural residues.
For the reasons stated above, only rough estimates are possible. For example, Smil (1999) has calculated that in the mid-1990's the amount of crop residues amounted to about 3.5 to 4 billion tonnes annually, with an energy content representing 65 EJ, or 1.5 billion tonnes oil equivalent. Hall et al (1993) estimated that just using the world's major crops (e.g. wheat, rice, maize, barley, and sugar cane), a 25% residue recovery rate could generate 38 EJ and offset between 350 and 460 million tonnes of carbon per year. There is no doubt that a considerable proportion of the residues are wasted or handled inappropriately, causing undesirable effects from an environmental, ecological and food production viewpoint. For example, Andreae (1991) estimated that over 2 billion tonnes of agricultural residues were burned annually world-wide, while Smil (1999) estimates the total as between 1.0 and 1.4 billion tonnes, producing 1.1 to 1.7 billion tonnes/yr of CO_2. The worldwide generation capacity from agricultural residues (straw, animal slurries, green agricultural wastes) is estimated to be about 4 500 MW_t.

The most reasonable approach would be to concentrate efforts on the most promising residues from the sugar cane, pulp and paper, and sawmill industrial sectors. More than 300 million tonnes of bagasse are produced worldwide, mostly used as fuel in sugar cane factories. FAO data show that about 1 248 million tonnes of cane was produced in 1997. About 25% is bagasse, representing some 312 million tonnes. The energy content of one tonne of bagasse (50% moisture content) is 2.85 GJ/tonne cane milled. This excludes barbojo (top and leaves) and trash - representing the largest energy fraction of the sugar cane (55%) - which is currently mostly burned off or left to rot in the fields. This large potential is thus currently almost entirely wasted.

Table 10.1 shows the estimated potential of bagasse available by country in 1999. The largest producing region is Asia with 131 million tonnes, followed by South America with about 89 million tonnes. Sugar producers have been using bagasse to raise steam for on-site processes for centuries, but very inefficiently. However, more recently economic pressures have forced many sugar-cane mills to look for alternatives and to achieve greater energy self-sufficiency, and some are selling electricity to the national grids. Interest in cogeneration has increased considerably in many sugar cane producing countries, of which Brazil, India, Thailand and Mauritius are good examples. A recent study (Larson & Kartha, 2000) shows that in developing countries as a whole "excess" electricity (i.e. above and beyond that needed to run the sugar/ethanol mill) could amount to 15% to 20% of the projected electricity generation from all sources in such countries in 2025, or about 1 200 TWh/yr out of a total production of over 7 100 TWh. Thus it makes good economic sense to take maximum advantage of these readily available resources.

Forestry residues.
Forestry residues obtained from sound forest management can enhance and increase the future productivity of forests. One of the difficulties is to estimate, with some degree of accuracy, the potential of residues that can be available for energy use on a

national or regional basis, without more data on total standing biomass, mean annual increment, plantation density, thinning and pruning practices, current utilisation of residues, etc. Recoverable residues from forests have been estimated to have an energy potential of about 35 EJ/yr (Woods & Hall, 1994). A considerable advantage of these residues is that a large part is generated by the pulp and paper and sawmill industries and thus could be readily available. Currently, a high proportion of such residues is used to generate energy in these industries, but there is no doubt that the potential is considerably greater. For example, Brazil's pulp and paper industry generates almost 5 mtoe of residues that is currently largely wasted. The estimated global generation capacity of forestry residues is about 10 000 MW_e.

Livestock residues.

The potential of energy from dung alone has been estimated at about 20 EJ worldwide (Woods & Hall, 1994). However, the variations are so large that figures are often meaningless. These variations can be attributed to a lack of a common methodology, which is the consequence of variations in livestock type, location, feeding conditions, etc. In addition, it is questionable whether animal manure should be used as an energy source on a large scale, except in specific circumstances. This is because of:

i. its greater potential value for non-energy purposes: e.g. if used as a fertiliser it may bring greater benefits to the farmer;
ii. it is a poor fuel and people tend to shift to other better quality biofuels whenever possible;
iii. the use of manure may be more acceptable when there are other environmental benefits, e.g. the production of biogas and fertiliser, given large surpluses of manure which can, if applied in large quantities to the soil, represent a danger for agriculture and the environment, as is the case in Denmark;
iv. environmental and health hazards, which are much higher than for other biofuels. (Rosillo-Calle, 2001).

Energy forestry/crops.

Energy crops can be produced in two main ways: i) as dedicated energy crops in land specifically devoted to this end and ii) intercropping with non-energy crops. Energy forestry/crops have considerable potential for improvement through the adoption of improved management practices. It is difficult to predict at this stage what will be the future role of biomass specifically grown for energy purposes. This is, in many ways, a new concept for the farmer, which will have to be fully accepted if large-scale energy crops are to form an integral part of farming practices.

In the past decade a large number of studies have tried to estimate the global potential for energy from future energy forestry/crop plantations. These range from about 100 million ha to over a billion ha, e.g. Hall et al (1993) estimated that as much as 267 EJ/yr could be produced from biomass plantations alone, requiring about one billion hectares. However, it is highly unlikely that such forestry/crops would be used on such a large scale, owing to a combination of factors, such as land availability, possible fuel versus food conflict, potential climatic factors, higher investment cost of degraded land, land rights, etc. The most likely scenario would be at the lower end of the scale, e.g. 100-300 million ha.

Modern applications of bio-energy.
For biomass energy to have a future, it must be able to provide people with things they want, e.g. lighting, electricity, water pumping, etc. Modern applications simply mean clean, convenient, efficient, reliable, economically and environmentally sustainable uses. There already exist many mature technologies which can meet such criteria, and which are not necessarily more expensive than fossil fuels if all costs are internalised.

The modernisation of biomass embraces a range of differing technologies that can be grouped into:

a) biomass-fired electric power plants/CHP;
b) liquid fuels e.g. bio-ethanol and bio-diesel;
c) biogas production technology;
d) improved cookstove technology.

There are many modern applications including:

i household applications, e.g. improved cooking stoves, use of biogas, ethanol, etc;
ii cottage industrial applications e.g. brick-making, bakeries, ceramics, tobacco curing, etc;
iii large industrial applications, e.g. CHP/electricity generation, etc.

One of the most promising areas for modernisation of biomass energy on a large industrial scale is the sugar cane, pulp and paper and sawmill industries, as demonstrated by various studies.

The pace of technological advance is opening up many new opportunities for RE in general, and biomass-based high-quality fuels in particular. Some of the relevant advances in bio-energy production and use include improved integrated biomass gasifier/gas turbine (IBGT) systems for power generation and gas turbine/steam turbine combined cycle (GTCC); circulating fluidised bed (CFB) and integrated gasification combined cycles (IGCC); cogeneration, co-firing; bio-ethanol production; improved techniques for biomass harvesting, transportation and storage; bio-diesel technology; continuous fermentation, e.g. simultaneous saccharification and fermentation; improved processes for obtaining ethanol from cellulosic material; better use of by-products; production of methanol and hydrogen from biomass; fuel cell vehicle technology, etc.

Gasification.
Gasification is the main alternative to combustion for power generation. There are many examples of biomass gasification projects in the RD&D stage, although the only technologies commercially deployed are CFB atmospheric pressure, air-blown units in biomass-based industries where they provide hot fuel gas for lime kilns, boilers, etc. (Walter et al, 2000). There are also various IGCC demonstration plants around the world, e.g. the Varnamo plant, the world's first biomass-fuelled IGCC plant, developed by Sydkraft AB, Sweden, which produces 6 MW_e and 9 MW_t.

Many small-scale gasification systems have been developed in the past few decades, many of which have failed to deliver the expected results. During the 1990's interest has grown again, mostly driven by concern over fossil fuels and their impact on climate change. (see Walter et al, 2000).

Substantial technological development and demonstration programmes have been carried out in the past two decades in a number of developing countries, e.g. China, India, Philippines, Thailand, etc. In India some 1 700 small units have been installed since 1987, with a current installed capacity of about 35 MW: this is one of the most comprehensive biomass gasification programmes in the range of small- to medium-scale gasifiers in the world. The major focus has been on the use of modified diesel engines to run in a dual-fuel mode (Jain, 2000).

Biomass Co-firing.
Co-firing with fossil fuels, particularly coal, has received considerable attention, especially in Denmark, the Netherlands and the USA. Biomass can be blended in differing proportions, ranging from 2% to 25+%. Extensive tests show that biomass energy can provide about 15% of the total energy input, with modifications only to the feed intake systems and burner. Co-firing has been evaluated for a variety of boiler technologies e.g. pulverised coal, cyclones, fluidised bed, etc. The technical feasibility of biomass co-firing is largely proven, although some problems still remain, e.g. effects on boiler efficiency, slagging, fuel feed control, combustion stability, fuel delivery, etc. One reason why biomass co-firing has not been put into commercial practice is because the economics are unfavourable, owing to the low cost of coal- and gas-based generation, and the low capital cost of GTCC power plants. The most critical factors are fuel costs and the capital cost of the modifications to the power plant to permit co-firing. Yet despite all these problems, biomass co-firing with coal in existing power boilers seems to be one of the most economical ways to use biomass for energy on a large scale in the near future. Co-firing in existing coal-fired power plants makes it possible to achieve greater efficiency in converting biomass into electricity compared to 100% wood-fired boilers. For example, biomass combustion efficiency to generate electricity would be close to 33%-37% when fired with coal. There are also important environmental benefits, e.g. lower sulphur emissions and about a 30% reduction in oxides of nitrogen (see NREL website: http://www.eren.doe.gov/biopower).

Micro-power.
Micro power also known as distributed generation, on-site generation, small-scale generation, self-generation, etc. offers the potential for a much cleaner environment. For the two billion people who remain without electricity, micro-power may represent one of their best hopes. The trend towards more open, decentralised, competitive electricity systems, may present many opportunities for the introduction of small-scale power. Proponents of micro-turbines believe that this technology will revolutionise the power industry.

Micro-power technologies can use renewable sources, e.g. small gasifier applications, as is the case in China and India. Ranging from 15 to 500 kW, these turbines have the advantage of being low-cost, easy to manufacture, long-lived, and simple to operate and maintain (see Harrison et al, 2000). The current biomass-based technology mostly used for distributed power is a fixed downdraft gasifier coupled with an internal combustion engine. Recent market projections indicate that the market for generators below 10 MW could represent a significant proportion of the 200 GW of new capacity added by 2003 worldwide, compared to the 17-35 GW estimated potential in 1999 (Dunn, 2000).

Tri-generation.
Tri-generation is also a new concept, which could potentially bring major benefits to many rural areas. Village-scale tri-generation, based on gasification of crop residues and use of microturbines for CHP, is said to offer a major promise in achieving multiple economic and environmental goals for rural development simultaneously. For example, the potential tri-generation based on surplus residues in China alone has been estimated at 22 GWe (Henderik & Williams, 2000). Other wood-based technologies which are developing rapidly include woodchip boilers, two-stage combustion log boilers, catalytic stoves and two-stage combustion stoves, wood pellet boilers, etc.

Liquid and gaseous fuels.
In the 1970's and 1980's, owing to high oil prices, there was considerable interest in ethanol fuel and biogas, but this interest subsided considerably in the late 1980's and 1990's as oil prices declined in real terms. However, in the late 1990's interest picked up again, largely for environmental and social reasons, helped by changes in the international energy markets.

Ethanol fuel.
The countries that pioneered ethanol fuel production on a large scale were Brazil, followed by the USA and, on a much smaller scale, the EU, Argentina, Kenya, Malawi, etc. Current world production of ethanol fuel is about 20 to 21 billion litres annually. There are no major new programmes in the pipeline on the scale of Brazil's ProAlcool. Ethanol is mostly used blended with gasoline in various proportions, and in a small percentage with diesel. The most dynamic market is the USA, followed by the EU, while the Brazilian market is stagnating. Various countries are considering the introduction of small-scale ethanol fuel programmes for blending with gasoline, e.g. Mexico, India, Argentina, Colombia, etc.

Ethanol fuel is a growing market, as it has a considerable potential for substituting oil given the right conditions. Predictions vary enormously depending on when cellulose, the most abundant raw material, can be used to produce ethanol commercially. For example, ORNEL estimates indicate that by 2020 over 30 billion litres (8 billion US gallons) could be obtained from cellulose-based material in the USA alone. The environmental benefits could be enormous, since about 2.3 tonnes of CO_2 are saved for each tonne of ethanol fuel, excluding other emissions, e.g. SO_2, although this may be debatable. The market for ethanol is not confined to road transport: it has many other applications, e.g. co-generation, domestic appliances, chemical applications, aviation fuel.

Carbon sequestration versus Carbon sink.
The considerable potential of biomass as a carbon sink and as a substitute for fossil fuels has long been recognised, e.g. in the Kyoto Protocol, articles 3.3 and 3.4. The Intergovernmental Panel on Climate Change (IPCC) estimates that between 60 and 87

billion tonnes of carbon could be stored in forests between 1990 and 2050, or between 12-15% of the forecast fossil fuel emissions. Various strategies have been put forward to tackle GHG emissions, including:

- i sustainable production and use of energy resources that result in neutral CO_2 production;
- ii sequestration of CO_2, which creates carbon sinks. Since it was first proposed in 1977 there have been numerous analyses of the potential for forests to mitigate the global CO_2-induced greenhouse effect by sequestering carbon in their standing biomass. Growing trees as a long-term carbon store will be important only where the creation of new forest reserves is deemed desirable for environmental or economic reasons, and on low-productivity land;
- iii direct substitution of fossil fuels, which seems to be the most advantageous and appropriate strategy, with its greater environmental, energy, and ecological benefits.

The potential greater benefits from the "direct substitution strategy" (DSS) appear to have been confirmed by various studies, e.g. Hall et al. (2000) indicate that displacing fossil fuel with biomass grown sustainably, and converted into useful energy by modern conversion technologies, would be more effective in decreasing atmospheric CO_2 than sequestering carbon in trees. The extent to which biomass energy would decrease CO_2 emissions depends on many factors. For example, the greater reactivity and lower sulphur content of wood compared with coal gives it considerable advantages in advanced conversion technologies. Thus, if biomass is considered primarily as a substitute for coal, using modern conversion technologies for producing either electricity or liquid synfuels, the effect on atmospheric CO_2 would be comparable to that which could be achieved with carbon sequestration, per tonne of biomass produced.

Overall, the DSS strategy offers greater benefits because: i) biomass energy can substitute fossil fuel carbon emissions directly and owing to potential future technological developments this option can bring even greater benefits in the longer term; ii) compared with sink-based options, bioenergy-based mitigation projects are less subject to measurement uncertainty; iii) a bioenergy-based project satisfies a specific demand for energy in replacement of fossil fuels: in this sense it differs fundamentally as demand cannot be shifted to another location; iv) emissions reduction through bioenergy activities are irreversible, since they are a direct consequence of fossil fuels replacement; v) IPCC data shows that over time biomass energy options are more land-efficient than biomass sink options (e.g. see Kartha, 2001).

The Kyoto Protocol (KP) has many shortcomings, many of which subsequent meetings have tried to put right. For example, the "carbon sequestration strategy" worked out by the Protocol suffered from a number of serious difficulties that have not been fully addressed. Despite the clouded uncertainty and the political unwillingness of some countries (e.g. the USA) to implement its outcome, the KP can still present many opportunities and challenges to biomass energy enthusiasts.

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Table 10.1 Bagasse: estimated potential availability - 1999

Excel files	Cane sugar production	Bagasse potential availability
	thousand tonnes	
Angola	32	104
Burkina Faso	30	97
Burundi	23	75
Cameroon	52	170
Chad	32	105
Congo (Brazzaville)	60	196
Congo (Democratic Rep.)	65	212
Côte d'Ivoire	152	497
Egypt (Arab Rep.)	939	3 060
Ethiopia	235	765
Gabon	16	52
Guinea	25	82
Kenya	512	1 670
Madagascar	85	277
Malawi	187	611
Mali	31	102
Mauritius	396	1 290
Morocco	125	408
Mozambique	46	149
Nigeria	17	55
Senegal	95	310
Sierra Leone	7	23
Somalia	20	66
South Africa	2 547	8 303
Sudan	635	2 071
Swaziland	571	1 862
Tanzania	114	370
Togo	3	10
Uganda	137	447
Zambia	210	685
Zimbabwe	583	1 902
Total Africa	**7 983**	**26 025**
Barbados	53	173
Belize	124	404
Costa Rica	378	1 231
Cuba	3 875	12 632
Dominican Republic	421	1 372
El Salvador	585	1 907
Guatemala	1 687	5 500
Haiti	10	33
Honduras	190	619
Jamaica	212	690
Mexico	5 030	16 397
Nicaragua	351	1 144
Panama	177	576
St. Christopher-Nevis	20	65
Trinidad & Tobago	92	299
United States of America	3 753	12 236
Total North America	**16 957**	**55 279**
Argentina	1 882	6 135
Bolivia	293	956
Brazil	20 646	67 304
Colombia	2 241	7 305
Ecuador	556	1 812

Table 10.1 Bagasse: estimated potential availability – 1999 contd.

	Cane sugar production	Bagasse potential availability
	thousand tonnes	
Guyana	336	1 094
Paraguay	112	364
Peru	655	2 135
Uruguay	9	29
Venezuela	535	1 744
Total South America	**27 264**	**88 881**
Bangladesh	162	529
China	8 574	27 950
India	17 406	56 744
Indonesia	1 490	4 858
Japan	187	611
Malaysia	107	349
Myanmar (Burma)	43	140
Nepal	15	49
Pakistan	3 699	12 059
Philippines	1 913	6 237
Sri Lanka	19	61
Taiwan, China	295	962
Thailand	5 456	17 785
Vietnam	878	2 862
Total Asia	**40 244**	**131 197**
Unspecified	154	502
Total Europe	**154**	**502**
Iran (Islamic Rep.)	280	914
Total Middle East	**280**	**914**
Australia	5 514	17 974
Fiji	377	1 229
Papua New Guinea	47	154
Total Oceania	**5 938**	**19 358**
TOTAL WORLD	**98 821**	**322 156**

Sources:
Cane sugar production from the *I.S.O. Sugar Yearbook 1999*, International Sugar Organization
Bagasse potential availability conversion factor from United Nations *Energy Statistics Yearbook 1997* (assumes a yield of 3.26 tonnes of fuel bagasse at 50% humidity per tonne of cane sugar produced)

COUNTRY NOTES

The Country Notes on biomass reflect the data and comments provided by WEC Member Committees in 2000/2001, supplemented where necessary by information provided for the 1998 WEC *Survey of Energy Resources*.

ARGENTINA

Biomass type:

Sugar cane bagasse	quantity of raw material available	7	million tonnes
	ethanol fuel production	3 816	TJ
	electricity generating capacity	74 063	kW
	electricity generation	618	TJ
	direct use from combustion	34 822	TJ
	total energy production	39 256	TJ
Forestry/wood-processing	quantity of raw material available	6.9	million tonnes
	electricity generating capacity	106 840	kW
	electricity generation	1 431	TJ
	direct use from combustion	65 647	TJ
	total energy production	67 078	TJ

AUSTRALIA

Biomass type:

Municipal solid waste	biogas production	5 330	TJ
	electricity generation	1 360	TJ
Sugar cane bagasse	quantity of raw material available	11.460	million tonnes
	electricity generation	2 340	TJ
	total energy production	108 400	TJ
Forestry/wood-processing	quantity of raw material available	6.887	million tonnes
	electricity generation	80	TJ
	total energy production	109 600	TJ
Sewerage	biogas production	3 660	TJ

Data refer to 1998-99

AUSTRIA

Biomass type:

Municipal solid waste	quantity of raw material available	1.03	million tonnes
	direct use from combustion	3 758	TJ
	total energy production	10 456	TJ
Other biomass	quantity of raw material available	5.65	million tonnes
	direct use from combustion	26 490	TJ
	total energy production	47 178	TJ

BELGIUM

Biomass type:

Municipal solid waste	quantity of raw material available	1.1	million tonnes
	electricity generating capacity	76 600	kW
	electricity generation	1 765	TJ
Black liquor/bark	quantity of raw material available	0.2	million tonnes
	electricity generating capacity	31 000	kW
	electricity generation	585	TJ

Data refer to 1996

BOLIVIA

Biomass type:

Animal dung	direct use from combustion	3 270	TJ
Sugar cane bagasse	direct use from combustion	10 458	TJ
Crop residues	direct use from combustion	307	TJ

Data refer to 1996

BRAZIL

Biomass type:

Sugar cane bagasse	quantity of raw material available	82.3	million tonnes
	electricity generating capacity	1 000 000	kW
	electricity generation	14 798	TJ
	direct use from combustion	689 200	TJ
	total energy production	723 701	TJ
Wood residues	quantity of raw material available	2.2	million tonnes
	electricity generation	1 505	TJ
	direct use from combustion	19 443	TJ
	total energy production	23 027	TJ
Cane juice *	quantity of raw material available	89.4	million tonnes
	ethanol production capacity †	302 100	TJ/year
	yield of ethanol	2.25	GJ/tonne
	ethanol production¶	201 506	TJ
	total energy production	224 570	TJ
Molasses	quantity of raw material available	9.3	million tonnes
	yield of ethanol	7.27	GJ/tonne
	ethanol production¶	67 600	TJ
	total energy production	69 899	TJ
Black liquor	quantity of raw material available	9.7	million tonnes
	electricity generating capacity ‡	520 000	kW
	electricity generation	10 572	TJ
	direct use from combustion	92 548	TJ
	total energy production	116 186	TJ

* 1 000 kg of sugar cane = 730 kg of cane juice
† includes installed capacity of molasses

‡ includes installed capacity of wood residues
¶ medium low heating value = 25 480 kJ/kg

Total energy production based on low heating values.

CANADA

Biomass type:

Municipal solid waste	quantity of raw material available	21	million tonnes
	biogas production	9 200	TJ
	electricity generating capacity	85 300	kW
	electricity generation	2 421	TJ
	direct use from combustion	8 820	TJ
	total energy production	20 441	TJ
Forestry/wood-processing	quantity of raw material available *	50.6	million tonnes
	solid fuel production capacity	6 240	TJ/year
	yield of solid fuel	17.865	GJ/tonne
	solid fuel production	3 560	TJ
	electricity generating capacity	1 586 000	kW
	electricity generation	45 014	TJ
	direct use from combustion	548 000	TJ
	total energy production	596 574	TJ
Crop residues - corn	quantity of raw material available	20	million tonnes
Crop residues - cereal grain	quantity of raw material available	25	million tonnes
Various – wheat	ethanol production capacity	466.4	TJ/year
	yield of ethanol	7.2	GJ/tonne
	ethanol production	466.4	TJ
Various – corn	ethanol production capacity	466.4	TJ/year
	yield of ethanol	7.8	GJ/tonne
	ethanol production	63.6	TJ

* comprising 17.7 wood waste + 21.9 black liquor + 11.0 cord wood

CROATIA

Biomass type:

Municipal solid waste	quantity of raw material available	1.1	million tonnes
Wood residues	quantity of raw material available	0.845	million tonnes
Crop residues - wheat straw	quantity of raw material available	0.25	million tonnes
Crop residues - maize stalks	quantity of raw material available	0.51	million tonnes
Crop residues - barley straw	quantity of raw material available	0.03	million tonnes
Crop residues - from fruit growing	quantity of raw material available	0.16	million tonnes

Data refer to 1996

CZECH REPUBLIC

Biomass type:

Municipal solid waste	quantity of raw material available	1.5	million tonnes
	biogas production	998	TJ
	electricity generation	4.5	TJ
Forestry/wood-processing	quantity of raw material available	2.6	million tonnes
Agricultural residues	quantity of raw material available	4	million tonnes
	biodiesel production capacity	2 440	TJ/year
	biogas production	201	TJ
	electricity generation	1 150	TJ
Industrial waste	quantity of raw material available	1	million tonnes
	electricity generation	2	TJ

DENMARK

Biomass type:

Municipal solid waste	quantity of raw material available	9	million tonnes
	biogas production	16	TJ
	electricity generating capacity	219 000	kW
	electricity generation*	4 196	TJ
	total energy production*	30 156	TJ
Forestry/wood-processing	quantity of raw material available	0.6	million tonnes
	solid fuel production	2 368	TJ
	electricity generating capacity	32 000	kW
	electricity generation	601	TJ
	total energy production	8 932	TJ
Agricultural residues - straw	quantity of raw material available	2.7	million tonnes
	electricity generating capacity	62 000	kW
	electricity generation	945	TJ
	total energy production	13 702	TJ
Agricultural residues - slurry etc	quantity of raw material available	24	PJ
	biogas production	1 210	TJ
	electricity generating capacity	20 000	kW
	electricity generation	370	TJ
	total energy production	1 580	TJ
Agricultural residues - other veg. waste	electricity generating capacity	9	kW
	electricity generation	72	TJ
	total energy production	664	TJ
Fish oil	total energy production	27	TJ
Sewage sludge	quantity of raw material available	3	PJ
	biogas production	510	TJ
	electricity generating capacity	10 000	kW
	electricity generation	152	TJ
	total energy production	718	TJ
Landfill gas and municipal waste gas	quantity of raw material available	1	PJ

biogas production	527	TJ
electricity generating capacity	9 000	kW
electricity generation	178	TJ
total energy production	705	TJ

* includes electricity from biogas, landfill/sewage sludge

ESTONIA

Biomass type:

Municipal solid waste	quantity of raw material available	0.569	million tonnes
	biogas production (landfill gas)	107	TJ
Forestry/wood-processing	quantity of raw material available	0.567	million tonnes
	solid fuel production	8 692	TJ

FINLAND

Biomass type:

Municipal solid waste	biogas production	764	TJ
	direct use from combustion	1 236	TJ
	total energy production	2 000	TJ
Forestry/wood-processing	direct use from combustion	72 670	TJ
Black liquor	direct use from combustion	142 623	TJ
Construction and demolition wood	direct use from combustion	6 800	TJ

FRANCE

Biomass type:

Municipal solid waste	quantity of raw material available	8.671	million tonnes
	biogas production	816	TJ
	electricity generation	4 104	TJ
	direct use from combustion	25 394	TJ
	total energy production	66 150	TJ
Forestry/wood-processing	electricity generation	5 346	TJ
	direct use from combustion	385 668	TJ
	total energy production	395 529	TJ
Agricultural residues	ethanol production capacity	219 000	tonnes/year
	yield of ethanol	35.6	GJ/tonne
	biodiesel production capacity	317 500	tonnes/year
	yield of biodiesel	26.8	GJ/tonne
	biogas production	4	TJ
Sewage sludge gas	biogas production	5 400	TJ
Other	biogas production	59	TJ

GERMANY

Biomass type:

Municipal solid waste	quantity of raw material available	7.3	million tonnes
	electricity generating capacity	555 000	kW
	electricity generation	9 526	TJ
	direct use from combustion	19 787	TJ
	total energy production	29 313	TJ
Forestry/wood-processing	electricity generation	842	TJ
	direct use from combustion	20 147	TJ
	total energy production	20 989	TJ
Agricultural residues - rape	biodiesel production	4 836	TJ
Agricultural residues - liquid manure	electricity generation	320	TJ
	direct use from combustion	135	TJ
	total energy production	455	TJ
Landfill gas	electricity generating capacity	170 000	kW
	electricity generation	2 491	TJ
	direct use from combustion	2 000	TJ
	total energy production	4 491	TJ
Sewage gas	electricity generating capacity	92 000	KW
	electricity generation	129	TJ
	direct use from combustion	2 800	TJ
	total energy production	2 929	TJ

GHANA

Biomass type:

Agricultural residues	quantity of raw material available		
	• coconut shell and husk	0.135	million tonnes
	• groundnut shells	0.0475	million tonnes
	• rice straw and husk	0.120	million tonnes

Data refer to 1990

HONG KONG, CHINA

Biomass type:

Municipal solid waste	quantity of raw material available	1.5	million tonnes
	electricity generating capacity*	6 540	kW

* for electricity generation from landfill gas.

HUNGARY

Biomass type:

Municipal solid waste	yield of biogas	21	GJ/tonne
	biogas production	132	TJ
	electricity generating capacity	25 300	kW
	electricity generation	338	TJ
	direct use from combustion	480	TJ
	total energy production	950	TJ
Forestry/wood-processing	electricity generating capacity	280	kW
	electricity generation	5	TJ
	direct use from combustion	3 800	TJ
	total energy production	3 805	TJ

ICELAND

Biomass type:

Municipal solid waste	direct use from combustion	45	TJ

INDONESIA

Biomass type:

Sugar cane bagasse	quantity of raw material available	6.5	million tonnes
Agricultural residues - rice husk	quantity of raw material available	14.3	million tonnes
Agricultural residues - coconut shells	quantity of raw material available	1.1	million tonnes
Agricultural residues - coconut fibre	quantity of raw material available	2.0	million tonnes
Agricultural residues - palm oil residues	quantity of raw material available	8.5	million tonnes

IRAN

Biomass type:

Municipal solid waste	quantity of raw material available	15.33	million tonnes
Forestry/wood-processing	quantity of raw material available	0.2	million tonnes

IRELAND

Biomass type:

Municipal solid waste	electricity generating capacity	14 732	kW
	electricity generation	324	TJ

ISRAEL

Biomass type:

Forestry/wood-processing	direct use from combustion	1 000 toe
Municipal sewage	electricity generating capacity	6 000 kW
	electricity generation	30 GWh
	direct use from combustion	7 000 toe
Industrial sewage	electricity generating capacity	500 kW
	electricity generation	25 GWh
	direct use from combustion	600 toe

ITALY

Biomass type:

Municipal solid waste	quantity of raw material available	2.0 million tonnes
	biogas production	6 800 TJ
	electricity generating capacity	296 398 kW
	electricity generation	2 341 TJ
	direct use from combustion	600 TJ
	total energy production	9 741 TJ
Forestry/wood-processing	direct use from combustion	500 TJ
Agricultural residues	biodiesel production	3 400 TJ
	biogas production	50 TJ
	electricity generating capacity	4 135 kW
Sewage sludge	biogas production	76 TJ
	electricity generating capacity	7 790 kW
Farm slurries	biogas production	70 TJ
	electricity generating capacity	2 060 kW
Crop residues/food industry by-products	electricity generating capacity	178 869 kW
	electricity generation	2 112 TJ
	direct use from combustion	39 600 TJ
	total energy production	41 712 TJ

JAPAN

Biomass type:

Municipal solid waste	quantity of raw material available	51 million tonnes
	electricity generating capacity	829 000 kW
Sugar cane bagasse	quantity of raw material available	0.2 million tonnes
	electricity generating capacity	27 000 kW
Forestry/wood-processing	quantity of raw material available	1.46 million tonnes
	electricity generating capacity	50 000 kW

JORDAN

Biomass type:

Municipal solid waste	quantity of raw material available	0.8 million tonnes

KOREA (REPUBLIC)

Biomass type:

Agricultural residues - leaves & branches	quantity of raw material available	0.081 million tonnes
	direct use from combustion	1 526 TJ
Industrial waste	direct use from combustion	61 798 TJ

LATVIA

Biomass type:

Wood residues	quantity of raw material available	0.7 million tonnes
	solid fuel production	2 200 TJ
	direct use from combustion	2 500 TJ
	total energy production	4 700 TJ
Grain and potatoes	ethanol production	270-300 TJ

Data refer to 1996

LUXEMBOURG

Biomass type:

Municipal solid waste	quantity of raw material available	0.087 million tonnes
	direct use from combustion	91 TJ

Data refer to 1996

MEXICO

Biomass type:

Sugar cane bagasse	quantity of raw material available	13.219 million tonnes

All fuel use of bagasse takes place in the sugar industry. The *balance nacional de energía 1999* shows that 86.582 PJ (equivalent to 12.3 million tonnes) of bagasse was consumed by that sector for energy purposes, including auto-production of electricity, in 1999.

MONACO

Biomass type:

Municipal solid waste	quantity of raw material available	0.07 million tonnes
	electricity generating capacity	2600 kW
	electricity generation	26 TJ
	direct use from combustion	72 TJ
	total energy production	98 TJ

Data refer to 1996

MOROCCO

Biomass type:

Animal dung	biogas production capacity	4.00 TJ/year
	yield of biogas	0.56 GJ/tonne
	biogas production	4.00 TJ

Data refer to 1996

NEPAL

Biomass type:

Sugar cane bagasse	quantity of raw material available	0.47 million tonnes
Agricultural residues - paddy	quantity of raw material available	9.45 million tonnes
	direct use from combustion	7.08 million tonnes
Agricultural residues - maize	quantity of raw material available	2.67 million tonnes
	direct use from combustion	2.01 million tonnes
Agricultural residues - wheat	quantity of raw material available	1.49 million tonnes
	direct use from combustion	1.11 million tonnes
Agricultural residues - jute	quantity of raw material available	0.098 million tonnes
	direct use from combustion	0.073 million tonnes

Data refer to 1995

NETHERLANDS

Biomass type:

Municipal solid waste	electricity generation	10 296 TJ
	direct use from combustion	1 085 TJ
	total energy production	11 381 TJ
Forestry/wood-processing	direct use from combustion	
	• households	5 400 TJ
	• industry	1 750 TJ
Landfill gas	biogas production	2 763 TJ
Sludge	biogas production	2 041 TJ
Fermentation	biogas production	5 632 TJ

NEW ZEALAND

Biomass type:

Forestry/wood-processing	electricity generating capacity	75 210 kW
	electricity generation	1 576 TJ
Various - biogas	electricity generating capacity	23 660 kW
	electricity generation	417 TJ
	direct use from combustion	140 TJ
	total energy production	557 TJ

PARAGUAY

Biomass type:

Sugar cane bagasse	quantity of raw material available	0.36	million tonnes
Cane juice	quantity of raw material available	0.038	million tonnes
	ethanol production capacity	861.6	TJ/year
	yield of ethanol	1.303	GJ/tonne
	ethanol production	295.4	TJ
Forestry/wood-processing	quantity of raw material available	1.433	million tonnes
	direct use from combustion	20 511.3	TJ
Agricultural residues - cotton	quantity of raw material available	0.285	million tonnes
	electricity generation	9.3	TJ
	direct use from combustion	4 089.9	TJ
	total energy production	4 099.2	TJ
Agricultural residues - other	quantity of raw material available	0.068	million tonnes
	electricity generation	37.3	TJ
	direct use from combustion	1 022.5	TJ
	total energy production	1 059.8	TJ

PHILIPPINES

Biomass type:

Sugar cane bagasse	quantity of raw material available	7.0367	million tonnes
	electricity generation	60 500	TJ
Wood residues	quantity of raw material available	1.235	million tonnes
Crop residues - rice hulls	quantity of raw material available	1.939	million tonnes
	direct use from combustion	22 355	TJ
Crop residues - rice straw	quantity of raw material available	2.230	million tonnes
Crop residues - coconut	quantity of raw material available	5.638	million tonnes
	direct use from combustion	76 806	TJ

Data refer to 1996

POLAND

Biomass type:

Agricultural residues - manure	biogas production	1 054	TJ
Agricultural residues - straw etc.	quantity of raw material available	20	million tonnes
	direct use from combustion	25 063	TJ
Industrial waste	direct use from combustion	13 970	TJ
Other	direct use from combustion	3 641	TJ

PORTUGAL

Biomass type:

Forestry/wood-processing	quantity of raw material available	3	million tonnes
	biogas production	92	TJ
	electricity generating capacity	350 000	kW
	electricity generation	28 468	TJ
	direct use from combustion	47 000	TJ
	total energy production	75 560	TJ
Forest residues	electricity generating capacity	10 000	kW
	electricity generation	12	TJ
Manure & sewage	biogas production	612	TJ

ROMANIA

Biomass type:

Forestry/wood-processing	quantity of raw material available	0.4	million tonnes
	electricity generating capacity	4 160	kW
	electricity generation	5	TJ
	direct use from combustion	3 687	TJ
	total energy production	3 692	TJ
Agricultural residues	quantity of raw material available	0.176	million tonnes
	direct use from combustion	1 630	TJ

SENEGAL

Biomass type:

Municipal solid waste	electricity generating capacity	20 000	kW
Agricultural residues – peanut shells	electricity generating capacity	22 000	kW
Biomass potential (per annum)	Peanut shells	197 500	tonnes (221 MW)
	Palmetto shells	1 740	tonnes
	Sugar cane bagasse	250 000	tonnes (20 MW)
	Rice husks	217 212	tonnes
	Sawdust	3 000	cubic metres
	Millet/Sorghum/Maize stalks	4 052 900	tonnes
	Typha reed	1 000 000	tonnes
	Cotton stalks	23 991	tonnes
	Peanut haulm	790 617	tonnes

SLOVAKIA

Biomass type:

Municipal solid waste	quantity of raw material available	0.16	million tonnes
	direct use from combustion	1 360	TJ
Animal dung	quantity of raw material available	0.06	million tonnes
	yield of biogas	0.22	GJ/tonne
	biogas production	13	TJ
	direct use from combustion	13	TJ
	total energy production	26.7	TJ
Wood residues	quantity of raw material available	0.3	million tonnes
	yield of solid fuel	11	GJ/tonne
	solid fuel production	3 300	TJ
Crop residues	quantity of raw material available	0.0025	million tonnes
	yield of solid fuel	13	GJ/tonne
	solid fuel production	33	TJ
Pulp industry residues	quantity of raw material available	0.46	million tonnes
	yield of solid fuel	14	GJ/tonne
	solid fuel production	6 440	TJ
Various - biopetrol	quantity of raw material available	0.002	million tonnes
	yield of ethanol	40	GJ/tonne
	ethanol production	80	TJ

Data refer to 1996

SLOVENIA

Biomass type:

Municipal solid waste	electricity generating capacity	2 776	kW
	electricity generation	43	TJ
Wood residues *	quantity of raw material available	0.94	million tonnes
	yield of solid fuel	10	GJ/tonne
	solid fuel production	9 000	TJ
	electricity generating capacity	8 500	kW
	electricity generation	120	TJ

*** Data refer to 1996**

SOUTH AFRICA

Landfill gas:

A study conducted in 1993 estimated that for a population of 40 million, the amount of solid waste required to produce 130 000 Nm^3 per annum was 15 million tonnes.

Vehicle fuel from digester gas:

The AEC has a small-scale plant which produces 15 Nm^3 per hour of natural gas equivalent from digester gas. The installed capacity when operated continuously is 4 TJ/year. This plant has a yield of 17 GJ per tonne of feed gas. The estimated figure for the energy produced is 0.2 TJ/year.

Electricity generation from helium-rich well gas:

Helium is recovered from well gas at an Afrox site in the Free State. The waste gas is enriched in methane by the membrane process and then fed into an installed generator set to provide electricity for the plant. The installed capacity of the generating set is 72 kWe and this produces about 0.6 TJ of energy per annum. The plant is not fully utilised.

Other estimates:

Bagasse production, wet (1993-1994)	3.801 million tonnes
Potential sunflower seed oil production	650 million litres

Potential ethanol production:

	Million litres	PJ
cassava	3 400	72.3
sugar cane	521	11.1
bagasse	263	5.6
molasses	110	2.3
maize	1 060	22.5
sorghum straw	157	5.1
wheat straw	218	7.0

Potential production of bioenergy:

	PJ
bagasse	41.4
maize	39.4
sorghum straw	13.0
wheat straw	14.2
Dung	
- beef cattle	1.7
- dairy cattle	1.5
- pigs	1.1
- poultry	3.5

Data reported in 1997

SPAIN

Biomass type:

Municipal solid waste	quantity of raw material available	14.3	million tonnes
	electricity generating capacity	93 700	KW
	electricity generation¶	1 887.8	TJ
Animal dung	biogas production †	25.9	TJ
	electricity generating capacity	618	KW
	electricity generation	1.6	TJ
	direct use from combustion	18.1	TJ
	total energy production°	19.7	TJ
Sugar cane bagasse	direct use from combustion	N	TJ
Wood residues *	quantity of raw material available	5.1	million tonnes
	solid fuel production capacity‡	500	TJ/year
	solid fuel production‡	250	TJ
	electricity generating capacity	112 897	KW
	electricity generation	2 091.5	TJ
	direct use from combustion	25 668.4	TJ
	total energy production°	27 759.9	TJ

Crop residues - olive	quantity of raw material available	1.5	million tonnes
	electricity generating capacity	12 900	KW
	electricity generation	345.7	TJ
	direct use from combustion	11 386.2	TJ
	total energy production°	11 731.9	TJ
Crop residues - grape	quantity of raw material available	0.1	million tonnes
	electricity generating capacity	2 100	KW
	electricity generation	11.3	TJ
	direct use from combustion	888.7	TJ
	total energy production°	900	TJ
Crop residues - dry fruit shells	quantity of raw material available	0.1	million tonnes
	direct use from combustion	1 808.4	TJ
Various †	biogas production	3 184.5	TJ
	electricity generating capacity	24 948	KW
	electricity generation	509	TJ
	direct use from combustion	3 004.2	TJ
	total energy production°	3 513.2	TJ

*including sawdust, shavings, bark and black liquor
†rubbish dump biogas, depurators biogas, depurators mud, cotton residues, straw and others
‡approximately
¶incineration of 1.382 million tonnes of refuse-derived fuel (RDF)
° including electricity generation and direct use only

Data refer to 1996

SWAZILAND

Biomass type:

Sugar cane bagasse	quantity of raw material available	0.874	million tonnes
	electricity generating capacity	40 000	kW
	electricity generation	720	TJ
	direct use from combustion *	13 350	TJ
Forestry/wood-processing	direct use from combustion *	1 310	TJ

* Data refer to 1996

SWEDEN

Biomass type:

Municipal solid waste	quantity of raw material available	2.2	million tonnes
	electricity generation	540	TJ
	direct use from combustion	15 000	TJ
	total energy production	15 540	TJ
Black liquor	electricity generation	3 340	TJ
	direct use from combustion	116 400	TJ
	total energy production	119 740	TJ
Wood and industrial waste	electricity generation	5 730	TJ
	direct use from combustion	136 000	TJ
	total energy production	141 730	TJ

SWITZERLAND

Biomass type:

Municipal solid waste	quantity of raw material available	2.586	million tonnes
	biogas production	2 355	TJ
	electricity generating capacity	244 000	kW
	electricity generation	4 092	TJ
	direct use from combustion (heat)	8 971	TJ
	total energy production	15 418	TJ

TAIWAN, CHINA

Biomass type:

Municipal solid waste	quantity of raw material available	9.4	million tonnes
	yield of biogas	0.38	GJ/tonne
	biogas production	334	TJ
	electricity generating capacity	265 000	kW
	electricity generation	17 698	TJ
	total energy production	18 032	TJ
Sugar cane bagasse	quantity of raw material available	0.53	million tonnes
	electricity generating capacity	60 980	kW
	electricity generation	4 142	TJ
	direct use from combustion	2 824	TJ
	total energy production	6 966	TJ
Forestry/wood-processing	quantity of raw material available	0.62	million tonnes
Agricultural residues - rice hulls	quantity of raw material available	0.3	million tonnes
Agricultural residues - hog manure	quantity of raw material available	79.2	million tonnes
	biogas production capacity	8 210	TJ/year
	yield of biogas	0.1	GJ/tonne
	biogas production	173	TJ
	electricity generating capacity	1 700	kW
	electricity generation	115	TJ
	direct use from combustion	753	TJ
	total energy production	1 041	TJ
Black liquor	direct use from combustion	8 171	TJ

THAILAND

Biomass type:

Municipal solid waste	quantity of raw material available	5.58	million tonnes
	electricity generating capacity	2 500	kW
Sugar cane bagasse	quantity of raw material available	15.61	million tonnes
	electricity generating capacity	301 000	kW
	electricity generation	4 605	TJ
	direct use from combustion	113 045	TJ
	total energy production	117 650	TJ
Agricultural residues - paddy husk	quantity of raw material available	4.936	million tonnes
	electricity generation	3 548	TJ
	direct use from combustion	30 373	TJ

total energy production	33 921 TJ

TURKEY

Biomass type:

Animal dung	quantity of raw material available	4.739 million tonnes
Wood residues	quantity of raw material available	1.790 million tonnes

UNITED KINGDOM

Biomass type:

Municipal solid waste	quantity of raw material available	2.6 million tonnes
	electricity generating capacity	158 600 kW
	electricity generation	4 892 TJ
	direct use from combustion	1 340 TJ
	total energy production	6 232 TJ
Forestry/wood-processing	quantity of raw material available	2.2 million tonnes
	direct use from combustion	29 740 TJ
Agricultural residues - straw	quantity of raw material available	0.2 million tonnes
	direct use from combustion	3 015 TJ
Agricultural residues - poultry litter, farm waste digestion and tyres	quantity of raw material available	0.8 million tonnes
	electricity generating capacity	83 880 kW
	electricity generation	1 852 TJ
Landfill gas	quantity of raw material available	23 950 TJ
	electricity generating capacity	309 000 kW
	electricity generation	6 131 TJ
	direct use from combustion	586 TJ
	total energy production	6 717 TJ
Sewage gas	quantity of raw material available	7 913 TJ
	electricity generating capacity	91 300 kW
	electricity generation	1 476 TJ
	direct use from combustion	2 261 TJ
	total energy production	3 737 TJ
General industrial and hospital waste	quantity of raw material available	0.2 million tonnes
	direct use from combustion	2 010 TJ

UNITED STATES OF AMERICA

Biomass type:

Municipal solid waste/Landfills	quantity of raw material available	167 million tonnes
	electricity generating capacity	2 862 000 kW
	electricity generation	71 405 TJ
	direct use from combustion	217 722 TJ
	total energy production	289 127 TJ
Forestry/wood-processing	electricity generating capacity	6 726 000 kW
	electricity generation	124 712 TJ
	direct use from combustion	2 306 026 TJ

	total energy production	2 430 738	TJ
Agricultural residues - corn	quantity of raw material available	13.5	million tonnes
	ethanol fuel production capacity	152 376	TJ/year
	yield of ethanol	8.8	GJ/tonne
	ethanol fuel production	118 010	TJ
Agricultural residues - soy bean oil and waste food oils	biodiesel production capacity	6 708	TJ/year
	yield of biodiesel	40	GJ/tonne
	biodiesel production	671	TJ
Wood pellets	quantity of raw material available	0.582	million tonnes
	direct use from combustion	8 872	TJ
Other biomass	electricity generating capacity	10 602 000	kW
	electricity generation	11 328	TJ
	direct use from combustion	102 084	TJ
	total energy production	113 412	TJ

URUGUAY

Biomass type:

Sugar cane bagasse	quantity of raw material available	0.04	million tonnes
	electricity generation	17	TJ
	direct use from combustion	415	TJ
	total energy production	432	TJ
Forestry/wood-processing	quantity of raw material available	0.4	million tonnes
Crop residues - rice husks	quantity of raw material available	0.27	million tonnes
	electricity generation	5	TJ
	direct use from combustion	508	TJ
Crop residues - sunflower husks	quantity of raw material available	0.05	million tonnes
	direct use from combustion	377	TJ
Black liquor	quantity of raw material available	0.04	million tonnes
	electricity generation	59	TJ
	direct use from combustion	531	TJ
	total energy production	590	TJ

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Chapter 11

SOLAR ENERGY

Introduction

Some issues are daily fare in the newspapers, but solar energy, in its various forms, is not among them. From time to time in the past fifty years it has made the news, but usually in conjunction with an energy or environmental crisis. That was the case during the first oil shock, in 1973, and it is so today too, now that the public has become concerned about global warming and climate change.

But even when the papers do talk about solar energy, they find it hard to treat it in a reasonably complete way. Like so many other topical subjects, solar energy is a complex matter, but usually the amount of space it receives in the media is only enough for a summary description. Nonetheless, some statistical projections remain in people's minds. One that is often cited – e.g., in a report by Shell Renewables, a division of one of the world's largest oil companies – is that by the year 2050, one half of the energy used worldwide will come from solar and other renewable sources.

Back in 1952, a report prepared by the Paley Commission for U.S. president Harry Truman predicted a bright future for solar energy. Among other things, the Paley report estimated that 13 million solar homes would have been built by the early 1970's – just when the world was hit by the first energy crisis of modern times. But the prospects outlined in the report quickly dimmed. Many people think this was due partly to the Atoms for Peace initiative, announced in 1953, which led countries all over the world to start programmes for peaceful uses of atomic energy.

In the past few years, however, modern solar technologies have been penetrating the market at faster and faster rates, and an optimistic view of the sector's future seems fully justified.

Nonetheless, past experience should make us aware of the fact that the most optimistic view of the future of solar energy could be set at naught by the appearance of an important invention or by unforeseeable events. Predicting the future is especially hard when the world is changing as quickly as it is in our day.

Can technological developments and the transition to a culture that is more aware of the need to safeguard the environment help create a world powered by the sun's energy?

A technologically advanced world

The fast pace of technological development is one of the most significant characteristics of our time. Today it takes only a few months to achieve the same number of important inventions and discoveries that took decades, if not centuries, in the past. This trend is accelerated by globalisation, which in turn is accelerated by the ever-growing use of the Internet. Technological development helps raise standards of living around the world. Diseases that afflicted humanity for centuries have been nearly eradicated, and life expectancy has lengthened in most countries. But many problems have not been solved yet, and others are in the offing.

The two common factors that underlie many of the problems threatening our future are the fast growing population and the ever increasing consumption of resources driven by the diffusion of life-styles that have developed in industrialised societies and are emulated in much of the world.

Until the discovery of fossil fuels and the beginning of the industrial revolution, the sun's energy – in its different forms, direct and indirect (such as wind and biomass) – was the sole energy source that inspired and enabled the development of human societies.

Since then, and especially in the past one hundred years - a relatively short span of time - a powerful energy infrastructure that now covers practically the entire planet and is based on fossil fuels and nuclear energy has been built. Today the world consumes 9 billion toe per year, compared with around 500 million toe in 1860. While these energy uses and infrastructure do not yet benefit billions of poor people who still try to make do with firewood, they give humanity a power over nature that earlier generations never knew; they had to survive with the renewable energy of the sun.

This power helps us live more comfortably than past generations, but while it meets new needs, it also carries the risk of irreversibly altering natural balances, both local and global.

The world's population has been growing rapidly over the last century and continues to grow. We were 1.6 billion in 1900; we have now passed the 6 billion mark. If this trend continues, the human population will rise to about 9 billion by 2050. The increasingly crowded world has also become a world of cities. Fifty percent of the population already live in cities and the figure is expected to rise to 75% by the year 2050. Dozens of cities already number more than 10 million people.

Dramatic contrast between wealth and poverty has become part of any urban landscape, with excessive consumption among the richer segments and the inability of the poorer segments, especially in the developing countries, to meet their most basic needs: decent homes, clean water, health care, education. If these legitimate and ever-growing needs are to be met, energy consumption must increase. What part can solar energy play in this process?

Solar energy, past and future

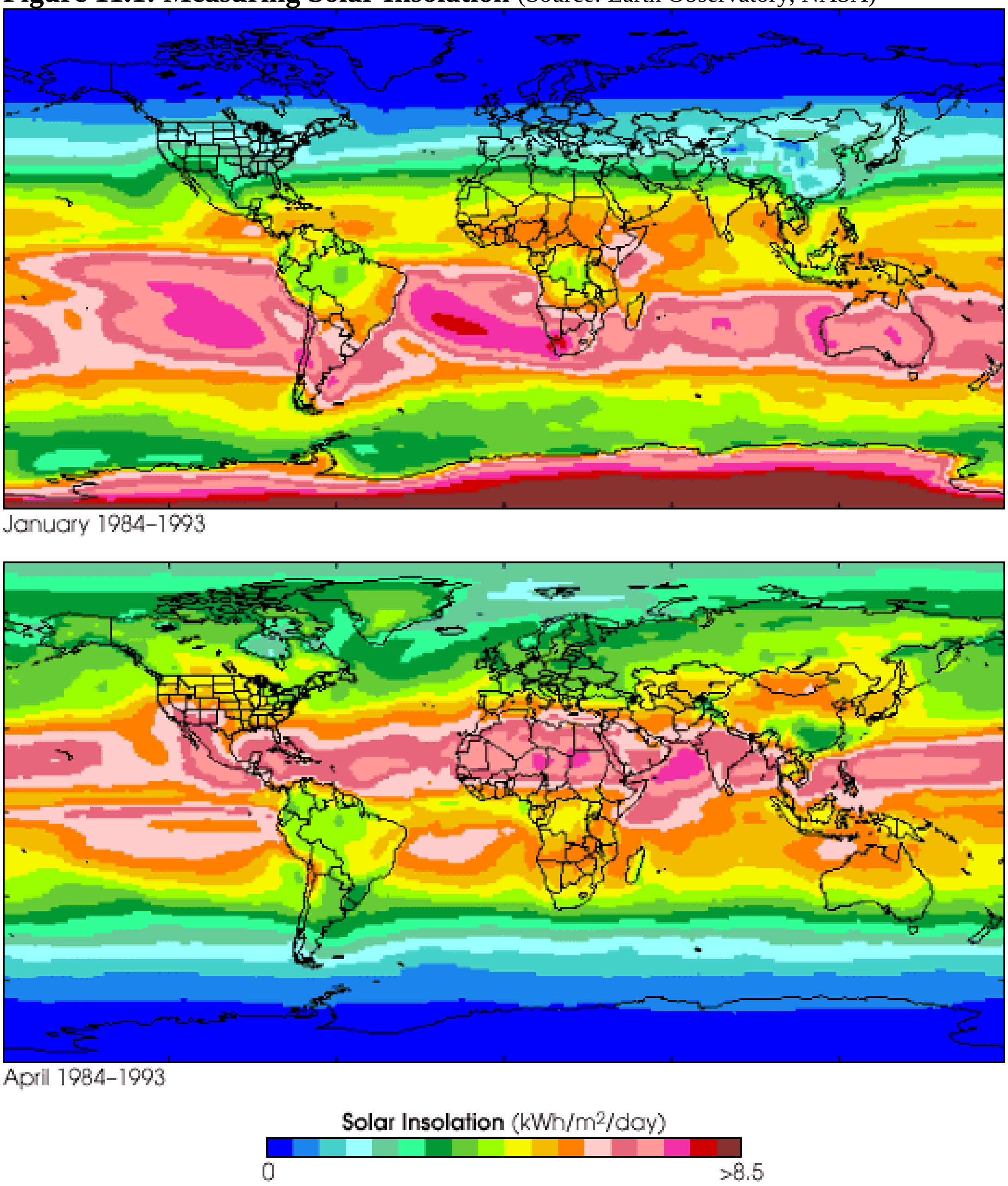
With the exception of nuclear, geothermal and tidal energy, all forms of energy used on earth originate from the sun's energy.

Some are renewable, some are not. Renewable is the term used for forms of energy that can be regenerated, or renewed, in a relatively short amount of time. The regeneration process may be continuous and immediate, as in the case of direct solar radiation, or it may take some hours, months or years. This is the case of wind energy (generated by the uneven heating of air masses), hydro energy (related to the sun-powered cycle of water evaporation and rain), biomass energy (stored in plants through photosynthesis), and the energy contained in marine currents.

The energy contained in fossil fuels – coal, oil and natural gas – likewise comes from the sun's energy, but it was stored in plants millions of years ago, and once used, it cannot be regenerated on a human time scale. The earth's remaining fossil fuel reserves can probably provide us with energy for another 100 to 500 years, but this is an insignificant amount of time in terms of the whole past history of human civilisation and (one hopes) of its future.

The flow of renewable solar energies on earth is essentially equal to the flow of energy due to solar radiation. Every year, the sun irradiates the earth's land masses with the equivalent of 19 trillion toe. A fraction of this energy could satisfy the world's energy requirements, around 9 billion toe per year.

Figure 11.1: Measuring Solar Insolation (Source: Earth Observatory, NASA)



For thousands of years, the sun's renewable energy was humanity's sole source of energy. Its role started to decrease only a few centuries ago, with the progress of industrialisation, the diffusion of new technologies, and the discovery of new fossil fuels (coal has been used since ancient times) and eventually nuclear power.

Today solar sources provide around 10% of the energy used worldwide, but in the developing countries their share is still of the order of 40%. This contribution could start growing again, thanks to progress in solar technology and the pressure of recurrent energy and environmental crises related to fossil fuels and nuclear power.

To raise the contribution to 50% of world energy use by 2050, as suggested in the Shell Renewables report, would require sweeping changes in our energy infrastructure. These changes can be achieved only through the parallel development of a new, more sophisticated way of thinking about our environment and how we generate and use energy: a new culture that should pervade every part of society and shape the responsibilities of each.

Current solar technologies

Solar technologies – some primitive, some more advanced – have been used in all ages and in every corner of the world, but the invention and development of modern solar technologies goes back only forty or fifty years. By now the world has seen numerous practical demonstrations that sophisticated solar-powered facilities can be built and operated successfully as part of energy systems ranging from the scale of an individual home, to a large industrial or commercial complex, or even a whole city or rural area.

As early as the 1980's, a 354-MW solar power plant was built in the Mojave desert, in California. Here the heat contained in solar rays, concentrated by reflecting troughs and raised to 400^{o}C, produces steam that runs a conventional power generator. When the sun is not shining, the plant switches to natural gas. The latest generation of this type of plant incorporates new engineering solutions and new scientific principles such as non-imaging optics, which makes it possible to build much more efficient concentrators at lower costs. These developments open new prospects for the technology in the sunniest parts of the world.

A solar technology that has already had a great impact on our lives is photovoltaics. Not in terms of the amount of electricity it produces (in 1999 only 200 MW were installed), but because of the fact that photovoltaic cells – working silently, not polluting – can generate electricity wherever the sun shines, even in places where no other form of electricity can be obtained.

The technology has been around since the 1950's, but the effect on our lives is not widely known. As the American solar-technology historian John Perlin observes, it was the determining factor in a whole series of otherwise unthinkable developments.

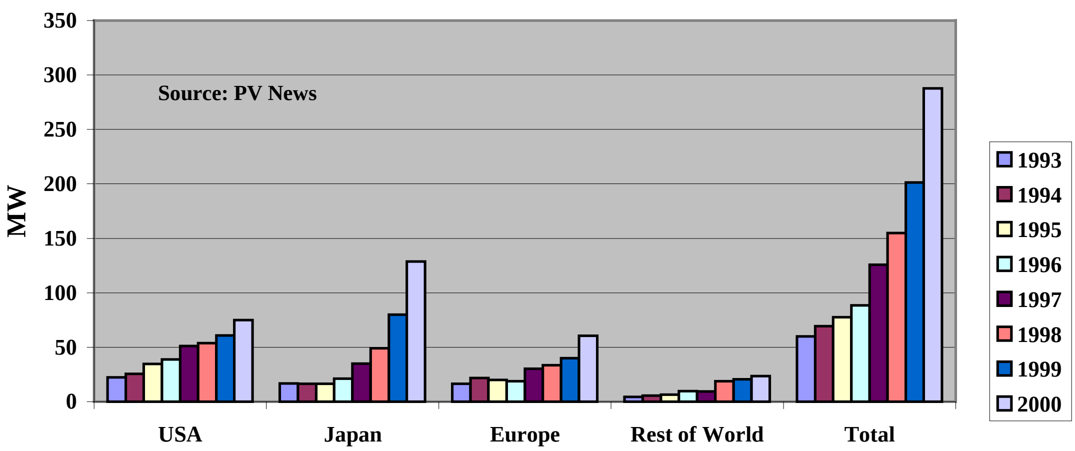
For instance, photovoltaic cells generate the power that runs space satellites. Without telecommunications satellites, many of our now-routine activities – from watching internationally broadcast entertainment to using cell phones – would still be in the realm of science fiction. And space exploration and research too might still be science fiction.

On earth, photovoltaic technology is used to produce electricity in areas where power lines do not reach. In the developing countries, it is significantly improving living conditions in rural areas. Thanks to its flexibility, it can be incorporated in packages of energy services and thus offer unique opportunities to improve rural health care, education, communication, agriculture, lighting and water supply.

In the industrialised countries, programmes that provide incentives for the incorporation of photovoltaic systems in building roofs and walls have tallied up thousands of completed projects in the United States, Japan and Europe.

Annual worldwide sales of photovoltaic systems are growing by around 30% and now stand at about one billion dollars.

Figure 11.2: World cell/module shipments 1993-2000 (consumer and commercial)



The use of energy in the form of heat is one of the largest items in the energy budget. In Europe, for instance, it accounts for around 50% of total energy consumption: around 630 million toe, of which 383 in low-temperature heat and 247 in medium- and high-temperature heat.

Today, low-temperature (<100°C) thermal solar technologies are reliable and mature for the market. Worldwide, they help to meet heating needs with the installation of several million square metres of solar collectors per year.

These technologies can play a very important role in advanced energy-saving projects, especially in new buildings and structures that require large amounts of hot water, heating and cooling.

Seeing buildings as complex energy systems and as the largest collectors of solar energy

Buildings are the modern world's main and most widespread technological systems, and the most direct expression of a people's culture of life and work. Most of the energy we use – around 40% of primary energy in Europe – goes into heating, cooling and lighting building interiors and into running a growing number of devices used in buildings. Designing, building and managing energy-efficient buildings with low environmental impact is an ongoing challenge.

Over the past few decades, building roofs and walls have been continually transformed by the incorporation of new energy-related elements such as insulating materials to high-performance windows, special glass, solar-powered heating and electricity-generation systems, and low-consumption light bulbs.

Architects are switching to the "whole building" approach, which sees the various problems and solutions as a whole and tackles them in an integrated and intelligent way right from the start of the design process, when every choice is decisive.

The challenge is to move beyond the simple concept of "energy saving" or "solar energy" and aim at a combination of these and optimal building management. The basic idea is to create better buildings by putting together a strongly interdisciplinary team capable of analysing and evaluating the different aspects involved in the building's life cycle, and striking a good balance among the proposed solutions. The factors involved include the building's site and position, and the use of active and passive solar systems.

The project must take account of waste management, maintenance, the choice and reuse of materials and products, optimisation of the technological installations, the financial aspects, the landscape and the environment, combining them all in an integrated whole.

The design process should dictate the choice of technologies, not the other way around, as often happens today, when available technologies and products guide the design process.

In recent years, the International Energy Agency's programmes on "Advanced Low-Energy Solar Buildings" have sponsored a number of products aimed primarily at energy saving and energy efficiency, but also at the introduction of solar technologies to meet the remainder of a building's energy requirements. These experiences have proved that it is possible to construct buildings that use on average only 44 kWh/m^2 per year, compared with 172 kWh/m^2 in other contemporary buildings. The lowest consumption obtained so far, 15 kWh/m^2, was in a home built in Berlin.

According to new building codes proposed in some northern European countries for future buildings, the amount of energy needed for winter heating can be reduced to practically zero with technologies that are already available (insulation, special glass, heat recovery, passive solar design and energy storage), and the remainder can be covered with active solar devices incorporated in the building's skin – devices that are not necessarily invisible, but are aesthetically designed for these buildings of the future.

Technological progress and cultural challenges

The invention and development of modern solar technologies began forty or fifty years ago. Tremendous progress has been made, especially in the last decade. A great number of solar, wind and biomass technologies for the production of fuel, heat and electricity are now available or close to commercialisation. They have been installed on a significant scale in both developed and developing countries. They are used in many different ways, stand-alone or incorporated in conventional energy networks and grids. They are already providing energy services to individual homes, villages and cities.

However, if we are to move from examples to worldwide applications of solar technologies in communities, cities, islands and rural areas, society as a whole must be interested and give its support. Solar energy infrastructure, whether installed in remote rural areas in a developing country or integrated in existing conventional infrastructure in a city in the developed world, needs to be better known and accepted.

If we want the use of solar energy to spread through the technologically advanced world to the extent mentioned above – 50% of world energy consumption by 2050 – we will need to enroll many more solar scientists and engineers, environmental scientists, entrepreneurs, financial experts, publicists and architects. Above all, we will need many more politicians and civil servants who know the subject and are more courageous and determined. A new generation of solar-energy pioneers has to be nurtured, especially to work in local communities and industries.

Solar energy exists everywhere, but has a weaker concentration of energy than fossil and nuclear sources. Using solar energy can teach us how to establish a more balanced relationship with nature. A new culture of energy efficiency can lead to a more concerned, socially responsible use of all natural resources. The use of solar energy – a local resource – can contribute to the preservation of local cultures and also promote new lifestyles and new concepts of wealth, prosperity and security that can help us all meet the challenges of the 21st century.

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TABLE NOTES

At this point in time, the quantification of solar energy in terms of installed capacity and annual output of electricity and heat presents extraordinary difficulties, which are probably greater than those encountered with any other source of energy. The combination of comparatively newly-developed technologies, rapid market growth and widespread, virtually worldwide, diffusion (often at the level of individual households, many in remote rural areas) makes comprehensive enumeration extremely difficult, if not impossible. This means that any aggregate data on a national level can be no more than indicative of the situation.

Table 11.1 is confined to data on photovoltaic generating capacity, as available from the following sources:

- WEC Member Committees, 2000/2001 and 1997/1998;
- *Trends in Photovoltaic Applications*, September 2000, IEA Photovoltaic Power Systems Programme;
- Ministry of Non-Conventional Energy Resources, Government of India;
- Data for Botswana, Egypt, Morocco, Bolivia, China and the Philippines are as reported by WEC Member Committees for the 1998 Survey and relate to PV capacity as at end-1996.

The data covered in Table 11.1 constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed.

Excel Files

Table 11.1 Solar Energy: installed photovoltaic capacity at end-1999

	kW_p
Africa	
Botswana	600
Egypt	2 000
Ghana	196
Morocco	3 000
Senegal	1 000
South Africa	1 160
Swaziland	60
North America	
Canada	5 826
Mexico	12 922
United States of America	117 300
South America	
Argentina	5 000
Bolivia	470
Asia	
China	8 800
India	44 000
Indonesia	5 000
Japan	205 300
Korea (Republic)	3 459
Nepal	1 122
Philippines	217
Taiwan, China	93
Thailand	4 600
Turkey	150
Europe	
Austria	3 672
Croatia	10
Czech Republic	10
Denmark	1 070
Finland	2 302
France	9 121
Germany	69 500
Italy	18 475
Netherlands	9 195
Norway	5 670
Portugal	503
Romania	6
Slovenia	50
Spain	9 080
Sweden	2 584
Switzerland	13 400
United Kingdom	1 131
Middle East	
Israel	401
Jordan	150
Oceania	
Australia	25 320

COUNTRY NOTES

The Country Notes on solar have been compiled by the editors. Numerous sources have been consulted, including the following:

- *Photovoltaic Power Systems Programme, Annual Report 1999*, International Energy Agency;
- *Trends in Photovoltaic Applications in Selected Countries between 1992 and 1999*, International Energy Agency – Photovoltaic Power Systems Programme, September 2000;
- *Survey of Stand-alone PV Programmes and Applications in Developing Countries in 1996*, International Energy Agency – Photovoltaic Power Systems Programme, 1999;
- *Renewable Energy World*, James & James (Science Publishers) Ltd.;
- US Department of Energy;
- *Promotion of Renewable Energy Sources in South-east Asia*, ASEAN Centre for Energy;
- International Solar Energy Society, national sections;
- National and international institutions and government departments.

Information provided by WEC Member Committees has been incorporated as available.

AUSTRALIA

Australia has a high level of solar energy availability, which is increasingly being utilised by the installation of thermo-electric devices and PV systems and by the application of passive solar design principles.

PV power received much publicity during the Sydney 2000 Olympics with the PV powered lighting pylons along the Olympic Boulevard, the 70 kW_p array on the Superdome and the 629 kW_p installed on houses in the athletes' village. The emphasis was on developing the world's largest solar-powered suburb, offering a model for future urban development.

Furthermore, the nature of the country is such that its sparsely populated regions are ideal for the installation of off-grid systems to service telecommunications, power supplies, navigation aids and transport route signalling, in addition to domestic applications. Growth during the 1990's recorded an annual average increase of 19.4% in the total installed PV power capacity; at end-1999 it stood at 25 320 kW_p of which 92% was off-grid. There has also been strong growth in the installation of grid-connected capacity in recent years.

The Government has recently initiated a number of new measures designed to support renewable energy and, in some cases, PV in particular. The Renewable Energy (Electricity) Act 2000 and the Renewable Energy (Electricity) (Charge) Act 2000 are designed to implement the Government's renewable energy target. The measures place a legal liability on wholesale purchasers of electricity to proportionately contribute towards the generation of an additional 9 500 GWh of renewable energy by 2010.

Solar and PV electricity generation, PV renewable stand-alone power supply systems and some solar hot water installations are all energy sources that will be eligible for renewable energy certificates, where the electricity is delivered to a grid, end-point user or directly to a retailer or wholesale buyer. With effect from April 2001, producers of electricity generation from such sources will "earn" the certificates and will subsequently be able to trade them.

Two programmes launched during July 2000 will operate for four years: the Remote Area Power Supply Programme aims to replace diesel-generated electricity with renewable energies in remote areas and the other, the Household PV System Programme, is aimed specifically at the expansion of PV systems. Both the Federal Government and the State

Governments offer rebates for the installation of small roof-top and building-integrated systems. Additionally, rebates are offered for community buildings and grants supporting off-grid systems.

Australian PV production capability has been expanded in recent years and is running at full capacity. BP Solar, a major manufacturer, has increased module production at its Homebush plant since providing the solar installations for the Sydney Olympic Games in 2000. Other companies, including new thin-film manufacturers, are planning their entry into the production phase. Currently supply exceeds demand and Australia exports a large part of its production to the Philippines and other countries in Asia.

CANADA

The solar resource in Canada is generally very good and compares favourably with other regions of the world, due in part to its "clear-sky" climate. However, with its abundant water power and natural gas resources, the country does not place a high priority on the development of solar energy.

Nevertheless Canada has in excess of 300 remote communities that depend on diesel generators for their electricity. PV systems can assist such remote locations and the bulk of the 5.8 MW_p installed capacity (end-1999) is used for off-grid applications where PV is proven to be price-competitive against grid-extension or conventional stand-alone power systems.

The largest individual PV system user in Canada is the Canadian Coast Guard with an estimated 7 000 navigational buoys, beacons and lighthouses using photovoltaic modules.

There are less than 40 grid-connected PV systems installed in Canada with a capacity of only 267 kW_p. Since the cost of PV power is still 5-10 times higher than for conventional power available on the grid, it is unattractive for grid-connected applications at this time. Many of the grid-connected systems in Canada were installed as technology demonstration projects. The Canadian PV industry has grown steadily over the past few years, serving both domestic and export markets. In 1999, there were more than 150 PV businesses active in Canada, mostly system suppliers and installers.

The most cost-effective active solar energy technologies are those used for low-temperature heating applications, such as domestic water heating, pool heating and commercial/industrial ventilation air pre-heating.

An estimated 12 000 residential solar hot-water systems and 300 commercial/industrial solar hot-water systems are currently in use and energy production from these systems is estimated at around 100 TJ/year. Following the collapse of oil and gas prices in the mid-1980's and the termination of off-oil government programmes, sales of new systems have slowed down considerably. Approximately 200 new systems are installed annually, representing sales of less than C$ 1 million.

CHINA

China's modern utilisation of solar energy began in the mid-1970's: following the first national solar conference in 1975, research into solar technologies and their promotion was increasingly undertaken. The development of solar energy was incorporated into some government programmes but it was not until after the Rio Conference of 1992 that the Government drew up "Agenda of 21st Century in China", concentrating on the renewable energies. In 1995 the State Development and Planning Commission (SDPC), the State Economic and Trade Commission (SETC) and the Ministry of Science and Technology (MOST) formulated a "Program on New and Renewable Energy from 1996-2010".

SDPC, SETC and MOST have launched the “Sunlight Program”, also running until 2010 but covering PV systems. It is designed to upgrade the country’s manufacturing capability of solar technologies, to establish large-scale PV and PV/hybrid village demonstration schemes, home PV projects for remote areas and to initiate grid-connected PV projects. The “Brightness Project” first launched in 1996 and coming to fruition in 2000 is aimed at providing electricity from solar and wind energy in a number of remote regions.

China is well-endowed with solar energy resources, two-thirds of the territory receiving in excess of 4.6 kWh/m^2/day solar radiation. With a large number of remote communities (including many hundreds of islands) without electricity, photovoltaic power generation could play an effective role in serving these areas.

During the 1980’s China introduced a solar-cell production capacity and in 1996, 1.5 MW solar panels were produced.

In 1996 there were the following installations utilising solar energy:

- 720 million m^2 solar green houses;
- 390 000 ha of polyethylene film-covered green houses;
- 62 million m^2 solar heated pigsties;
- >8 million m^2 (aperture area) of solar water heaters (of which 5.24 million m^2 were in rural areas);
- 7.4 million m^2 passive solar residential houses (of which 4.56 million m^2 were in rural areas);
- 7 MW PV panels;
- 195 000 solar cooker units.

In mid-2000 China announced that it planned to increase its use of renewable energy by 10% per annum, according to its five-year development plan. At the end of 2000, it was announced that, according to a timetable set by the SETC, renewable resources will account for 0.7% of the total commercial energy consumption by end-2005 and for 2% by 2015.

FRANCE

The French Agency for Environment and Energy Management (ADEME) is the government organisation charged with promoting the development of renewable energies. In the mid-1990’s ADEME was joined by the national electricity utility, Electricité de France (EDF) which added a new impetus to the solar energy sector.

Until a change of policy by the French Government (concerning energy management and the development of renewable energy sources) led to an grid-connected demonstration programme and thence to actual development, solar energy had been harnessed by off-grid installations. At end-1999 there was 9 121 kW$_p$ of installed PV power of which 8 772 kW$_p$ was off-grid. PV is mostly utilised in rural locations for water pumping and communication devices.

An ADEME action programme that will run until 2006 will, in addition to the promotion of other renewable energies, focus on further research, technological development and demonstration of PV projects. It was planned that following the installation of some 156 kW$_p$ of grid-connected “PV roofs” in the late 1990’s, a further 500 kW$_p$ built-integrated systems would be completed between 1999 and 2001.

There is some direct use of solar power: at end-1998 there was a total of 460 000 m^2 installed.

GERMANY

Various actions taken by the Federal Government during the past 25 years have ensured that since 1995 Germany has led Europe in installed PV power. Government funding of R,D&D for PV began in 1974 and has continued, with support from the Federal German Environmental Foundation (since 1990). During the 1980's demonstration projects led to more than 70 PV pilot systems becoming operational; the "1 000 Roofs Programme" launched in 1990 was oversubscribed and resulted in the installation of nearly 2 000 systems on domestic roofs between 1991-1996. The "Electricity Feed-in" law (*Stromeinspeisungsgesetz*) which came into effect in 1991 has been advantageous to electricity production from renewable energies. Furthermore, a new law, the Renewable Energy Act (effective 1 April 2000), is aimed at increasing the share of renewable energy in electricity production from 5% to 10% by 2010, thus providing even greater stimulation of the PV market.

Having grown 42% per annum between 1992 and 1999 installed PV capacity was 69 500 kW_p at end-1999, of which on-grid distributed capacity represented 71%. Following the "1 000 Roofs Programme", the Federal Ministry of Economics and Technology launched the "100 000 Roofs Programme" in January 1999. Loans are provided at low interest rates (0% in 1999) and repaid over a 10-year period. The target capacity for the Programme is 300 MW_p by 2003. The Programme has led to an increased number of companies manufacturing modules and it is planned to expand annual production capability to 70 MW_p by end-2001.

INDIA

The Indian Renewable Energy programme is well established, having been constituted under the Department of Science and Technology before being transferred to the newly-created Department of Non-Conventional Energy Sources in 1982. The Department was upgraded to the Ministry of Non-Conventional Energy Sources (MNES) in 1992 and MNES has since worked with the Indian Renewable Energy Development Agency (IREDA - created in 1987), to accelerate the momentum of renewable energy development. The promotion has been achieved through R&D, demonstration projects, government subsidy programmes, programmes based on cost recovery supported by IREDA and also private sector projects.

India receives a good level of solar radiation, the daily incidence ranging from 4 to 7 kWh/m^2 depending on location. Solar thermal and solar photovoltaic technologies are both encompassed by the Solar Energy Programme that is being implemented by the MNES. The Programme, regarded as one of the largest in the world, plans to utilise India's estimated solar power potential of 20 MW/km^2 and 35 MW/km^2 solar thermal. The country has also developed a substantial manufacturing capability, becoming a lead producer in the developing world.

The principal objective of the Solar Thermal Programme is the market development and commercialisation of solar water heaters, solar cookers etc. At the present time the installed systems account for some 500 000 m^2 collector area and some 485 000 solar cookers.

Solar water heating has been applied in a wide variety of circumstances from individual residences to hotels to industrial processes. The near-future potential for such systems is around 30 million m^2 of collector area. Solar air heating has been utilised in various parts of the country for drying agricultural produce and in timber kilns. Solar stills have been employed in large numbers to supply distilled water in rural hospitals, battery-charging stations and for the supply of drinking water in remote arid zones.

The MNES has been promoting the sales of box solar cookers since the early 1980's. This type of cooker is designed to prepare food for up to 4-5 people and can be supplied with or without electrical back-up. However, the Dish Solar Cooker designed for 10-15 people and the Community Solar Cooker for 35-40 people have also been developed. In March 1999 the world's largest Solar Steam Cooking System was installed at Mount Abu, Rajasthan. It is a hybrid system with back-up oil-fired boilers and is designed to prepare food for 10 000 people.

There is also a separate Solar Buildings Programme aimed at creating an awareness of the potential for solar-efficient buildings. The passive solar design concept is a climate-responsive architectural practice that is now being researched, developed and implemented throughout the country.

During 1999, a proposal for a 140 MW integrated solar combined-cycle power project with a solar thermal power capacity of 35 MW was agreed. The plant, based on the parabolic trough collector technology, is to be located in the Jodhpur district of Rajasthan and will have supplementary firing by naphtha/gas on sunless days. It is due for completion by end-2002.

A Solar PV Programme has been developed by the MNES for the past two decades, aimed particularly at rural and remote areas. To date approximately 44 MW have been installed (representing some 750 000 systems), of which street lighting and solar lanterns account for 2.8 MW each, home lighting systems for 4.3 MW, water pumps for 4.2 MW, telecommunications for 14.7 MW, power plants for 2.2 MW and other applications for 12.5 MW. Exports account for another 13.5 MW.

The MNES has instituted a plan for establishing solar PV power generation of 1 MW for use in specialised applications: voltage support at rural sub-stations and peak shaving in urban centres. At the present time 15 grid-interactive solar PV power projects have been installed in seven states and a further 10 are under construction.

INDONESIA

The archipelago of Indonesia comprises over 17 000 islands (according to the latest count using satellite mapping) of which approximately 6 000 are inhabited. Difficulties in extending the national grid across the islands to the widely-dispersed population meant that in 1995 only about 58% of the country's 62 000 villages were electrified. Historically, areas that could not be supplied with conventional electricity from the national grid have relied upon hydro-electric and stand-alone diesel generators to power mini-grids, or used kerosine for lighting.

Indonesia's situation close to the equator and its annual average insolation level make it highly suitable for the installation of solar energy devices, especially for the huge rural population and in remote areas. PV systems were first demonstrated in 1979 through a water-pumping project and the development of solar energy has since been supported by the Government, with assistance from the World Bank and foreign aid agencies.

The first successful demonstration of the rural electrification of an Indonesian village using PV occurred in 1989 in Sukatani (Java). The installation which comprised 85 solar home systems (SHS), seven public systems and 15 street lights, led to the electrification of a second village, Lebak, in which a further 500 systems were installed.

The 50 MW_p Programme, originally devised in 1992 continues to progress. In 1997 the government set a target of 50 MW_p of PV by 2005, aiming to install one million SHS nationwide. The Agency for Application and Assessment of Technology, which coordinates all PV sub-programmes under the 50 MW_p programme, provides favourable financing conditions, usually in collaboration with foreign donors.

A 1993 programme for rural medical clinics where kerosine-powered lighting and refrigeration facilities have been replaced by PV modules has continued. By 1999 some 5 500 clinics had been converted, bringing safely stored vaccines and reliable radio communications to remote areas.

The government has also set targets for the installation of PV systems for a variety of applications: pumping stations for rural clean water supplies, TV repeaters, fishing boat lighting, grid-interconnected housing etc.

Many local PV projects are sourced through government-instituted village cooperatives (KUDs). The KUDs participate in the installation, maintain the systems thereafter, collect payments and act on behalf of the individual end-users with banks and government.

ISRAEL

With an annual incident solar irradiance of approximately 2 000 kWh/m^2 and few natural energy resources, Israel has pioneered the use of solar energy. Since the early 1970's the Israeli Government has dedicated much time and money to R&D of solar energy technologies and on demonstration programmes. Nationally, solar power has been harnessed through both photovoltaic modules and solar domestic hot water systems although it is the latter technology that has brought Israel to the forefront of global development.

The law requiring the installation of solar water heaters in Israel was introduced in 1980. The "Solar Law" is an amalgam of different legislative measures, all designed to lay down national standards and regulations. The Planning and Building Law requires the installation of solar water heaters for all new buildings (including residential buildings, hotels and institutions, but not industrial buildings, workshops, hospitals or high-rise buildings in excess of 27 m), dictating the size of the installation required for a particular type of building; the Land Law governs solar installations in existing multi-apartment buildings and the Supervision of Commodities and Services Law provides governmental supervision of the quality of installations and their guarantees. Furthermore, Israel is the only country in the world that legally requires the education of energy managers to include solar energy.

During 1997 in excess of 80% of Israeli families had solar water heaters, representing over 1.3 million installations. The solar contribution was equivalent to 21% of the electricity used by the domestic sector, 5.2 % of national electricity consumption and 3% of Israel's primary energy consumption.

In addition to being used extensively in the domestic sector, solar energy is also used for a variety of agricultural purposes (greenhouses, drying and water heating), minerals extraction at the Dead Sea Works and water heating/steam production in many educational/commercial buildings.

At end-1999 there were 401 kW$_p$ of installed PV power, of which 381 kW$_p$ was off-grid. Approximately half of the applications are lighting systems and about 15% are remote electrification systems. However, the extensive national grid precludes the same penetration by PV as has been enjoyed by solar water systems. There is no PV module manufacturing capability within the country and currently most activity is concentrated on maintaining the technical excellence that has been achieved through academic research.

The Ministry of National Infrastructures estimates that by 2025 solar water heaters will account for 2.4% of the estimated national energy consumption, solar houses for 0.1%, concentrating collectors for 0.5%, solar towers for 0.3% and PV for 0.03%.

ITALY

Italy has been involved with all aspects of the development of photovoltaic energy since the early 1980's. Research on materials and power plant operation and analysis have been undertaken and by end-1994 the country was ranked first in Europe with 14.1 MW$_p$ of installed PV capacity. However, during the second half of the 1990's, the coincidence of the German Federal Government's strong support of its solar energy sector together with the privatisation of Italy's electricity industry and the changing role of governmental bodies resulted in rapidly increasing German capacity and only very modest growth in Italy. Whilst Germany achieved an increase of 52 MW_p between end-1995 and end-1999, Italy only increased its installed capacity by 3 MW_p. Moreover, exports of modules also declined. By end-1999 Italy's installed capacity stood at 18.5 MW_p.

The Vasto plant, consisting of a 1 MW_p array, financed by the VALOREN Project of the European Union and the Italian region of Abruzzo was the first large modular PV power plant in Europe. The 3.3 MW_p PV at Serre in central southern Italy, in operation since mid-1994, is the largest grid-connected PV power station in Europe.

The government originally launched its 5-year "10 000 roof-top" programme in 1998 but delays followed and it finally got under way in March 2001. The programme foresees the rationalisation of PV plants in the range of 1-50 kW_p, grid-connected and integrated on roofs and facades. It will be implemented in two phases. It is expected that the first phase will see 10 000 systems, totalling 50 MW_p and, depending on the results of this phase, a second phase for an additional 40 000 systems totalling 200 MW_p. During 2001 three projects will be implemented: PV plants for public buildings, for private customers and for integration in large buildings with special architectural features. During 2000, 1 MW_p installed capacity was added and it expected that a further 5 MW_p will be added in 2001 and 10 MW_p in 2002.

Communities, isolated from a local grid or where environmental restrictions apply, have been served by the introduction of off-grid installations (59% of total capacity at end-1999). On-grid centralised installations accounted for 36% of installed capacity at end-1999 and on-grid distributed for 5%.

The country possesses one of the largest PV module manufacturers in Europe: Eurosolare - with a production capacity of approximately 2.7 MW_p/year per shift.

At the end of 2000 a large solar thermal power programme was launched in Italy.

JAPAN

The Japanese Government instituted its *Sunshine Project* in answer to the problems created by the oil crises of the 1970's. In 1993, as a way to efficiently overcome barriers related to new energy, the *New Sunshine Program* (NSS) was launched. This programme has been conducted under the aegis of the Agency of Industrial Science and Technology (AIST) in the Ministry of Economy, Trade and Industry (METI, formerly MITI) and includes an R&D renewable energy programme that extends to 2010. The R&D policies for the PV sector are designed to lead to technologies for a self-perpetuating market: the promotion of low-cost mass production, in turn promoting greater demand and economies of scale, in turn creating a stable market.

Following the 1997 enactment of The Law for New Energy Promotion Introduction, the Advisory Committee for Energy (an advisory body of METI) launched in mid-1998 *The Total Primary Energy Supply Outlook*. The Outlook specifies that the target for installed PV is 5 000 MW by 2010. During 1999 a further *New Energy Technology Strategy* was launched and a New Energy Subcommittee was established. The work being undertaken by the various government agencies is designed to bring about an increasing public awareness of PV.

METI is encouraging the growth of PV at a governmental and industrial level as well as in the residential sector - to this end several large demonstration programmes have been put in place. The *Residential PV System Dissemination Program* aims to subsidise the PV installation cost for individuals with the proviso that they perceive the significance of PV and provide the operational data of their PV system. Between 1994 and 1998, PV systems were installed on 15 596 houses with a further 17 396 houses accepted in 1999 under this programme. When these are installed the total capacity will be 121.2 MW_p. Residential PV systems are typically 3-5 kW_p and account for over 80% of the demand for PV in Japan. The incentives resulted in an annual average increase of 41% between 1992 and 1999 for installed PV power: as at end-1999 Japan lead the world with 205 300 kW_p of which 145 500 kW_p was on-grid distributed capacity.

In 1999 the Ministry of Construction authorised PV modules as roofing materials and regional "Solar-town" projects are coming to fruition.

KENYA

It was the search for alternative energy sources following the oil crises of the 1970's, the favourable climatic conditions for solar technologies and the slow progress of the Rural Electrification Plan of 1973 and the 1994 Rural Electrification Master Plan that led to the development of PV systems in Kenya. With a very large percentage of the urban population and almost all of the rural population having no access to a public supply of electricity, solar-based power could play a significant role in redressing the energy supply/demand picture, raising living standards and stimulating the economy.

In the early phase of growth of the Kenyan PV market, the majority of the components for the systems were imported with the help of foreign donor aid. During the 1980's a domestic manufacturing expertise was gradually developed which helped to reduce the prices for consumers and boosted sales of PV systems. However, during the same period, whilst worldwide technological improvements contributed to steadily falling prices for PV components, the political situation precipitated the withholding of donor aid from Kenya. From 1992 prices increased dramatically, inflation was rampant and PV sales were very badly affected. The uncertain financial situation persisted until the mid 1990's but following the stabilisation of the currency, the market began to recover, although government duties and taxes continued to complicate the situation.

Potentially a very large market for PV systems exists in Kenya, but to date implementation has been confined to affluent sections of society. Nevertheless, it was reported in 1996 that about 40 000 – 60 000 households had installed solar energy systems, comprising more than 1 MW_p of PV power. In addition to such domestic installations, over the past ten years several hundred PV refrigerators have been installed for the safe storage of vaccines, several water pumping projects have been initiated and a programme to make low-cost solar lanterns widely available has been started.

KOREA (REPUBLIC)

The Government actively began to advance renewable energies when the "Promotion Act for the New and Renewable Sources of Energy (NRSE) Development" was passed in 1987. However, in order to enhance the development of NRSE, the law was amended in late-1997 and became the "Promotion Act for Development, Utilisation and Dissemination of NRSE". The National PV Program was incorporated into the Ministry of Commerce, Industry and Energy's (MOCIE) "10 Year Development Plan for Energy Technology, 1997-2006". The goal of the Plan is to increase the share of NRSE to 2% of total energy consumption by 2006. The economic problems of the late-1990's resulted in a reduction in the R,D&D budgets but all aspects of the photovoltaic technology sector have been given the highest priority.

At end-1999 there were 3 459 kW_p of installed PV power of which 92% was off-grid. These applications, which predominated until 1997, include installations for private residences, telecommunications, lighthouses, public lighting, road and aviation signalling etc. In addition, PV–diesel hybrid systems have been installed in isolated houses and on remote islands. In recent years government interest appears to have shifted to grid-connected systems and various demonstration projects and field tests have taken place.

Direct use of solar energy is also utilised and by end-1999 in excess of 200 000 domestic hot water systems, together with 157 large-scale hot water systems, were in use.

MEXICO

Mexico's average solar energy resource is estimated at 5 kWh/m^2/day. There are currently approximately 50 000 isolated PV systems installed throughout the country in order to provide electricity to rural areas separated from the grid. They are mainly used for pumping and domestic and public lighting and also for powering telephones, microwave repeaters and signalling systems (both marine and terrestrial). At end-1999 there were 328 000 m^2 of flat plate solar collectors installed, mainly used for water heating for various purposes.

NETHERLANDS

The Dutch Ministry of Economic Affairs is responsible for policies regulating renewable energies and as part of its *Towards a Renewable Energy Policy* document, has implemented programmes that will promote the development of both photovoltaic solar energy and thermal solar energy.

The aims of the National Multi-year Research Programme on Solar Energy (Photovoltaic cells) are:

- improving the price-performance ratio by 300% by 2000;
- a solid industrial base and expansion of PV cell technology;
- a healthy market for stand-alone PV systems;
- knowledge of PC cell applications in the built environment;
- broader public support.

In order to translate these aims into practice, it is hoped that the Programme's budget will provide the wherewithal for an effective balance between R&D on the one side and demonstration projects and commercialisation on the other.

In April 1997 a PV energy covenant was signed (with further signatories in 1998 and 1999) by industrial bodies, utilities, the R&D sector and Government to make an effective contribution to the development of PV energy. Originally designed to run until 2000, a new covenant is being prepared for the period 2001-2007. It will focus on further broadening support for PV energy.

In 1997 the Government published an Action Programme for the period 1997-2000. The programme was aimed at increasing the share of renewable energy in the national energy supply to 3% in 2000 and 10% in 2020. The Ministry stipulated certain goals for the installation of PV: 12.5 MW$_p$ by 2000, 250 MW$_p$ by 2010 and about 1 500 MW$_p$ by 2020. At end 1999 installed PV capacity stood at 9.2 MW$_p$ of which 58% was on-grid distributed.

The aims of the National Multi-year Programme on the Thermal Conversion of Solar Energy 1996-2000 are:

- achieving an increase in the number of solar boilers installed of at least 80 000 by 2000;
- preparing for the market launch of other active thermal solar energy applications;
- ensuring that the optimum use of passive solar energy is widely applied in the construction and renovation of residential dwellings and other buildings.

To encourage the expansion in the numbers of solar boilers installed, the Ministry operates a subsidy scheme and also, like the energy covenant for PV, a covenant for solar boilers was signed at the beginning of 1999. It will run until the end of 2001 with an option to extend it to 2007. The signatories have undertaken to create a market which will enable the installation of 400 000 solar boilers by 2010. The participating companies have committed themselves to installing more than 40 000 additional solar boilers by the end of 2000 and almost 65 000 solar boilers by 2002.

NORWAY

The majority of Norway's commercial solar market consists of off-grid PV systems. At end-1999 a total of about 75 000 systems had been installed, mostly in recreational cabins. The panels, used for re-charging batteries for lighting, are typically 50-60 W in size.

In addition, the Norwegian coastal service has installed some 2 200 solar beacons along the coast. It is planned that all off-grid lighthouses will be thus supplied in the future.

SOUTH AFRICA

The annual global solar radiation average received by South Africa is approximately 5.5 kWh/m^2/day, one of the highest national levels in the world. The resource began to be utilised to a limited extent from the early 1980's, when a PV industry was established. PV modules are now widely used for powering the telecommunications network and are also applied in small-scale remote stand-alone power supplies in domestic situations, game farms, water pumping etc.

In 1994 the newly elected government of national unity launched their *Reconstruction & Development Programme* and thereby accelerated the trend for PV installations. In the same year Eskom undertook to electrify 1.75 million homes by 2000: a figure that was achieved by end-1999. A three-year target for a further 600 000 connections was then set. In a country where a vast number of households are too distant to be considered for an interconnection to the grid, PV systems are a cost-effective solution. At the beginning of 1999 the first Powerhouse system in the world's largest commercial solar rural electrification project was launched in the Eastern Cape. The project, a joint venture between Eskom and Shell Renewables, will provide a solar panel, a charge-controlled battery and a security and metering unit for 50 000 homes.

At the beginning of 2000, the Department of Minerals and Energy published a consultative draft document, *Implementation Strategy for Renewable Energy in South Africa*. Within the overall renewable energy scene for the short to medium term, the Strategy outlined the main thrusts for solar energy:

- the launching of a non-grid electrification programme as an integral element of the National Electrification Programme. Photovoltaic solar home systems should be installed in at least 1.5 million homes within 10 years with a continuance of the project thereafter. Electrification projects already under way for rural schools and health clinics would be integrated into the programme;
- the introduction and use of passive solar building design so that, in particular, houses being built as part of the national housing programme could achieve greater thermal efficiency. In addition to new housing, it is planned to extend better design to commercial and government buildings;
- the development and implementation of a long-term programme aimed at the widespread use of solar water heating, thus reducing the need for additional power plants;
- the long-term commercial dissemination of solar cookers;
- the South African technological base is being used to study the possible development of solar thermal power generation in the Northern Cape area. Eskom (together with the Council for Scientific and Industrial Research, the national, provincial and Namibian governments) has already conducted preliminary studies of Solar Trough technology, Sterling Dish technology and Solar Power Tower technology. It is

envisaged that a feasibility study will be undertaken on a grid-connected Solar Thermal installation.

SPAIN

A Renewable Energy Programme 1991-2000 that set a target of 2.5 MW installed PV solar energy was far exceeded even before its final year, but at the present time solar energy still does not contribute very significantly to Spain's total electricity generation. However, several measures are in place for renewable energy (including solar power) to be boosted: a Royal Decree approved at the end of 1998 specifies the subsidies to be granted to electrical power generated from renewable energies and a further Royal Decree approved during September 2000 defines the conditions attached to the operation of PV cells connected to the low-tension grid.

In recent years Spain has been active on two fronts in the development of solar energy - the installation of PV power and the development of cells, modules and systems. In the latter development, Spain joins Germany and France as the European leaders in the manufacturing process. Research and development in the design and application of PV technology are conducted extensively by Spanish universities, research institutes and manufacturing companies.

At end-1999 Spanish installed PV capacity stood at about 9 MW_p, approximately level with the Netherlands and France. These three countries represent the second rank behind the European leaders (Germany, Italy and Switzerland). Spanish installed capacity consisted of 77% off-grid, 16% on-grid centralised and 7% on-grid distributed. One particular type of installation is helping to revitalise rural parts of the country: the establishment in isolated communities of stand-alone PV power plants, (consisting of, for example, a 10 kW_p array, a 180 kWh battery bank and a power conditioner) which have their electricity distributed via micro-grids. During installation, other domestic services can be supplied – the sites that would otherwise have become depopulated are now viable once more.

SWITZERLAND

The Swiss Government launched a 10-year national programme in November 1990, known as *Energy 2000*. As part of the programme the Government intended to actively promote the advantages of both solar energy systems and the employment of passive heating. At the beginning of *Energy 2000*, an investment of 150 million Swiss Francs per year was planned by the confederation for the programme and it was intended that by 2000 some 50 MW_p of grid-connected PV would have been installed. However, Parliament decided to reduce the credit to only 50 million Swiss Francs per year and to date, all attempts to increase this sum have failed. As a result in this reduction, only about one quarter of the PV target has actually been achieved.

In September 2000 a public referendum took place on the introduction of a levy on non-renewable energy and a longer-term ecological tax reform. However, a rise in fuel prices prior to the referendum contributed to only 48% of the electorate voting in favour. The outcome of the referendum will undoubtedly result in a slow-down of the Government's once ambitious programme.

THAILAND

The Thai Government has for many years recognised the need to diversify its energy supplies and the energy *Master Plan* prepared during the 1980's has been developed under successive five-year plans. The New and Renewable Energy Programme under the National Energy Policy Office's (NEPO) Energy Conservation Promotion Programme states that renewable energy is expected to play a major role in the future.

Owing to the country's location near the equator, the consequent good level of insolation is utilised for both solar thermal and solar PV installations.

Government agencies are involved in the PV sector and those with substantial PV installations are: the Department of Energy Development and Promotion (DEDP), Provincial Electricity Authority (PEA), the Telephone Organisation of Thailand (TOT), the Public Work Department (PWD), the Ministry of Education and the Ministry of Public Health.

The Electricity Generating Authority of Thailand (EGAT) has over the years played a central role in the development of solar energy systems, although the first PV applications were installed in 1976 by the Ministry of Public Health and the Medical Volunteers Foundation at rural health stations for communications equipment.

By end-1999 about 5 MW_p of PV modules had been installed in the country, of which TOT had 1 MW_p installed for use in microwave repeaters, PWD had 1.5 MW_p for water pumping systems (both for domestic and irrigation) and the Ministry of Education had some 20 kW_p installed in remote schools.

EGAT has also developed stand-alone projects, grid-connected systems and hybrid hydro-PV, diesel-PV and wind-PV systems. In recent years EGAT has collaborated with NEPO to implement a rooftop PV project. Following the successful installation of PV panels on 10 households, 100 more were selected and the programme has now been expanded to include government buildings.

Currently some 50 000 m^2 of flat-plate collectors have been installed on commercial buildings, hospitals and private residences and solar thermal capacity is expanding at a rate of some 3 000 – 3 500 m^2 of solar water heaters per year.

EGAT is supporting an R&D programme for concentrated solar collector and storage systems and NEPO is preparing a solar hot water programme for hotels, resorts and hospitals.

UNITED STATES OF AMERICA

The US Department of Energy's Office of Energy Efficiency and Renewable Energy directs the National PV Program through its Office of Solar Energy Technologies.

Early in 1998 the Million Solar Roofs Initiative was launched: the goal being to put a million solar systems (PV units or thermal systems) on the roofs of commercial and residential building by 2010. Although Federal legislation approving tax credits for such installations has not yet been passed, the DOE is awarding grants to State and Local Partnerships in order to assist the financing and deployment of such systems. In addition, net metering (a device to facilitate accounting for electricity produced from a PV system) has been introduced into 30 states. As at end-June 2001, it is estimated that at least 140 000 solar energy systems had been installed in the USA, of which 100 000 are pool heaters, 38 000 are hot water systems and 2 000 are PV (solar electric systems).

During 1999 the PV industry in the USA drew up an *Industry Roadmap* with the aim of setting out the strategies and goals for PV in the period to 2020. Its strategies are:

- to maintain the worldwide technological leadership that the US enjoys;

- to achieve economic competitiveness with conventional technologies;
- to maintain a sustained market and PV production growth;
- to make the industry profitable and attractive to investors.

Its goals are:

- to maintain a 25% annual production growth rate;
- during 2020, to ship approximately 7 GW_p of PV for installation worldwide, 3.2 GW_p of which will be used in domestic installations;
- to decrease costs to the end-user (including costs for operation and maintenance) to US$ 3 per Watt AC by 2010 and to approximately US$ 1.50 per Watt AC by 2020.

At the beginning of 2000, and in conjunction with the Roadmap, The National Center for Photovoltaics (NCPV) released its report, “Photovoltaics – Energy for the New Millennium: The National Photovoltaics Program Plan 2000-2004”.

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Chapter 12

GEOTHERMAL ENERGY

Geothermal energy is the natural heat of the earth. Enormous amounts of thermal energy are continuously generated by the decay of radioactive isotopes of underground rocks and stored in our globe's interior. This heat is as inexhaustible and renewable as solar energy. The temperature in the core of the earth is in the order of 4 000^{o}C, while active volcanoes erupt lava at about 1 200^{o}C and thermal springs, numerous on land and present on the oceanic floor, can reach 350^{o}C. Presently geothermal energy is exploited by producing the underground water stored in permeable rocks from which it has absorbed available heat (hydro-thermal systems) or, in certain types of geothermal heat pumps, extracting heat directly from the ground.

In another approach, still in the experimental stage, hot rocks are artificially fractured and water is let in and circulated between injection and producer wells, gathering, on the way, the rock heat (HDR systems). Still further away is exploitation of the large quantities of heat stored locally at accessible depth in molten rock (magma). Up to 100^{o}C underground water can provide at present, energy for many applications, ranging from district heating to individual residential heating, to agricultural and spa uses and for selected industries. Geothermal fluids between 100^o and 150^{o}C can (besides direct heat uses) generate electricity with special (binary) power plants. Above 150^{o}C, the optimal use of the resource is for electricity production.

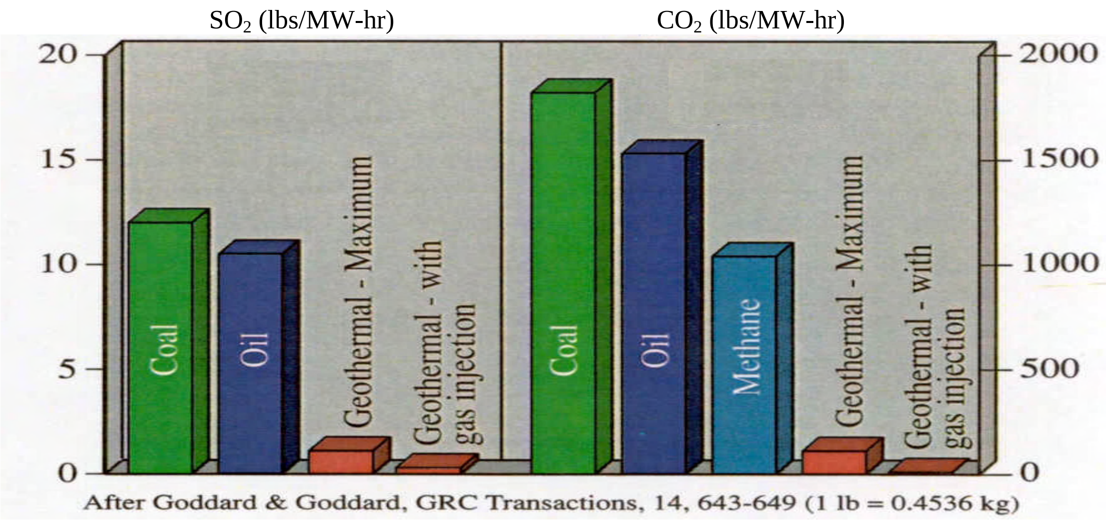

Figure 12.1: Comparison of Emissions

Hydrothermal resources are renewable within the limits of equilibrium between offtake of reservoir water and natural or artificial recharge. It has been calculated (Megel, Rybach 1999) that the life of a low-temperature system (exploited by a couple of producing-injector wells) can extend over more than 150 years, provided alternating periods of production and halt are adopted. In the commercial development of high-temperature fields, however, the resource is produced for economic reasons at a level exceeding the recharge rate, thus exhausting the fluids, while leaving much heat under the ground.

Geothermal energy use has a net positive environmental impact. Geothermal power plants have fewer and more easily controlled atmospheric emissions than either fossil fuel or nuclear plants (Figure 12.1). Direct heat uses are even cleaner and are practically non-polluting when compared to conventional heating. Another advantage, which differentiates geothermal energy from other renewables, is its continuous availability, 24 hours a day all year round.

While production costs are at times competitive and in other cases marginally higher than conventional energy, front-end investment is quite heavy and not easily funded.

Technology

To generate electricity, fluids above 150°C are extracted from underground reservoirs (consisting of porous or fractured rocks at depths between a few hundred and 3 000 metres) and brought to the surface through production wells. Some reservoirs yield steam directly, while the majority produce water from which steam is separated and fed to a turbine engine connected to a generator. Some steam plants include an additional flashing stage. The used steam is cooled and condensed back into water, which is added to the water from the separator for reinjection (Figure 12.2). The size of steam plant units ranges from 0.1 to 150 MW_e.

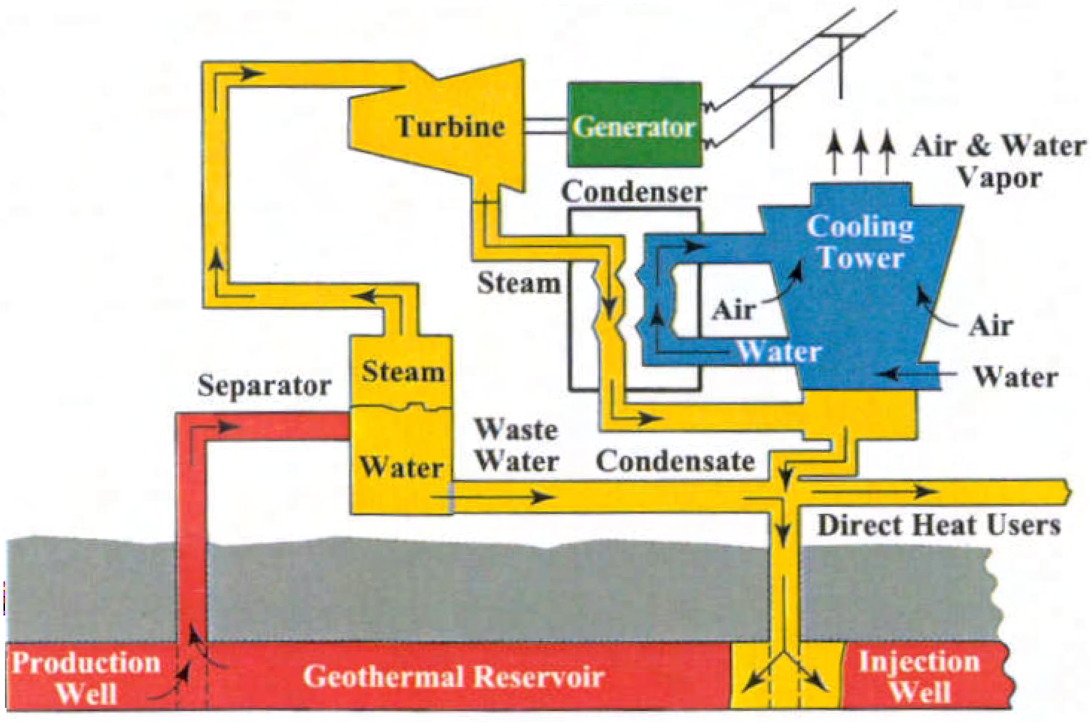

Figure 12.2: Flash Steam Power Plant (Source: *Geothermal Energy*, 1998, University of Utah)

If the geothermal resource has a temperature between 100° and 150°C, electricity can still be generated using binary plant technology. The produced fluid heats, through a heat exchanger, a secondary working fluid (isobutane, isopentane or ammonia), which vaporises at a lower temperature than water. The working fluid vapour turns the turbine and is condensed before being reheated by the geothermal water, allowing it to be vaporised and used again in a closed-loop circuit (Figure 12.3).

The size of binary units range from 0.1 to 40 MW_e. Commercially, however, small sizes (up to 3 MW_e) prevail, often used modularly, reaching a total of several tens of MW_e installed in a single location. The spent geothermal fluid of all types of power plants is generally injected back into the edge of the reservoir for disposal and to help maintain pressure. In the case of direct heat utilisation, the geothermal water produced from wells (which generally do not exceed 2 000 metres) is fed to a heat exchanger before being reinjected into the ground by wells, or discharged at the surface. Water heated in the heat exchanger is then circulated within insulated pipes that reach the end-users. The network can be quite sizeable in district heating systems. For other uses (greenhouses, fish farming, product drying, industrial applications) the producing wells are next to the plants serviced.

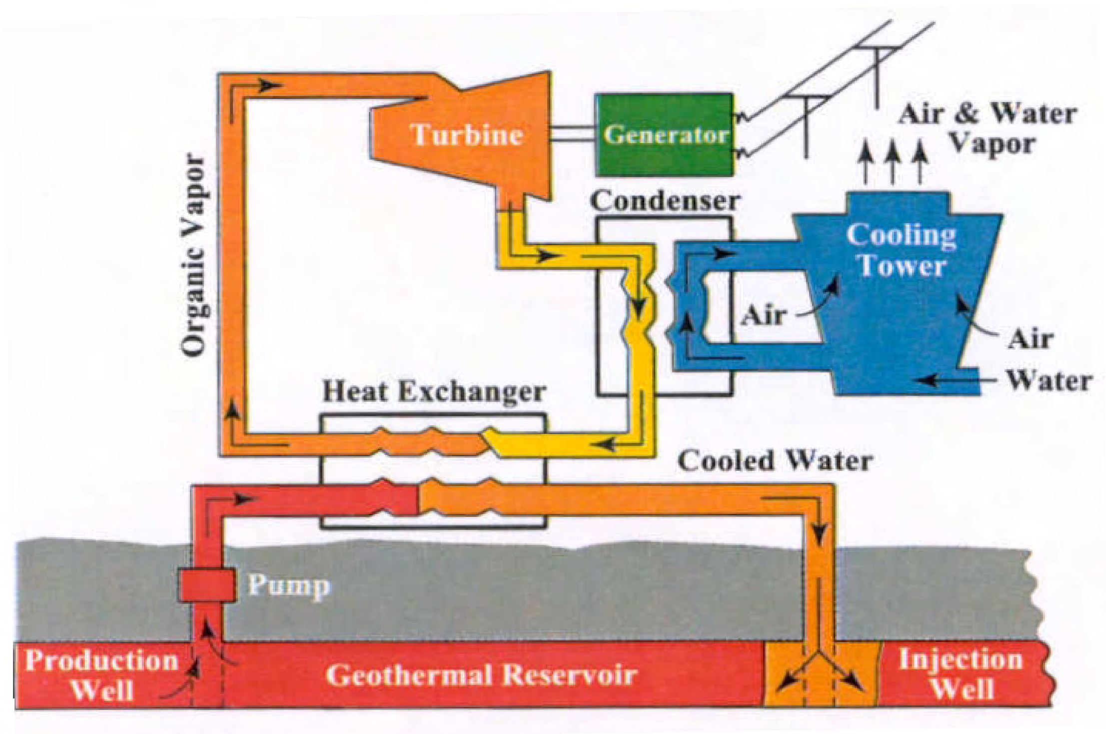

Figure 12.3: Binary Cycle Power Plant (Source: *Geothermal Energy*, 1998, University of Utah)

A very efficient way to heat and air-condition homes and buildings is the use of a geothermal heat pump (GHP) that operates on the same principle as the domestic refrigerator. The GHP (Figure 12.4) can move heat in two ways: during the winter, heat is withdrawn from the earth and fed into the building; in the summertime, heat is removed from the building and stored under-ground. In some GHP systems heat is removed from shallow ground by the means of an antifreeze/water solution circulating in plastic pipe loops (either inserted in vertical wells less than 200 m deep which are then backfilled or buried horizontally in the ground). In other GHP systems flow water produced from a shallow borehole through the heat pump, discharges the water either in another well or at surface. The heat pump unit sits inside the building and is coupled either with a low-temperature floor or wall heating net or with a fan delivering heat and cold air.

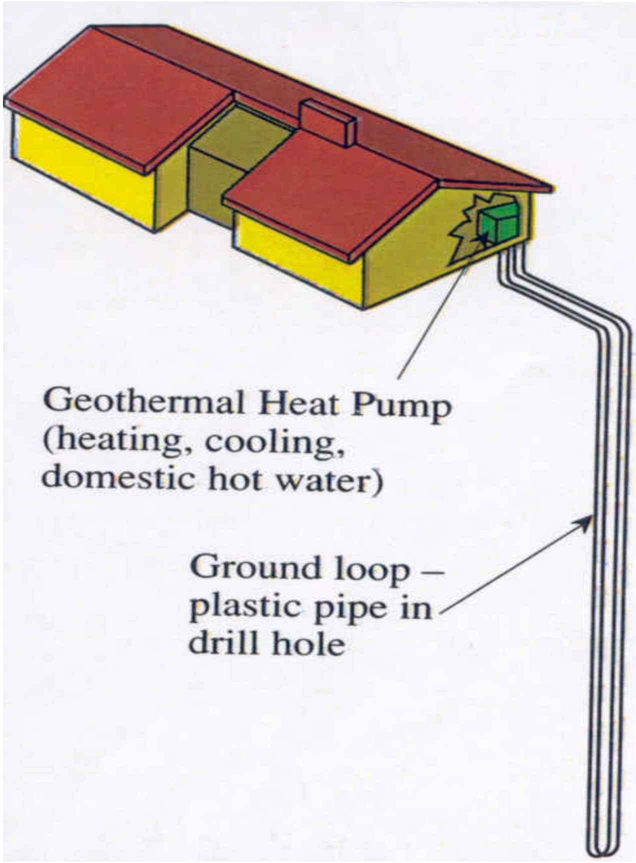

Figure 12.4: Geothermal Heat Pump (Source: *Geothermal Energy*, 1998, University of Utah)

Location of Resources

Worldwide, those hot areas with fluids above 200^{o}C at economic depths for electricity production are concentrated in the young regional belts. They are the seats of strong tectonic activity, separating the large crustal blocks in which the earth is geologically divided (Figure 12.5). The movement of these blocks is the cause of mountain building and trench formation. The main geothermal areas of this type are located in New Zealand, Japan, Indonesia, Philippines, the western coastal Americas, the central and eastern parts of the Mediterranean, Iceland, the Azores and eastern Africa.

Elsewhere in the world, underground temperatures are lower but geothermal resources, generally suitable for direct-use applications, are more widespread. Exploitable heat occurs in a variety of geological situations. It is practically always available in the very shallow underground where GHPs can be installed. The risk for a prospector (of not locating hot water in the quantity and with the quality required) is limited in shallow depth targets where prior knowledge gained from earlier surveys is available. There are greater uncertainties on deeper resources where insufficient survey work has been conducted.

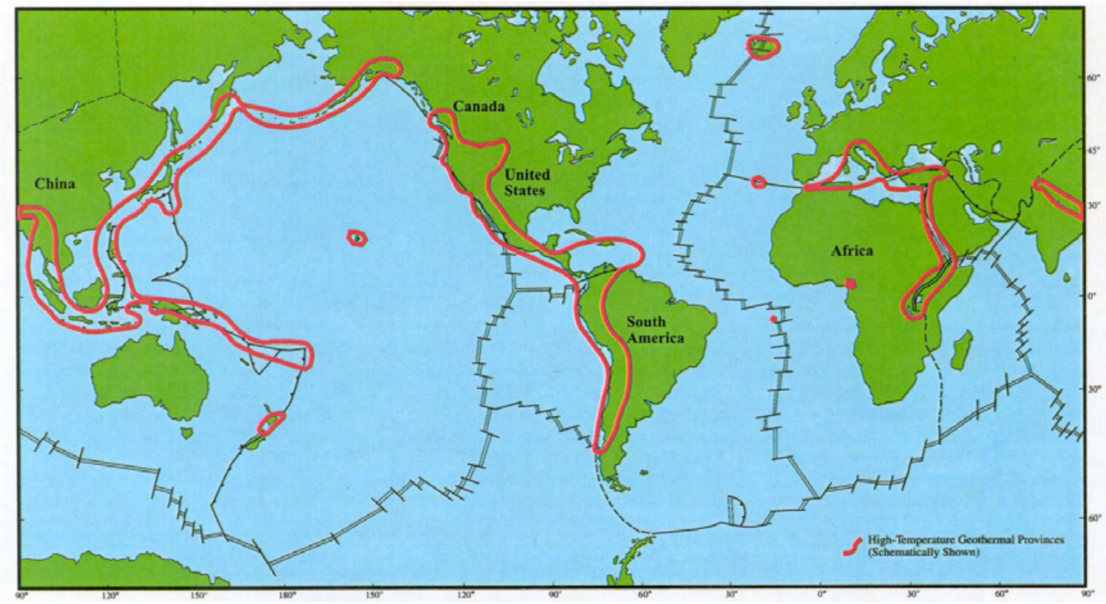

Figure 12.5: World High Temperature Geothermal Provinces (Source: *Geothermal Energy*, 1998, University of Utah)

Recent Developments

Comparing statistical data for end-1996 (SER 1998) and the present Survey, it can be seen that there has been an increase in world geothermal power plant capacity (+9%) and utilisation (+23%) while direct heat systems show a 56% additional capacity, coupled with a somewhat lower rate of increase in their use (+32%).

Geothermal power generation growth is continuing, but at a lower pace than in the previous decade, while direct heat uses show a strong increase compared to the past.

Going into some detail, the six countries with the largest electric power capacity are: USA with 2 228 MW_e is first, followed by Philippines (1 863 MW_e); four countries (Mexico, Italy, Indonesia, Japan) had capacity (at end-1999) in the range of 550-750 MW_e each. These six countries represent 86% of the world capacity and about the same percentage of the world output, amounting to around 45 000 GWh_e.

The strong decline in the USA in recent years, due to overexploitation of the giant Geysers steam field, has been partly compensated by important additions to capacity in several countries: Indonesia, Philippines, Italy, New Zealand, Iceland, Mexico, Costa Rica, El Salvador. Newcomers in the electric power sector are Ethiopia (1998), Guatemala (1998) and Austria (2001). In total, 22 nations are generating geothermal electricity, in amounts sufficient to supply 15 million houses.

Concerning direct heat uses, Table 12.1 shows that the three countries with the largest amount of installed power: USA (5 366 MW_t), China (2 814 MW_t) and Iceland (1 469 MW_t) cover 58% of the world capacity, which has reached 16 649 MW_t, enough to provide heat for over 3 million houses. Out of about 60 countries with direct heat plants, beside the three above-mentioned nations, Turkey, several European countries, Canada, Japan and New Zealand have sizeable capacity.

With regard to direct use applications, a large increase in the number of GHP installations for space heating (presently estimated to exceed 500 000) has put this category in first place in terms of global capacity and third in terms of output. Other geothermal space heating systems are second in capacity but first in output. Third in capacity (but second in output) are spa uses followed by greenhouse heating. Other applications include fish farm heating and industrial process heat. The outstanding rise in world direct use capacity since 1996 is due to the more than two-fold increase in North America and a 45% addition in Asia. Europe also has substantial direct uses but has remained fairly stable: reductions in some countries being compensated by progress in others.

Concerning R&D, the HDR project at Soultz-sous-Forêts near the French-German border has progressed significantly. Besides the ongoing Hijiori site in Japan, another HDR test has just started in Switzerland (Otterbach near Basel).

The total world use of geothermal power is giving a contribution both to energy saving (around 26 million tons of oil per year) and to CO_2 emission reduction (80 million tons/year if compared with equivalent oil-fuelled production).

The Future

The short to medium term future of geothermal energy is encouraging, providing some hurdles that have recently slowed its growth are overcome. Among them: the Far Eastern economic crisis (especially in Indonesia and Philippines, which had ambitious development plans); the strong production decline at The Geysers field in USA; the extended period of low energy prices. Where possible, actions are being taken to improve the situation. At The Geysers an effluent pipeline (to be completed by 2002) is under construction from the town of Santa Rosa, so as to inject into the reservoir as much waste water as is being produced, thus increasing the field potential.

Energy prices have increased significantly since the second half of 1999. Plans already drafted at the end of the 1990’s, but partly delayed, by Indonesia, Philippines and Mexico aim at an additional 2 000 MW_e before 2010. In the direct use sector, China has the most ambitious target: substitution of 13 million tons of polluting coal by geothermal energy.

Improved use of hydrothermal resources, limitation of front-end costs and increased ground heat extraction are the keys to a steady development of conventional geothermal energy. Installation of a large number of binary power plants will increase electricity production from wide geographical areas underlain by medium-temperature resources: a good example is the Altheim plant just inaugurated in Austria, which has added power production to district heating with 106^{o}C water. Heat readily available in spas can be optimised by adding compatible uses. New horizons for geothermal energy can be opened up with fresh applications, for example drinking water production on islands and in coastal areas with scarce resources (e.g. the project starting in 2001 on Milos, Greece). Finally, GHP systems can be replicated in many parts of the world.

The long-range future of geothermal energy depends on HDR systems becoming a technological and economic reality. It has been estimated that the heat resources located at economically accessible depths could support, in North America and Europe, an amount of power generation capacity by HDR systems of the same order or greater than present nuclear capacity.

Early in 2001 the European Economic Interest Grouping (EEIG) formed by the oil major Shell, the Italian geothermal power producer ERGA and three French and German utilities began a five-year programme to drill additional wells and build a power plant in Soultz-sous-Forêts.

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TABLE NOTES

The data shown in Table 12.1 reflect as far as possible those reported by WEC Member Committees in 2000.

When not available from WEC Member Committees, data were drawn from the *Proceedings of the World Geothermal Congress*, Kyushu & Tohoku, Japan, 28 May-10 June, 2000, International Geothermal Association. National statistical sources have also provided a small amount of data.

Installed electricity generating capacity in the USA (2 228 MW) reflects the level reported by the World Geothermal Congress in 2000.This level is significantly lower than that published by the DOE/EIA and reported by the US WEC Member Committee (2 898 MW). The difference is attributable to the treatment of downrated capacity.

In one instance (Spain), the end-1996 data published in the WEC *Survey of Energy Resources 1998* have been retained, as data were not available for end-1999 from other sources.

The direct use of geothermal energy is not only inherently difficult to quantify but in some instances can be subject to constraints on reporting for reasons of confidentiality, etc. The statistics shown for both capacity and output should therefore be treated as, at best, indicative of the situation in a particular country. As far as possible, direct use includes the capacity and output of geothermal (ground-source) heat pumps.

Annual capacity factors have been calculated on the basis of end-year capacity levels, as average-year data were not available. In general, therefore, the factors shown will tend to be understated. The capacity factors of 1.00 given for direct use of geothermal energy in certain countries reflect the assumptions made in the surveys consulted.

Table 12.1 Geothermal energy: electricity generation and direct use at end-1999

Excel Files

	Electricity generation			Direct use		
	Installed capacity	Annual output	Annual capacity factor	Installed capacity	Annual output	Annual capacity factor
	MW_e	GWh		MW_t	GWh	
Algeria				100	441	0.50
Ethiopia	9	30	0.40			
Kenya	45	390	0.99	1	3	0.25
Tunisia				20	48	0.28
Total Africa	**54**	**420**	**0.89**	**121**	**492**	**0.46**
Canada				378	284	0.09
Costa Rica	115	804	0.80			
El Salvador	161	552	0.39			
Guadeloupe	4	25	0.67			
Guatemala	33	216	0.74	3	30	1.00
Honduras				1	5	0.76
Mexico	750	5 642	0.86	164	1 089	0.76
Nicaragua	70	583	0.95			
United States of America	2 228	16 813	0.86	5 366	5 640	0.12
Venezuela				1	4	0.63
Total North America	**3 361**	**24 635**	**0.84**	**5 913**	**7 052**	**0.14**
Argentina	1	N	0.67	26	125	0.55
Chile				N	2	0.55
Colombia				13	74	0.63
Peru				2	14	0.65
Total South America	**1**	**N**	**0.67**	**41**	**215**	**0.60**
China	29	100	0.39	2 814	8 724	0.35
Georgia				250	1 752	0.80
India				80	699	1.00
Indonesia	590	4 575	0.89	7	12	0.19
Japan	547	3 451	0.72	258	1 621	0.72
Korea (Republic)				51	299	0.67
Nepal				1	6	0.66
Philippines	1 863	10 594	0.65	1	7	0.79
Thailand	N	1	0.38	1	4	0.68
Turkey	15	81	0.62	820	4 377	0.61
Total Asia	**3 044**	**18 802**	**0.71**	**4 283**	**17 501**	**0.47**
Austria				255	447	0.20
Belgium				4	30	0.87
Bulgaria				107	455	0.48
Croatia				114	153	0.15
Czech Republic				13	36	0.33
Denmark				3	15	0.52
Finland				81	167	0.24
FYR Macedonia				81	142	0.20
France				326	1 365	0.48
Germany				397	436	0.13
Greece				57	107	0.21
Hungary				328	1 400	0.49
Iceland	170	1 138	0.76	1 469	5 603	0.44
Italy	621	4 403	0.81	680	2 500	0.42
Lithuania				21	166	0.90
Netherlands				11	16	0.17
Norway				6	9	0.17
Poland				69	76	0.13
Portugal	20	79	0.45	6	10	0.20
Romania				110	120	0.12

Table 12.1 Geothermal energy: electricity generation and direct use at end-1999 contd.

	Electricity generation			Direct use		
	Installed capacity	Annual output	Annual capacity factor	Installed capacity	Annual output	Annual capacity factor
	MW_e	GWh		MW_t	GWh	
Russian Federation	23	85	0.42	307	1 703	0.63
Serbia, Montenegro				80	660	0.94
Slovakia				132	588	0.51
Slovenia				103	300	0.33
Spain				70	292	0.47
Sweden				377	1 147	0.35
Switzerland				547	663	0.14
United Kingdom				3	10	0.38
Total Europe	**834**	**5 705**	**0.78**	**5 757**	**18 616**	**0.37**
Israel				63	476	0.86
Jordan				153	428	0.32
Total Middle East				**216**	**904**	**0.48**
Australia	N	1	0.60	10	82	0.90
New Zealand	410	2 323	0.65	308	1 967	0.73
Total Oceania	**410**	**2 324**	**0.65**	**318**	**2 049**	**0.74**
TOTAL WORLD	**7 704**	**51 886**	**0.77**	**16 649**	**46 829**	**0.32**

COUNTRY NOTES

The Country Notes on geothermal energy have been compiled by the editors, drawing principally upon the *Proceedings of the World Geothermal Congress*, Kyushu & Tohoku, Japan, 28 May-10 June, 2000, International Geothermal Association.

Information provided by direct communications with geothermal specialists, WEC Member Committees and national and international publications has been incorporated as available.

ARGENTINA

Argentina is in the forefront of South American utilisation of geothermal resources. High-temperature geothermal heat exists in the western region, along the Andes range, and moderate to low-temperature thermal fields have been identified in other parts of the country.

As a 670 kW binary-cycle pilot plant at Copahue went off-line in 1996, the emphasis is now on the development of direct uses of geothermal power. The government has instituted a National Geothermal Plan to aid this development.

At present there are 134 direct use projects with an installed capacity of 25.7 MW_t. The projects range between:

- the six new thermal areas in the north-east being exploited for recreational and therapeutic purposes;
- at a tourist complex in the Copahue-Caviahue area of the Andean foothills, a snow-melting scheme using geothermal steam to enable year-long accessibility to an international thermal baths centre;
- greenhouse heating, shrimp farming and a thermal therapeutic centre south of Buenos Aires.

A pisciculture scheme using thermal fluids is currently under development in Chubut province.

AUSTRALIA

In recent years the geothermal situation in Australia has changed dramatically. The expansion of activity has been caused by the successful demonstration of binary hydrothermal power plants, the commercial success of ground-source heat pumps and also increasing government support of initiatives to reduce greenhouse gas emissions.

Geothermal energy is used directly by the numerous hot water bathing pools throughout the country and a district heating scheme in western Victoria. A hot water spa in the latter region received local government approval in 1999. However, a paper plant in Victoria that used hot water in the manufacturing process has ceased production. Ground and water-source heat pumps have increased in popularity throughout the country, with at least 2,000 installations in place; an expansion in the market of 50% per annum is expected, including commercial-size hot water systems and systems for drying fruit and vegetables.

Australia has also been found to have a very significant ‘hot dry rocks’ (HDR) resource, particularly in the centre of the country, extending over the north-eastern corner of South Australia and the south-western corner of Queensland. Research aimed at evaluation of HDR began in 1994.

Following a private feasibility study, fourteen Federal and private entities established Hot Rock Energy Pty (HRE) as an R&D corporation in early-1995. A 5-year licence was awarded to Pacific Power Corporation for exploration in the upper valley of the Hunter River: drilling began in April 1999.

There are only two geothermal electric power sites in Australia. A 20 kW experimental plant at Mulka (South Australia) operated for three and half years in the late 1980’s. An eight-fold scale-up of Mulka was commissioned at Birdsville (Queensland) in 1992 and ran until end-1994. After environmental considerations dictated a change in the working fluid, and also after a change of ownership, the plant was put back on line in mid-1999.

AUSTRIA

There has been considerable development of Austrian geothermal resources in the period since 1995. Until recently, the country possessed four geothermal plants, all in Upper Austria. The aggregate installed capacity of 27.3 MW_t is utilised for direct applications such as district heating, spa heating, bathing, swimming and the heating of greenhouses.

A binary power plant at Altheim was brought into operation in January 2001. Installed capacity is 1 MW_e and the expected annual output is 3.8 GWh.

In addition, it has been reported that there are in the order of 19 000 heat pump installations throughout the country, with an estimated total capacity of 228 MW.

CANADA

It has been demonstrated from research undertaken since 1974 that Canada has a plentiful and widespread geothermal potential. The abundance of hydro-electric resources and inexpensive fossil fuels have, however, proved disincentives to large-scale development. Resources of high-temperature geothermal energy have been established but to date none have been utilised. Rather it has been applications utilising the low-temperature resources that have come to fruition.

Direct utilisation of geothermal energy has followed four routes (geothermal heat pumps, aquifer thermal energy storage, energy from mine waters and hot spring resorts) and provides an estimated total installed capacity of 377.6 MW_t.

It has been estimated that 30 000 heat pump units (with a total capacity of 360 MW_t) have been installed to provide heat and/or cooling to commercial buildings and larger private homes. In some large-scale buildings the units have combined heat exchangers and aquifer thermal storage technologies whereby recycled geothermal energy is able to provide both heating and cooling. A low-temperature resource at a disused coal mine in Nova Scotia provides an estimated 11 MW_t of direct-use geothermal energy for space heating at a local industrial site. Western Canada is known to possess numerous medium and high-temperature hot springs and an estimated 6.6 MW_t capacity is utilised for recreational purposes at 11 commercial hot pools and 8 resorts in British Columbia and Alberta.

CHINA

With fast economic growth and increasing environmental concerns, the development of geothermal energy in China increased by 12% per annum during the 1990's. Studies have identified more than 3,200 geothermal features, of which some 50 fields have been investigated and explored. High-temperature resources are mainly concentrated in southern Tibet and western parts of Yunnan and Sichuan Provinces, whereas low-medium temperature resources are widespread over the vast coastal area of the south-east, North China basin, Songliao basin, Jianghan basin, Weihe basin etc.

The primary development has been in the growth of geothermal energy used directly. In 1998 it was reported that there were in excess of 1,600 sites being used for installations as diverse as drying, fish farming, irrigation and earthquake monitoring, etc. However, the main emphasis has been on the expansion of installations for space heating, sanatoria and tourism.

The development of geothermal power generation has been, by comparison, relatively slow, owing to the large hydro-electric resources in those provinces with high-temperature geothermal resources (Tibet and Yunnan). The largest power complex is located at Yangbajing (Tibet). At end-1999 its total installed capacity was 25.18 MW_e (gross), generated by nine single flash, double flash and hybrid cycle power plants. China's aggregate capacity is approximately 30 MW_e, generating 100 GWh annually.

In future there may be some scope for combining the generation from geothermal power with hydro-power generation. Additionally, the country is placing an emphasis on the replacement of some coal-fired projects with geothermal. It has been projected that 13.4 million tonnes of coal will be displaced by geothermal over the period 2001-2010.

COSTA RICA

The Central American volcanic belt passes through Costa Rica, evidenced by numerous volcanoes and geothermal areas. The fields of Miravalles, Tenorio and Rincón de la Vieja are located in the north-western part of the country and have been studied in detail.

To date, Costa Rica's geothermal resources have only been utilised for electric power generation. A 55 MW_e single flash condensing unit was commissioned in March 1994 at Miravalles, followed soon afterwards by an additional 5 MW_e backpressure unit. A second 55 MW_e condensing unit came on stream in 1998, bringing the energy produced by these plants to some 20% of the country's total energy consumption. Miravalles III, 27.5 MWe, was brought on line in March 2000 and it is hoped to add a further 19 MW_e in 2003, bringing the total to 161.5 MW_e.

Feasibility studies of the Tenorio geothermal project are now under way, and the first of four deep wells has been completed. In addition, a pre-feasibility study of the Rincón de la Vieja project has been successfully completed. Both sites are either in or partially in National Parks. If all environmental considerations are met, then by 2010, both Tenorio and Rincón de la Vieja should significantly add to the country's installed geothermal capacity.

EL SALVADOR

Like Costa Rica, El Salvador lies on the Central American volcanic belt and thus there is a plentiful geothermal resource. The main emphasis has been on using the resource for power generation and although a potential exists for the direct use of geothermal, it has not yet been developed.

Exploration began in 1954, with the first power plant coming on stream in 1975 at Ahuachapán in the far west of the country. The single flash, 30 MW_e plant was doubled in capacity in 1976 and in 1980, a double flash 35 MW_e unit was added bringing the total to 95 MW_e. However, overworking of the geothermal field caused power output to decline to 48 MW_e by 1994. A rehabilitation project (begun in 1996) has ensured that the power output has risen and continues to do so.

The Berlín geothermal field in the eastern part of the republic was explored from the 1960's onwards, eventually leading to the installation of two 5 MW_e back pressure plants in 1992. In mid-1999 a 56 MW_e (2 x 28 MW_e) condensing plant was added.

Two other prospective geothermal areas are San Vicente in the centre of the country and Chinameca in the east; each has an estimated capacity of 50 MW_e. Future studies are also planned for Coatepeque, Santa Rosa Lima and Obrajuelo Lempa.

Since 1996 there has been reform of the electricity legislation and regulation in El Salvador. Whilst geothermal generation now competes favourably with other energy sources in an open market, its prospects would be affected by projects under way to interconnect all of Central America. The result would be one large market and moreover, with plans to build a gas pipeline from Mexico to El Salvador and/or from Colombia to Panama, the effects would be felt throughout the electricity sector.

ETHIOPIA

Ethiopia is one of a minority of African countries that possesses geothermal potential. Considerable resources of both high- and low-enthalpy geothermal have been located in the Ethiopian Rift valley and in the Afar depression. Exploration that began in 1969 has, to date, revealed the existence of 24 prospects having about 700 MW_e potential.

Until 1998 the only utilisation of geothermal energy was for leisure and therapeutic purposes, but no data are available. In mid-1998 the Aluto-Langano geothermal plant (two-unit 8.5 MW_e gross) became operational. When commissioning occurred in mid-1999 Aluto-Langano became the first geothermal power plant in Africa to use integrated steam and binary power technology. The plant consists of one 3.9 MW_e combined cycle unit operating on geothermal steam and one 4.6 MW_e Ormat energy converter operating on both geothermal brine and low pressure steam.

In addition to the Aluto-Langano geothermal field, a production test and feasibility study in the Tendaho field is currently under way. Further exploratory work in the regions of the Lakes District, the Main Ethiopian Rift, Southern Afar and Northern Afar will also take place. Ethiopia's geothermal potential is such that if adequate finance becomes available to fund development then not only would the power be used for domestic consumption, but also potentially for export.

FRANCE

There are only low-enthalpy geothermal resources in metropolitan France; high-enthalpy geothermal resources are found only in France's overseas departments.

Although the first geothermal district heating plant was constructed in 1969 in the Paris region, the main development of geothermal energy began following the oil crises of the 1970's. The resources are found in two major sedimentary basins: the Paris Basin and the Aquitaine Basin in the southwest. Other areas (Alsace and Limagne) have geothermal potential but it cannot be so readily utilised. By end-1986 there were 74 plants in operation but by end-1999 this number had been fallen to 61, of which 41 are in the Paris region, 15 in the Aquitaine Basin and 5 in other regions. The installed capacity is mainly used for space heating (97%) but also greenhouse heating (2%) and fish and animal farming (1%). In addition, during the 1980's France's very low-enthalpy resources began to be utilised by the installation of heat pumps. At the present time several thousand plants exist, mainly for collective or individual building heating.

During the 1980's the French authorities began to promote research into the potential of Hot Dry Rocks. This long-term research programme has three main phases: 1987-1997 scientific evaluation of the Soultz-sous-Forêts experimentation site; 1998-2005 construction and testing of a scientific plant; after 2005 construction of an industrial prototype plant.

The dissemination of ground-source heat pump technologies, the further development of metropolitan low-enthalpy resources and development in the use of high-enthalpy resources in Overseas Departments are all continuing.

GEORGIA

Geothermal resources are prevalent throughout the area of the South Caucasus and are utilised intensively in Georgia. It has been reported that the country's considerable reserves are being particularly efficiently used in the Tbilisi field. The installed capacity effectively available for direct heat applications has been estimated to be in the region of 250 MW_t.

GERMANY

Germany does not possess high-enthalpy steam reservoirs and to date it has not been economically viable to produce electricity from its low-enthalpy resources, which are more suited to direct utilisation. The country's Hot Dry Rock (HDR) resource could substantially alter this situation and result in power generation, but at the present time German research into HDR technology is at a formative stage. The geothermal resources are located in the north German sedimentary basin, the Molasse Basin in southern Germany and along the Rhine graben.

At end-1999 total installed capacity for direct use of geothermal energy stood at 397 MW_t of which 55 MW_t represented 27 major centralised plants and 342 MW_t small decentralised earth-coupled heat pumps and groundwater heat pumps.

The 27 units comprise heating plants, thermal spas (sometimes combined with space heating), greenhouses and clusters of ground heat exchangers used for space heating or cooling. However, only 22 of the 27 plants use purely geothermal energy: the remaining five require back-up oil and gas burners to cover peak demand. Thus total installed capacity utilising thermal power of a purely geothermal nature can be put at 34.9 MW_t. It is expected that 9 projects currently under development will yield an additional 81.5 MW_t by 2002.

The exact number of small decentralised heat pumps, widespread throughout the country, has not been quantified but is thought to be in excess of 18 000 and likely to grow in future years, possibly by around 40 MW_t by the end of 2002.

GUADELOUPE

The 4.2 MW_e double flash plant at La Bouillante in the French Overseas Department of Guadeloupe is at present the only example of the island's geothermal energy being utilised for electricity production. The plant was commissioned in 1985 but was closed between 1991 and 1996.

The French Agency for Environment and Energy Management (ADEME) will contribute to the next planned phase of the development of the Bouillante high-enthalpy field. It will support 20% of the cost of the new wells being drilled in 2000. The objective of this phase of development is to increase the existing production capacity, supplying 2% of the island's electricity supply, to 20 MW_e and 10% of supply.

GUATEMALA

Guatemala has been found to possess 13 geothermal areas; following the 1996 Electricity Law, the Instituto Nacional de Electrificación (INDE) has five of them in reserve to develop. All five areas (Zunil, Amatitlán, Tecuamburro, San Marcos and Moyuta) lie in the active volcanic chain in southern Guatemala. INDE has conducted investigative work and development of geothermal power since 1972 and to date 58 MW_e has been proved, with a further 398 MW_e as estimated additional capacity.

The first geothermal power plant in the country was constructed in the Amatitlán area; electricity production from a 5 MW_e back-pressure plant began in November 1998. It will continue to provide power for the national grid for a period of 3 years. Eventually expansion of the field and the construction of a condensing 25-30 MW_e plant are envisaged. In addition, the Amatitlán field also supports the direct use of geothermal energy, in the form of using steam for drying concrete blocks and in a fruit dehydration plant.

A second geothermal plant (in the Zunil I field) has been in commercial operation since September 1999. Following INDE's exploratory drilling work, a contract was signed with

Ormat for the private installation and operation of the plant. Until 2019 the company will buy steam from INDE and sell power to the national grid. Exploratory drilling in the Zunil II field has shown that it possesses 50 MW_e potential.

According to the Electricity Law INDE will no longer invest in exploratory works and the future of Guatemala's geothermal development thus depends on links being forged between the government body and private industry.

HUNGARY

Hungary possesses very considerable geothermal resources and it has been estimated that the country has the largest underground thermal water reserves and geothermal energy potential (low and medium enthalpy) in Europe.

To date, there has been no utilisation of geothermal energy for the production of electricity. As at end-1999 the principal applications of geothermal power used directly were greenhouse heating (64%), space heating (22.5%), industrial process heat (0.5%) and other uses (13%). It has been reported that geothermal heat pumps represent an additional 3.8 MW_t and four spas supply a further 14.2 MW_t.

In the mid-1990's the Hungarian Oil and Gas Company (MOL) began a programme to promote the development of geothermal energy. Three pilot projects have been studied, two of which involve cascaded use of geothermal heat for electricity production and subsequent direct applications.

ICELAND

Geothermal energy resulting from Iceland's volcanic nature and its location on the Mid-Atlantic Ridge has been utilised on a commercial scale since 1930. The high-temperature resources are sited within the volcanic zone, whilst the low-temperature resources lie mostly in the peripheral area.

Approximately 50% of total primary energy is supplied by geothermal power and the percentage of electrical generation from geothermal resources more than doubled between 1996 and 1999 (7% growing to 16%): Iceland's wealth of hydro-electric resources provided almost all of the balance.

Currently geothermal energy is mainly used for space heating, with about 86% of households being supplied, mostly via large district heating schemes. Reykjavik Energy, operator of the largest of the country's 26 municipally-owned geothermal district heating schemes, supplies virtually the entire city (approximately 160 000 inhabitants) and four neighbouring communities.

Whilst 77% of the direct use of geothermal heat is used for space heating, 8% is used for industrial process heat, 6% for swimming pools, 4% for greenhouses, 3% for fish farming and 2% for snow melting. Total installed capacity for direct use was 1 469 MW_t at end-1999: usage during the year amounted to 5 603 GWh.

In recent years there has been an expansion in Iceland's energy-intensive industrial sector. To meet an increased demand for power, the capacity of geothermal plants has grown rapidly from 50 MW_e and currently stands at 170 MW_e. Geothermal electricity generation was 1 138 GWh in 1999, equivalent to 15.8% of total power output.

There are two conventional power plants operating: a 3 MW_e back-pressure unit at Bjarnarflag and a 60 MW_e double flash unit at Krafla. Svartsengi and Nesjavellir are both co-generation plants. At Svartsengi, the generation of power is secondary to that of pumping of geothermal brines for district heating: 45 MW_e capacity is installed for power generation and 200 MW_t for production of hot water. Hot water production has also been the primary purpose of Nesjavellir since it commenced operating in 1990. However, during 1998 60 MW_e of capacity was brought on stream to generate power and it is now planned to increase this further to 76 MW_e by 2005.

INDONESIA

The islands of Indonesia possess enormous geothermal resources: geological surveys have identified as many as 217 prospects, of which 70 are specified as high-temperature reservoirs with an estimated total resource potential of nearly 20 000 MW_e. Of this potential, about 49% is in Sumatra, 29% in Java-Bali, 8% in Sulawesi and 14% in other islands.

A very small amount of geothermal energy is used directly for bathing and swimming, all instances being in West Java.

Despite the financial crisis that hit Indonesia towards the end of 1997 and the resultant adverse affect that it had on the power sector demand and growth, the development of geothermal energy has continued (albeit at a lower growth rate) and has still been geared towards the production of electricity. At end-1999 installed capacity stood at 589.5 MW_e distributed in four Javanese-Balinese fields as follows: 140 MW_e at Kamojang, 330 MW_e at Salak, 55 MW_e at Darajat and 60 MW_e at Dieng. In addition, two pilot plants were rated at 4.5 Mw_e (a 2 MW_e plant at Sibayak on Sumatra and a 2.5 MW_e plant at Lahendong on Sulawesi). However, not all capacity was operational (Dieng and Lahendong are not functioning, owing to the economic situation) and available capacity stood at 527 MW_e. It has been reported that by end-2000 installed capacity had increased to 862 MW_e.

In the future the Government plans to significantly alter the fuel mix of electricity generation by increasing the use of coal, geothermal energy and hydro power and thus reducing the use of oil and gas. By 2005 it is hoped that a total of 15 fields will have been developed, with an installed capacity of 1,927 MW_e. This will be accomplished through the development of new fields and extensions to existing fields. If the plan succeeds, geothermal energy would account for 7% of the projected national power demand.

ITALY

Italy is one of the world's leading countries in terms of geothermal resources. The high-temperature steam-dominated reservoirs lie in a belt running through the western part of the country from Tuscany to Campania (near Naples). Commercial power generation from geothermal resources began in Italy in 1913 with a 250 kW unit. Subsequently the main emphasis has been on the production of power rather than on direct use of the heat. Geothermally-produced electricity reached an all-time high of 4.4 billion kWh in 1999, representing nearly 2% of total electricity production.

Following the limited development of resources during the first half of the 20th century, it was the second half that saw rapid growth. By end-1999, total Italian installed geothermal capacity stood at 621 MW_e.

It is planned to bring an additional 390 MW_e capacity on line in the period to 2005, of which 245 MW_e will replace units to be decommissioned (229 MW_e) and 145 MW_e will be related to new field developments.

In addition to the Italian country report presented at the World Geothermal Congress 2000, a detailed analysis of direct uses was also presented (Carella and Sommaruga). The analysis found that several large geothermal fish farms (approximately 110 MW_t), larger hotels and balneological spa uses (in the Abano district and on the island of Ischia) had been excluded from the country report.

Italian direct uses (excluding balneological/swimming pool use) can be conservatively estimated at about 470 MW_t with a production of approximately 5 000 TJ/year. Inclusion of even a limited portion of balneological uses (spa swimming pools) would add another 1 000 TJ to the yearly heat production. The low-medium temperature resources used for such purposes are mostly located north of Rome.

JAPAN

Japan has a long history of geothermal utilisation, both direct and for power generation. The first experimental power generation took place in 1925, with the first full-scale commercial plant (23.5 MW_e) coming on-line at Matsukawa, in the north of the main island of Honshu, in 1966. Following each of the two oil crises, development of Japan's geothermal resources was accelerated and by end-1984, 314.6 MW_e capacity had been commissioned. Growth continued and unit size decreased as technological improvements occurred. By end-1999, installed capacity stood at 546.9 MW_e (consisting of 19 units at 17 locations). The existing plants are all located in the Tohoku region of northern Honshu and on the southern island of Kyushu.

At the present time only an additional 20 MW_e capacity is planned to be in service by 2005, although the country's power generation potential from geothermal is estimated to be in the region of 2 500 MW_e. The planned government deregulation of the electricity sector, bringing about lower medium and long-term electricity costs, is expected to result in geothermally-generated power becoming uncompetitive. Thus for the further utilisation of geothermal energy, there will be an incentive to undertake the advanced technological research necessary to develop unused resources and for the consequent generation to be competitive with other energies.

Direct use of geothermal hot water has a long tradition in Japan, where enjoyment of natural baths is a national recreation. There is widespread usage of geothermal heat for purposes other than bathing (which accounts for 11% of capacity): space heating (including hot water supply) 51%; greenhouse heating 13%; snow melting 12%; fish breeding 9%; air conditioning (cooling) 2% and industrial process heat and other 1% each. The quantification of direct use capacity is particularly difficult in Japan. It is thought to be considerably larger than the reported figures.

Hot spring water above 15^{o}C is widely available, thus there is little demand for heat pumps.

From the beginning of 1980 the New Energy and Industrial Technology Development Organisation (NEDO) has initiated 52 surveys to evaluate those areas with the most promising geothermal potential for power generation. In the context of Japan's "New Sunshine Project", NEDO is promoting technical developments in the surveying, drilling and exploitation of geothermal resources. Research is also being carried out into deep-seated resources and a hot dry rock generation system. In addition to various other governmental research organisations, private sector research bodies are also involved.

KENYA

Kenya possesses substantial geothermal resources at Olkaria near Lake Naivasha (about 80 km north-west of Nairobi) and at other locations in the Rift Valley.

The first geothermal unit came into operation at Olkaria in July 1981, with an initial installed net capacity of 15 MW_e. Two more 15 MW_e units were added, so that by end-1999 the 45

MW_e represented just over 5% of Kenya's electricity generating capacity and produced 8% of its power output.

173 MW_e of geothermal capacity is planned to be in operation by 2005 and a total of 576 MW_e by 2017. In order to attract sufficient investment funds to achieve this goal, the restructuring of the power industry, begun in the early 1990's, must continue. It is expected that in the future the power industry will be a partnership of the private and public sectors. The first instance of a private geothermal plant arose in August 2000 when Ormat® (which had won an international bid issued by the Kenya Power and Light Company) initiated 8 MW_e capacity at Olkaria III. By end-2000, an additional 4 MW_e of the 64 MW_e project had been commissioned.

Exploratory work has been undertaken in the Longonot and Suswa prospects and following drilling in these locations, surface exploration will then be undertaken in Menengai and other fields north of Olkaria along the Rift Valley.

A minimal amount of geothermal energy is used for direct heat: one well in the Olkaria field with an output capacity of 1.286 MW_t, supplies heat to a neighbouring farm for greenhouses. For the time being flowers are being grown on an experimental basis, but it is intended that this should become a commercially viable operation.

MEXICO

Reflecting the country's location in a tectonically active region, Mexico's geothermal manifestations are particularly prevalent in the central volcanic belt, as well as in the states of Durango, Chihuahua, Baja California and Baja California Sur. Development has, in the main, been concentrated on electric power production although there is some utilisation of geothermal power for direct purposes.

The first Mexican geothermal unit (single flash) came into operation in 1973 at the Cierro Prieto field in the north-west, close to the border with the USA. More units (single and double flash) were added at this location between 1979 and 1987. The first back-pressure unit at Los Azufres (Michoacán State) was commissioned in 1982 followed by the first back-pressure unit at Los Humeros (Puebla State) in 1990. In total, 27 units were operating in the three fields by end-1999; their combined generation represented some 3% of Mexican electric power output.

It was expected that during 2000 four more units would be commissioned at Cerro Prieto and it has been reported that at end-2000 total installed capacity had increased to 855 MW_e. A further four units at Los Azufres are expected to follow in 2001. In addition, it is planned that a new plant would come on line during 2001 at Las Tres Vírgenes (Baja California Sur State) and, depending on the resolution of an environmental concern, during 2002 at La Primavera (Jalisco State). By 2005 it is planned that Mexican geothermal capacity will be in excess of 1 000 MW_e.

Geothermal heat used directly is predominantly utilised for bathing and swimming. Of the reported 164.19 MW_t installed capacity (end-1999), virtually 100% was located in resorts throughout the volcanic zone. Minimal amounts of direct heat are utilised for space heating, greenhouse heating, agricultural drying, timber drying and mushroom breeding.

NEW ZEALAND

New Zealand possesses seven major high-enthalpy fields, as well as a large number of other geothermal features. Substantial capacity exists for both the generation of geothermally-produced power and also for geothermal energy used directly.

The first geothermal power plant came into operation at Wairakei, north of Lake Taupo (North Island) in November 1958, with an initial capacity of 69 MW_e. The second stage of development, which added a further 123 MW_e of capacity, began operation in October 1963. Wairakei was the second geothermal power station to be built in the world and the first to tap a hot pressurised water resource. Owing to an initial very rapid run-down in field pressure, the maximum output achieved from the station was 173 MW_e. In 1983 all high-pressure turbine/generator units were decommissioned, owing to the decline in high-pressure steam output from the field. The current installed capacity of Wairakei is 162 MW_e with an additional 15 MW_e binary power planned to be in service by 2005.

Between 1966 and 1990 three more power plants were commissioned within the central North Island's Taupo Volcanic Zone (TVC), in the localities of Reporoa and Kawerau. Their combined capacity (one back pressure unit, 3 binary units and 4 combined cycle units) amounted to 130 MW_e.

Between 1996 and 1999 four plants were commissioned: the 55 MW_e McLachlan plant (Taupo locality), a 25 MW_e combined-cycle plant at Rotokawa (Taupo locality), the 9 MW_e Ngawha binary plant (Northland locality, about 245 km north of Auckland: the only high-temperature geothermal field outside the TVC) and a 55 MW_e combined-cycle at Mokai (Taupo locality). Whilst the sum of the these plants totals 436 MW_e, Table 12.1 reflects the capacity reported by the New Zealand WEC Member Committee, quoting the Ministry of Economic Development.

In 1986, the New Zealand Government began the process of reforming the electricity supply industry. The reform continued throughout the 1990's and by 1999, following the restructuring of all aspects of the sector, all geothermal power plants had passed into private ownership.

Potential generation capacity from the geothermal resources of the TVC has been conservatively estimated at 2000 MW_e.

At end-1999 installed capacity for direct heat uses stood at 307.9 MW_t. The main user of direct heat is at Kawerau. A 210 MW_t plant generates clean process steam for various procedures within a pulp and paper mill operation. Geothermal steam at other locations is also used for agricultural drying (10% of direct-heat capacity), bathing and swimming (9%), space heating (7%) and fish and animal farming (6%).

NICARAGUA

The Marrabios range of volcanos, running parallel to the Pacific coast, gives rise to Nicaragua's large geothermal potential. Exploratory studies were undertaken at the end of the 1960's and priority given to the Momotombo and San Jacinto-Tizate fields.

Exploitation of geothermal power in the Momotombo area, located at the foot of the volcano of the same name, began when the first 35 MW_e single-flash unit was commissioned in 1983. A second unit 35 MW_e unit was added in 1989. Gross output of electricity reached a peak of 468 GWh in 1992 but subsequently fell away to a low of 121 GWh in 1998 owing to overexploitation of the field and a lack of re-injection. In April 1999 an agreement was signed between Ormat® International and Nicaragua's national power utility (ENEL) for Ormat® to rehabilitate and operate the power plant facilities at Momotombo. Work began in June 1999 and it is planned that the installed capacity will be returned to its rated level. Ormat® will sell the electricity produced to ENEL for a 15-year period, at the end of which the plant will be returned to ENEL.

Studies associated with the Nicaraguan Geothermal Master Plan began in August 1999. The main objectives are to re-evaluate and classify the country's resources in terms of generation potential and to plan for the exploration and development activities that will follow. In addition to Ormat®'s work in the Momotombo area, the Government has identified another four concession areas: El Hoyo Monte Galán, San Jacinto-Tizate, Ñajo-Santa Isabel, Casita. Studies on the concession areas are at different stages but SAI Geotérmica Nicaragua S.A. intends to build a 60 MW_e electric plant in the Ñajo-Santa Isabel area.

To date all geothermal energy has been used for power generation but the Government, with support from the European Union and the UN Economic Commission for Latin America and the Caribbean, will conduct a geothermal rural electrification and direct application pilot project in the areas of the Cosigüina Volcano and Ometepe Island. Low-enthalpy fluids will be investigated for use in grain-drying, fish farming and heating greenhouses.

PHILIPPINES

The Philippines archipelago is exceptionally well-endowed with geothermal resources. At end-1999 the country was the world's second largest user of geothermal energy for power generation.

In addition, a low-enthalpy well, while being utilised for power generation (1.5 MW_e), also has its exhaust used directly to operate a multi-crop drying plant, although in mid-1999 the plant was out of operation for well and turbine maintenance.

The geothermal plants in the Philippines are generating about one-fifth of the national electricity supply from six fields, in which there are 11 areas in production. The fields, spread throughout the islands, are at Mak-Ban (Luzon), Tiwi (Luzon), Tongonan (Leyte), Palinpinon (Negros), Bac-Man (Luzon) and Mindanao (Mindanao). Operations began in 1979 with 278 MW_e and grew steadily until the mid-1980's, when installed capacity reached 894 MW_e. Further capacity was not added until 1993, after which it grew steadily again to reach 1 863 MW_e by end-1999.

Three new geothermal areas at Mt. Labo (Luzon), Northern Negros (Negros) and Cabalian (Leyte) are presently in an advanced exploration and development stage.

Within the terms of the Philippine Energy Plan, the Government is planning, by 2008, to increase geothermal capacity by 526 MW_e. Output would increase to 13 865 GWh but the geothermal contribution would fall to 18.5% (from a current 23%) owing to the use of natural gas for power generation, beginning by 2002.

PORTUGAL

The limited geothermal resources in mainland Portugal have been developed for direct use, whereas geothermal occurrences in the Azores are utilised for the production of electricity as well as being used directly.

There are about 50 natural low-enthalpy occurrences spread throughout the mainland. The installed capacity of 3.97 MW_t (end-1999) is utilised for space heating (including domestic hot water), greenhouse heating, bathing and swimming.

Twelve areas with potential for developing geothermal electricity generation have been identified on the islands of Faial, Pico, Graciosa, Terceira and São Miguel in the Azores. At the present time there are 3 power stations on São Miguel at Pico Vermelho and Ribeira Grande. A 3 MW_e back-pressure pilot plant was built in 1980 in the northern sector of the island. This was followed by a 2 x 2.5 MW_e binary units in May 1994 in the central sector and in October 1998 by a further 8 MW_e (2 x 4.0 MW_e binary units), again in the northern sector. However, the Portuguese WEC Member Committee reports an end-1999 installed capacity of 20 MW_e.

As the estimated potential of the Ribeira Grande field is in the region of 80 MW_e, it is envisaged that an additional 25-30 MW_e capacity could be constructed by 2010, thereby meeting 40-45% of the electrical demand of the island.

São Miguel also has an installed capacity of 1.5 MW_t (end-1999) using geothermal energy for direct heat. Six small greenhouses use the 90°C waste water from a nearby geothermal power plant in order to grow experimental crops.

RUSSIAN FEDERATION

Geothermal resources have been identified in several areas of the Federation: the Northern Caucasus (Alpine and Platform provinces), Western Siberia, Lake Baikal and, most significantly, in Kamchatka and the Kuril Islands. It has been estimated that the high-temperature resources defined to date on the Kamchatka Peninsula could ultimately support generation of 1 130 MW_e or more. However, at the present time Russia’s energy sector is based on fossil fuels and the exploitation of hydroelectric and nuclear power, and therefore the contribution from geothermal energy is tiny. Over the past 30 years there has been some development of high-temperature resources for power generation, but the main thrust of Russian geothermal utilisation has been, and continues to be, for direct purposes. Although a 3 MW_e plant is planned (but is unlikely to be constructed) in the North Caucasus area, the only electricity-generating facilities are in the Kuril Islands and Kamchatka. Furthermore the Federation’s economic situation in recent years has not been conducive to this type of development.

Investigations into using geothermal energy for power generation in Kamchatka began in 1957, and in 1966 a 5 MW_e single-flash plant was commissioned at Pauzhetka. It was enlarged to 11 MW_e in 1980; it is expected that the 18 MW_e of geothermal capacity under construction in 2000 will replace the original 11 MW_e (which will then be retired).

Also in Kamchatka but at Verkhne-Mutnovka, in the upper sector of the high-temperature Severo-Mutnovka field, a 4 MW_e single-flash unit came on stream in 1998. Two more 4 MW_e units came on stream in 1999 and another 9 MW_e are planned for 2001. A future project located in the same field plans for 2 x 25 MW_e single-flash units by 2001 and another two by 2005.

It has been reported that in the Kuril Islands there currently exists 15 MW_e installed capacity on the islands of Paramushir, Iturup and Kunashir, with another 28 MW_e planned for construction. However, verification of Russian data is extremely difficult.

At end-1999 installed capacity for direct use amounted to more than 300 MW_t. The heat is used mainly for space and district heating but also for a range of agricultural purposes (greenhouses, soil heating, fish and animal farming, cattle-breeding), for various industrial processes (manufacturing, wool washing, paper production, wood drying, oil extraction) and for spas and recreational bathing.

Although there is much scope for the installation of heat pumps in Russia, their use is presently at an early stage of development.

SWEDEN

The only reported use of the geothermal energy resource in Sweden is from heat pumps. It is has been estimated that by 1998 in the region of 55 000 had been installed, with an aggregate capacity of 377 MW_t.

SWITZERLAND

Switzerland's installed capacity for utilising geothermal energy has grown rapidly in recent years and the country now ranks among the world leaders in direct-use applications (there is no geothermal-based electricity). There are two main components to Switzerland's geothermal energy: the utilisation of shallow resources by the use of horizontal coils, borehole heat exchangers (BHE), foundation piles and groundwater wells, and the utilisation of deep resources by the use of deep BHE's, aquifers by singlet or doublet systems, and tunnel waters. In virtually all instances heat pumps are the key components.

At end-1999 there were in the region of 21 000 ground-source heat pumps installed throughout the country, representing about 500 MW_t. The remaining approximately 50 MW_t of capacity was utilised for bathing and swimming (17 locations, 25 MW_t), space heating (20 MW_t), air conditioning (5 locations, 2.2 MW_t), and snow melting (0.1 MW_t)

Following successful drilling to tap deep aquifers for a district heating network at Riehen (on the border with Germany and operational since 1994), the network was extended and thus became the first example of cross-border geothermal utilisation.

There remains substantial room for growth in Switzerland's geothermal sector. The annual growth rate for heat pumps is estimated at 15% and the Government is actively supporting research and development into geothermal energy. Moreover, the Swiss Federal Office of Energy is promoting a project (initiated in 1996) called "Deep Heat Mining". It is planned that a first pilot plant to produce electricity and/or heat by HDR technology will be in place between 2005 and 2010.

THAILAND

Investigations of geothermal features in Thailand began in 1946 and in the intervening period more than 90 hot springs located throughout the country have been mapped. However, it was not until 1979 that systematic studies of the resources began.

A small (0.3 MW_e) binary-cycle power plant was installed at Fang, in the far north near the border with Myanmar. Since commissioning in December 1989, this sole Thai geothermal plant has operated successfully, with an 85-90% availability factor. In addition, the Electricity Generating Authority of Thailand (EGAT) is using the 80^{o}C exhaust from the power plant to demonstrate direct heat uses to the local population. The exhaust is being used for air conditioning, cold storage and crop drying. A further example of utilising the heat directly is a public bathing pond and sauna that have been constructed by the Mae Fang National Park.

Geothermal systems at San Kampaeng, Pai and nine other locations are reported to be under further investigation, but to date Thailand's national programme on geothermal energy has still not been firmly established and no other developments have occurred.

TURKEY

A significant factor in Turkey's high geothermal potential, estimated as being in the region of 31 500 MW_t, is the fact that the country lies on the Alpine-Himalayan orogenic belt. Geothermal exploration began during the 1960's, since when about 170 fields have been identified. Although some of this number are high-enthalpy fields, 95% are low-medium enthalpy resources and thus more suited to direct-use applications.

At end-1999, geothermal installed capacity for direct uses totaled 820 MW_t, of which 392 MW_t provided the space heating and thermal facilities of 51 600 residence-equivalents, 101 MW_t provided heating for 45.4 ha of greenhouses and 327 MW_t was utilised for bathing and swimming (194 spas). The engineering design to supply a further 150 000 houses with geothermal heat has already been completed. Projections for 2010 indicate that 500 000 residence-equivalents (3 500 MW_t) will be so equipped and by 2020, 1.25 million residence-equivalents (8 300 MW_t). Installed capacity for spas and other uses is projected to reach 895 MW_t by 2010 and 2 300 MW_t by 2020.

Following research undertaken in 1968 into using geothermal resources for the production of electricity, a 0.5 MW_e pilot plant was installed in 1974 in the Kizildere field (near Denizli in south-western Turkey). In 1984 the 20.4 MW_e single-flash Kizildere geothermal power plant came into operation. In addition to electricity generation, the plant has an integrated liquid CO_2 and dry ice production factory that utilises the geothermal fluids.

To date, at least four other geothermal fields with electric power generating potential have been discovered and studied to varying degrees. The first instance of additional installed capacity was to be the first 25 MW_e stage of the Germencik plant near Aydin, planned for 2000. By 2010, 500 MW_e is planned and by 2020, 1 000 MW_e.

UNITED STATES OF AMERICA

The USA possesses a huge geothermal resource, located largely in the western half of the country. Research has shown that geothermal energy has been used in North America for many thousands of years but the first documented commercial use was in 1830 in Arkansas. In 1922 an experimental plant began generating electricity in California but, proving to be uneconomic, it soon fell into disuse. Another 38 years were to pass before the first large-scale power plant began operations at The Geysers, north of San Francisco, California. The USA is the world's largest producer of electricity generated from geothermal energy.

Only California, Nevada, Hawaii and Utah utilise geothermal energy for power generation; investigative studies undertaken in Oregon during the early 1990's proved to be unsuccessful. However, the 1990's saw dramatic change in the geothermal power industry: plants came on line, plants were retired, there were changes of ownership (resulting, in some cases, in operational efficiencies) etc. Whereas during the period 1989-1998 in the region of 69% of power capacity had been owned by the electric utilities, in 1999 this percentage had dropped to 9%. By end-1999 total effective capacity stood at 2 228 MW_e.

Generation from geothermal energy of 16 813 GWh in 1999 represented 0.5% of total US electricity production. At The Geysers, a major area of development in California, a project for injecting recycled wastewater into the reservoir has become the world's first wastewater-to-electricity system. In Phase 1 treated wastewater effluent from various communities is transported to The Geysers geothermal field for injection and recovery as steam for power generation. Plans are under way for Phase 2 and an additional project to treat the wastewater from the city of Santa Rosa is expected to come on line in 2002.

Geothermal heat suitable for direct utilisation is far more widespread through the US, ranging from New York State in the east to Alaska in the west. At end-1999 a total 566 MW_t installed capacity was used for fish and animal farming (129 MW_t), greenhouse heating (119 MW_t), bathing and swimming (107 MW_t), district heating (99 MW_t), space heating (83 MW_t), agricultural drying (20 MW_t), industrial process heat (7 MW_t) and snow melting (2 MW_t). In addition, it is estimated that 45 000 heat pumps have lately been installed annually, resulting in a total capacity of some 4 800 MW_t at end-1999. Apart from a decline in industrial process heat, direct uses of geothermal energy continue to expand. The heat pump market is expected to continue to grow strongly, to reach an estimated 1.5 million units in service by 2010.

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Chapter 13

WIND ENERGY

Introduction

World wind energy capacity has been doubling every three years during the last decade and growth rates in the last two years have been even faster, as shown in Figure 13.1. It is doubtful whether any other energy technology is growing, or has grown, at such a rate. Total world wind capacity at the end of 2000 was around 17 500 MW and generation from wind now approximately equates to annual consumption of electricity in Chile or Singapore. Germany, with over 6 000 MW, has the highest capacity but Denmark, with over 2 000 MW, has the highest level per capita and the production accounts for about 12% of Danish electricity.

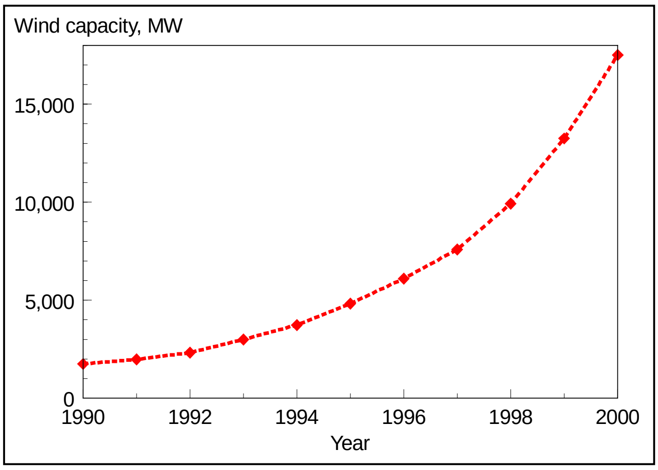


Figure 13.1: Growth of world wind capacity

The attractions of wind as a source of electricity which produces minimal quantities of greenhouse gases has led to ambitious targets for wind energy in many parts of the world. More recently, there have been several developments of offshore wind installations and many more are planned. Although offshore wind-generated electricity is generally more expensive than onshore, the resource is very large and there are few environmental impacts.

Whilst wind energy is generally developed in the industrialised world for environmental reasons, it has attractions in the developing world as it can be installed quickly in areas where electricity is urgently needed. In many instances it may be a cost-effective solution if fossil fuel sources are not readily available. In addition there are many applications for wind energy in remote regions, worldwide, either for supplementing diesel power (which tends to be expensive) or for supplying farms, homes and other installations on an individual basis.

Types of Modern Wind Turbine

Early machines - less than twenty years ago - were fairly small (50-100 kW, 15-20 m diameter) but there has been a steady growth in size and output power. Several commercial types of wind turbine now have ratings over 1 MW and machines for the offshore market have outputs up to 3 MW.

Machine sizes have increased for two reasons. They are cheaper and they deliver more energy. The energy yield is improved partly because the rotor is located higher from the ground and so intercepts higher velocity winds, and partly because they are slightly more efficient. The higher yields are clearly shown in Figure 13.2, which shows data from machines in Denmark; the productivity of the 600 kW machines is around 50% higher than that of the 55 kW machines. Reliability has improved steadily and most wind turbine manufacturers now guarantee availabilities of 95%.

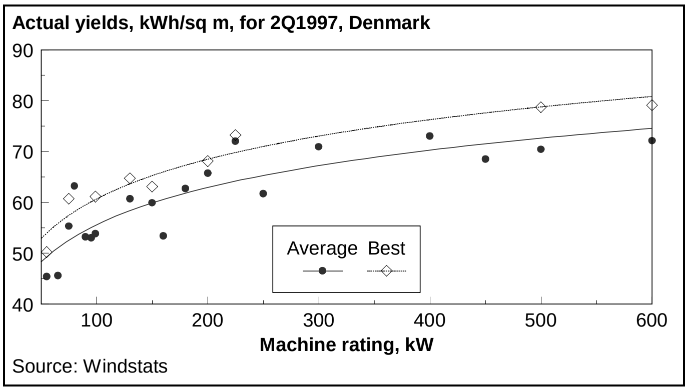


Figure 13.2: Energy productivity and machine rating

The majority of the world's wind turbines have three glass-reinforced plastic blades. The power train includes a low speed shaft, a step-up gearbox and an induction generator, either four or six-pole. There are numerous other possibilities, however. Wood-epoxy is an alternative blade material and some machines have two blades. Variable speed machines are becoming more common and most generate power using an AC/DC/AC system. Variable speed brings several advantages - it means that the rotor turns more slowly in low winds (which keeps noise levels down), it reduces the loadings on the rotor and the power conversion system is usually able to deliver current at any specified power factor. A few manufacturers build direct-drive machines, without a gearbox. These are usually of the variable speed type, with power conditioning equipment.

Towers are usually made of steel and the great majority are of the tubular type. Lattice towers, common in the early days, are now rare, except for very small machines in the range 100 kW and below.

As the power in the wind increases with the cube of the wind speed, all wind turbines need to limit the power output in very high winds. There are two principal means of accomplishing this, with pitch control on the blades or with fixed, stall-controlled blades. Pitch-controlled blades are rotated as wind speeds increase so as to limit the power output and, once the "rated power" is reached, a reasonably steady output can be achieved, subject to the control system response. Stall-controlled rotors have fixed blades which gradually stall as the wind speed increases, thus limiting the power by passive means. These dispense with the necessity for a pitch control mechanism, but it is rarely possible to achieve constant power as wind speeds rise. Once peak output is reached the power tends to fall off with increasing wind speed, and so the energy capture may be less than that of a pitch-controlled machine. The merits of the two designs are finely balanced, which accounts for the roughly equal numbers of machines.

Energy Production

Contrary to popular opinion, energy yields do not increase with the cube of the wind speed, mainly because energy is discarded once the rated wind speed is reached. To illustrate a typical power curve and the concept of rated output, Figure 13.3 shows a typical performance curve for a 1.65 MW machine. Most machines start to generate at a similar speed - around 3 to 5 m/s - and shut down in very high winds, generally around 20 to 25 m/s.

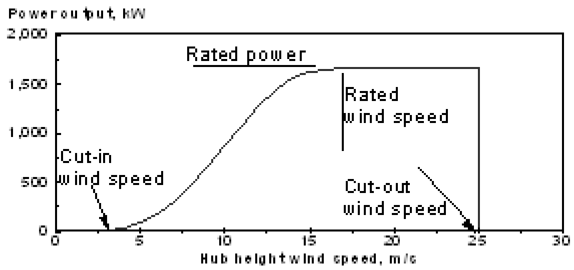


Figure 13.3: Power curve for a 1.65 MW wind turbine

Annual energy production from the turbine whose performance is charted in Figure 13.3 is around 1 500 MWh at a site where the wind speed is 5 m/s, 3 700 MWh at 7 m/s and 4 800 MWh at 8 m/s. Wind speeds around 5 m/s can be found, typically, away from the coastal zones in all five continents, but developers generally aim to find higher wind speeds. Levels around 7 m/s are to be found in many coastal regions and over much of Denmark; higher levels are to be found on many of the Greek Islands, in the Californian passes - the scene of many early wind developments - and on upland and coastal sites in the Caribbean, Ireland, Sweden, the United Kingdom, Spain, New Zealand and Antarctica.

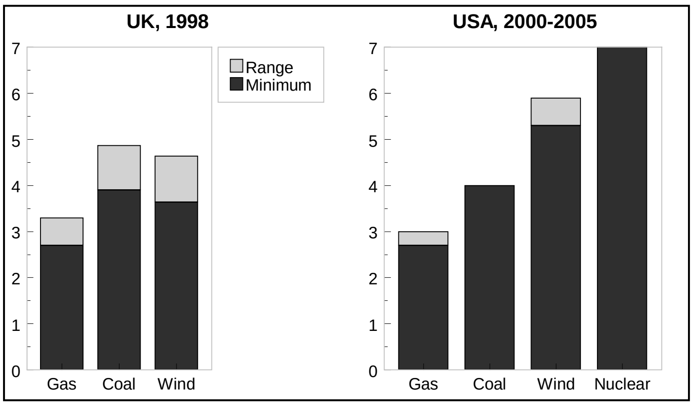
Wind speed is the primary determinant of electricity cost, on account of the way it influences the energy yield so, roughly speaking, developments on sites with wind speeds of 8 m/s will yield electricity at one third of the cost for a 5 m/s site. Offshore wind speeds are generally higher than those onshore. Offshore wind farms have been completed, or are planned, in Denmark, Sweden, Germany, the United Kingdom, Ireland and elsewhere. Offshore wind is attractive in locations such as Denmark and the Netherlands where pressure on land is acute and windy hill top sites are not available. In these areas offshore winds may be 0.5 to 1 m/s higher than onshore, depending on the distance. The higher wind speeds do not usually compensate for the higher construction costs but the chief attractions of offshore are a large resource and low environmental impact.

Wind Energy Costs

As wind energy is not generally cost-competitive with the thermal sources of electricity generation, the pattern of development has been largely dependent on the support mechanisms provided by national governments.

Wind costs have declined steadily and a typical installed cost for onshore wind farms is now around US$ 1 000/kW, and for offshore around US$ 1 600/kW. The corresponding electricity costs vary, partly due to wind speed variations and partly due to differing institutional frameworks. Wind prices are converging with those from the thermal sources but it is not easy to make objective comparisons, as there are few places where totally level playing fields exist. Two examples may be given. Until recently, the UK operated a competitive tender market for renewable energy sources which guaranteed payments for 15 years. Vigorous competition drove prices down rapidly and the prices realised in the last round of the Non-Fossil Fuel Obligation may be compared with prices for new gas and coal-fired plant. These comparisons, shown in Figure 13.4, show that wind prices are very similar to those for coal-fired plant and only a little more than those of gas-fired plant. The second set of comparisons, shown in Figure 13.5, has been drawn from two US sources: a Department of Energy projection for 2005 and a recent analysis for the State of Oregon in 2000. This comparison shows a bigger gap between wind and gas although wind is significantly cheaper than nuclear. Other US data suggest that wind prices down to around 4 US cents/kWh can be realised in some areas.

Figures 13.4 and 13.5 Electricity prices (in US cents/kWh) for wind and the thermal sources, UK and USA



Wind farms

The way in which wind energy has developed has been influenced by the nature of the support mechanisms. Early developments in California and subsequently in the UK, for example, were mainly in the form of wind farms, with tens of machines, but up to 100 or more in some instances. In Germany and Denmark the arrangements favoured investments by individuals or small cooperatives and so there are many single machines and clusters of two or three. Economies of scale can be realised by building wind farms, particularly in the civil engineering and grid connection costs and possibly by securing "quantity discounts" from the turbine manufacturers. Economies of scale deliver more significant savings in the case of offshore wind farms and many of the developments involve large numbers of machines. Figure 13.6 gives an indication of typical parameters for offshore and onshore wind farms. It may be noted that the offshore project uses machines with three times the power rating of the onshore project.

Figure 13.6: Key features of an onshore and an offshore wind farm

	Onshore	**Offshore**
Project name	Hagshaw Hill	Middelgrunden
Project location	50 km S of Glasgow in the Southern Highlands of Scotland	Near Copenhagen, Denmark
Site features	High moorland surrounded by deep valleys.	Water depth of 2-6 metres
Turbines	26, each 600 kW	20, each 2 MW
Project rating	15.6 MW	40 MW
Turbine size	35 m hub height, 41m diameter	60 m hub height, 76 m rotor diameter.
Special features of turbines	Turbine structure modified for high extreme gust wind speed; special low-noise features of blades.	Modified corrosion protection, internal climate control, built-in service cranes.
Turbine siting	Irregular pattern with two main groups, typical spacing 3 rotor diameters.	180 m apart in a curve and a total windfarm length of 3.4 km.
Energy production (annual)	57 000 MWh	85 000 MWh (3% of Copenhagen's needs)
Construction period	August to November 1995	March 2000 to March 2001

Source: Bonus Energy A/S, Denmark

Small wind turbines

There is no precise definition of "small", but it usually applies to machines under about 10 kW in output. In developing countries small wind turbines are used for a wide range of rural energy applications, and there are many "off-grid" applications in the developed world as well - such as providing power for navigation beacons. Since most are not connected to a grid, many use DC generators and run at variable speed. A typical 100 W battery-charging machine has a shipping weight of only 15 kg.

A niche market, where wind turbines often come into their own as the costs of energy from conventional sources can be very high, is in cold climates. Wind turbines may be found in both polar regions and in northern Canada, Alaska, Finland and elsewhere. To illustrate the point about economic viability, data from the U.S. Office of Technology Assessment quotes typical costs of energy at 10 kW capacity in remote areas:

Micro-Hydro	~ US$ 0.21/kWh
Wind	~ US$ 0.48/kWh
Diesel	~ US$ 0.80/kWh
Grid Extension	~ US$ 1.02/kWh

Environmental Aspects

No energy source is free of environmental effects. As the renewable energy sources make use of energy in forms that are diffuse, larger structures, or greater land use, tend to be required and attention may be focused on the visual effects. In the case of wind energy, there is also discussion of the effects of noise and possible disturbance to wildlife - especially birds. It must be remembered, however, that one of the main reasons for developing the renewable sources is an environmental one - to reduce emissions of greenhouse gases.

Noise

Almost all sources of power emit noise, and the key to acceptability is the same in every case - sensible siting. Wind turbines emit noise from the rotation of the blades and from the machinery, principally the gearbox and generator. At low wind speeds wind turbines generate no noise, simply because they do not generate. The noise level near the cut-in wind speed (see Figure 13.3) is important since the noise perceived by an observer depends on the level of local background noise (the masking effect) in the vicinity. At very high wind speeds, on the other hand, background noise due to the wind itself may well be higher than noise generated by a wind turbine. The intensity of noise reduces with distance and it is also attenuated by air absorption.

The exact distance at which noise from turbines becomes “acceptable” depends on a range of factors. As a guide, many wind farms with 400-500 kW turbines find that they need to be sited no closer than around 300-400 m to dwellings.

Television and Radio Interference

Wind turbines, like other structures, can scatter electro-magnetic communication signals, including television. Careful siting can avoid difficulties, which may arise in some situations if the signal is weak. Fortunately it is usually possible to introduce technical measures - usually at low cost - to compensate.

Birds

The need to avoid areas where rare plants or animals are to be found is generally a matter of common sense, but the question of birds is more complicated and has been the subject of several studies. Problems arose at some early wind farms that were sited in locations where large numbers of birds congregate - especially on migration routes. However, such problems are now rare, and it must also be remembered that many other activities cause far more casualties to birds, such as the ubiquitous motor vehicle.

In practice, provided investigations are carried out to ensure that wind installations are not sited too near large concentrations of nesting birds, there is little cause for concern. Most birds, for most of the time, are quite capable of avoiding obstacles and very low collision rates are reported where measurements have been made.

Visual effects

One of the more obvious environmental effects of wind turbines is their visual aspect, especially that of a wind farm comprising a large number of wind turbines. There is no measurable way of assessing the effect, which is essentially subjective. As with noise, the background is also vitally important. Experience has shown that good design and the use of subdued neutral colours - “off-white” is popular - minimises these effects. The subjective nature of the question often means that extraneous factors come into play when acceptability is under discussion. In Denmark and Germany, for example, where local investors are often intimately involved in planning wind installations, this may often ensure that the necessary permits are granted without undue discussion. Sensitive siting is the key to this delicate issue, avoiding the most cherished landscapes and ensuring that the local community is fully briefed on the positive environmental implications.

Integration into supply networks

Electricity systems in the developed world have evolved so as to deliver power to the consumers with high efficiency. One fundamental benefit of an integrated electricity system is that generators and consumers both benefit from the aggregation of supply and demand. On the generation side, this means that the need for reserves is kept down. Consumers benefit from a high level of reliability and do not need to provide back-up power supplies. In an integrated system the aggregated maximum demand is much less than the sum of the individual maximum demands of the consumers, simply because the peak demands come at different times.

Wind energy benefits from aggregation; it means that system operators simply cannot detect the loss of generation from a wind farm of, say, 20 MW, as there are innumerable other changes in system demand which occur all the time. Numerous utility studies have indicated that wind can readily be absorbed in an integrated network until the wind capacity accounts for about 20% of maximum demand. Beyond this, some modest changes to operational practice may be needed, but there are no "cut-off" points. Practical experience at these levels is now providing a better understanding of the issues involved.

Future Developments

Recent rapid growth in Denmark, Spain and Germany shows no sign of slowing and there are plans for further capacity in the United States, Canada, the Middle East, the Far East and South America. If the current growth rate continues, there may be about 150 GW by 2010. The rate of development will depend on the level of political support from the national governments and international community. This, in turn, depends on the level of commitment to achieving the carbon dioxide reduction targets now internationally agreed. Although the technology has developed rapidly during the past ten years, further improvements can be expected both in performance and cost.

David Milborrow
Consultant
United Kingdom

Table 13.1: Wind energy: installed generating capacity and annual electricity output at end-1999

Excel File	Installed capacity	Annual output
	MW_e	GWh
Cape Verde Islands	3	5
Egypt (Arab Rep.)	15	25
Morocco	N	1
Somalia	N	N
South Africa	N	N
Total Africa	**18**	**31**
Canada	125	193
Costa Rica	46	75
Guadeloupe	1	2
Jamaica	3	5
Mexico	3	8
United States of America	2 251	4 488
Total North America	**2 429**	**4 771**
Argentina	14	35
Brazil	18	30
Chile	25	45
Uruguay	N	N
Total South America	**57**	**110**
China	253	450
India	1 081	1 900
Indonesia	1	2
Japan	83	376
Korea (Republic)	7	6
Philippines	N	N
Sri Lanka	3	5
Taiwan, China	N	N
Thailand	N	N
Turkey	9	21
Total Asia	**1 437**	**2 760**
Austria	35	60
Belgium	9	13
Czech Republic	5	8
Denmark	1 771	3 029
Estonia	N	N
Finland	18	49
France	18	36
Germany	4 445	7 400
Greece	107	160
Ireland	67	187
Italy	232	403
Latvia	1	2
Luxembourg	10	15
Netherlands	408	645
Norway	13	25
Poland	3	4
Portugal	53	88
Romania	N	N
Russian Federation	5	8
Spain	1 539	3 750
Sweden	215	369
Switzerland	3	3
Ukraine	24	25
United Kingdom	344	897
Total Europe	**9 325**	**17 176**

Table 13.1: Wind energy: installed generating capacity and annual electricity output at end-1999 contd.

	Installed capacity	Annual output
	MW_e	**GWh**
Iran (Islamic Rep.)	10	17
Israel	7	14
Jordan	2	3
Total Middle East	**19**	**34**
Australia	9	28
New Caledonia	3	5
New Zealand	36	39
Total Oceania	**48**	**72**
TOTAL WORLD	**13 333**	**24 954**

Notes:

1. The data shown largely reflect those reported by WEC Member Committees in 2000/2001, supplemented by national and international published sources, in particular: *IEA Wind Energy Annual Report 1999* and *Windpower Monthly*

2. In many instances, output in 1999 has been estimated by the editors

COUNTRY NOTES

The Country Notes on wind have been compiled by the editors. In addition to national Wind Energy Associations' web sites and government publications/web sites, numerous national and international sources have been consulted, including the following publications:

- *IEA Wind Energy Annual Report 1999*; International Energy Agency;
- *Wind Directions*, Magazine of the European Wind Energy Association;
- *Renewable Energy World*, James & James (Science Publishers) Ltd.;
- *CADDET Renewable Energy Newsletter*, IEA/OECD.

Information provided by WEC Member Committees has been incorporated as available.

ARGENTINA

In order to promote wind energy and solar power, the Argentinian Government implemented the *Regimen Nacional de Energía Eolica y Solar* Law at the end of 1999.

The most important aspects of the legislation are to establish a mechanism to transfer resources towards the development of the renewable energy technologies, to guarantee a price for electricity fed into the grid (for grid-connected applications) or used for public service (for stand-alone applications) and to provide tax relief on capital investment for generating equipment utilising either wind or solar power.

In addition to 4 small wind plants totalling 3 MW, the country's currently installed capacity of 14 MW includes 11 MW installed at Comodoro Rivadavia (Chubut Province) on the Atlantic coast of Patagonia; during the second half of 2001, another 10.6 MW capacity will be brought into service at this location.

Further projects are planned to take advantage of the extremely high average wind speeds along the coast: 50 MW at Comodoro Rivadavia and 10 MW at Puerto Madryn (also Chubut Province) in 2002, 117 MW at Bahia Blanca (Buenos Aires Province) in 2003.

An official study has forecast that there could be up to 1 GW of wind power installations in the country by 2015. However, the Argentinian Wind Energy Association has claimed that more than 2 GW could be accommodated before 2012.

CANADA

Canada has a long history of utilising its huge wind energy potential but despite Government support for its development, the country has not embarked on a vigorous wind power programme. At the present time no specific wind energy deployment rates have been set. However, *Action Plan 2000 on Climate Change* is the Government's contribution to the First National Climate Change Business Plan and contains specific initiatives to support the research, development and deployment of renewable and alternative energy technologies. For example, the market for emerging renewable energies will be expanded by increasing the Government's electricity purchases from emerging low- and non-emitting energy sources to 20%. The document outlines the broad policies to be adopted but the funding for the final package of measures will not be confirmed until the 2001 budget.

The Wind Energy Research and Development Program (WERD) is coordinated by Natural Resources Canada, a department of the Federal Government. The programme oversees technical development, resource assessment, test facilities and information/technology transfer. Moreover, the Government has formulated various financial incentives to encourage the deployment of wind power which, to date, has mostly been conducted by the private sector.

During the last years of the 1990's there was considerable growth in the installed capacity but by end-1999 there was only 125 MW in place. It is reported that by end-2000 capacity had increased to 137 MW, of which 74% was located in Quebec and 25 % in Alberta.

CHINA

In the early 1990's China drew up its Agenda 21 Program, which defined a strategy to lead the country on a sustainable development path in the 21st century. One section of Agenda 21 dealt with renewable energies under the heading of "Sustainable Energy Production and Consumption". In addition to providing detailed resource estimates this section also dealt with specific development objectives and activities required to achieve them. It had been estimated that Chinese wind power resources are some 3 200 GW of which about 10% is exploitable. The areas with greatest wind energy potential are the provinces and autonomous regions of Inner Mongolia, Xinjiang, Heliongjiang, Gansu, Jilin, Hebei, Liaoning, Shandong, Jiangxi, Jiangsu, Guangdong, Zhejiang, Fujian and Hainan. Most other provinces have recourse to isolated wind resources.

Despite the Government's stated goal of 1 000 MW of installed wind power by 2000 (and 3 000 MW by 2010), only 25 MW capacity was added during 1999, bringing the end-year figure to 253 MW. The slow deployment of wind turbines has been in part due to the Chinese insistence on bilateral donor support for projects - the projects have therefore been small.

In 1995 the US Department of Energy (DOE) and the Chinese Government signed a Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Development and Utilisation. Furthermore, in late-1996, Annex II to the Protocol was signed. The objective of Annex II is to promote the sustainable, large-scale deployment of wind energy systems for both grid-connected and off-grid village power applications in China. Twelve provincial and autonomous power corporations are engaged in developing wind power and 19 wind farms have been established in two high-wind zones. The 64 MW Xinjiang Dabancheng wind farm is China's largest and the 42 MW Guangdong Nanao wind farm is the largest island-based installation in Asia.

In addition to large wind power plants (typically 20-100 MW) for connection to the national grid, it is planned to install clusters of small wind turbines (10-100 kW) in townships and villages for rural electrification and also on a very small scale (0.5-10 kW) in individual homes to provide electricity for domestic uses.

DENMARK

At end-1999 Danish installed wind capacity stood at 1 771 MW. The recent rate of growth is such that by end-2000 it was reported that there were in excess of 6 000 wind turbines, representing a capacity of over 2 000 MW. The largest turbines incorporate technology that is competitive to the extent that the use of wind-produced electricity is one of the cheapest ways of reducing CO_2 emissions from power production.

The 2005 target set by the Government's Renewable Energy Initiative Package (Energy 21) (specifying that 10% of the country's electricity demand should be met by a wind capacity of 1 500 MW) was attained prior to the end of 1999. However, as turbines have become larger, the availability of appropriate sites has decreased and it has become increasingly difficult to locate the installations. Most new capacity continues to be built by private companies.

The present Energy 21 published in 1996 is the fourth of the energy strategies and specifies energy policy for the period to 2030. Any increase in onshore wind turbine capacity after 2005 will be affected by various actions, including the renovation of wind turbine areas as well as by the removal or replacement of existing turbines in accordance with regional and municipal planning.

In the longer term the main thrust of new development will take place offshore, following the first demonstration installations at Vindeby in the Baltic Sea (1991) and Tunø Knob in the area between Jutland and Samsø (1995).

In June 1999 the Government approved five sites for large-scale offshore wind farms with a total capacity of 750 MW. The installations will be built and owned by power utilities and the first two, each of about 150 MW, are expected to be operational in 2002. However, as a forerunner to these projects, a smaller offshore wind farm (Middelgrunden, located just outside Copenhagen harbour) became operational at end-2000. With twenty 2 MW turbines producing approximately 85 million kWh of electricity per annum, this is the world's largest offshore wind farm.

Addtionally, in order to provide the population with greater opportunities to contribute to the use of cleaner energy, small wind turbines (household-sized) producing electricity for heat and power have been erected in recent years.

Wind power economics continually improve in line with the increased turbine capacity. As a result the Danish Government has reduced the subsidy to the pay-back rate for the electricity and in 2001 a market system with Green certificates will be introduced.

GERMANY

The "Electricity Feed-in" law (*Stromeinspeisungsgesetz*) was the progenitor of German wind power development in the early 1990's: installed capacity almost doubled each year during the period (1991-1994) after the law was passed.

From 1 211 turbines and an installed capacity of 167 MW in 1992, German wind capacity had grown to 7 879 turbines and 4 445 MW by end-1999, making it the world leader in wind energy. Following annual increases in excess of 80%, growth in the second half of the 1990's slowed to 35%-55%, but even with lower growth 1999 saw a record-breaking 1 500 MW of capacity being added. Furthermore, it is reported that by the end of 2000 capacity had increased to just over 6 000 MW. The years between 1992 and 1999 saw the average size of turbine grow from under 200 kW to over 900 kW.

Wind turbines are installed throughout the German Länder: at end-1999 approximately 58% of the wind power was located in the coastal states (Lower Saxony, Schleswig-Holstein and Mecklenburg-West Pomerania), about 25% in the north German lowland states and 17% in the low mountain states.

With typical wind conditions, German turbines presently produce approximately 2% of total electricity production, but the continuing dynamism of the industry is inextricably linked with two political actions. The *Stromeinspeisungsgesetz* obliges utilities to accept all electricity produced with renewable energies. The price paid for wind power is 90% of the average electricity tariffs for all customers (excluding tax). Due to liberalisation, electricity prices have decreased and an amendment to the law will serve to uncouple the reimbursement paid to wind farmers from the average electricity price. Additionally, the Renewable Energy Act, a new law aimed at increasing the share of renewable energy to 10% of electricity production, will clarify the position of wind energy within the renewables scene. However, the rate of growth seen in recent years is likely to decrease rapidly, partly due to land constraints. Future projects will depend on offshore wind resources being utilised and/or further legislative action being taken to promote greater onshore development.

GREECE

Greece has a very substantial wind resource potential, the exploitation of which is supported by the Government as part of its National Programme to substitute renewable energies for imported fossil fuels.

The systematic study of wind potential in the Greek islands was begun by the Greek Public Power Corporation (DEI) in the mid-1970's. It has continued, aided by the European Union (Thermie Programme) and the Centre for Renewable Energy Sources (CRES), the national organisation for the promotion of renewable energies and the certifying authority for wind turbines. In 1995 the Greek Government set a target of 350 MW installed wind power capacity to be in place by 2005 and provided financial assistance programmes to assist this policy.

The utilisation of Greece's wind resource has been successfully implemented by locating wind turbines in many of the country's isolated and island communities. Hitherto, these areas could only be expensively supplied with electricity and yet there were abundant supplies of wind power available. By end-1999 there were 306 wind turbines representing 107 MW of installed capacity, a more than doubling of the 1998 capacity. Until recent years DEI owned about 90% of wind generators, but the Government's lifting of the restriction on privately generated power has promoted great interest in the private sector to develop wind power projects. The island of Crete now has the country's first privately-developed wind farm, consisting of seventeen 600 kW turbines.

INDIA

The Indian wind power programme was initiated in 1983-84 and a *Wind Energy Data Handbook* published in 1983 by the Department of Non-conventional Energy Sources (now the Ministry of Non-conventional Energy Sources, MNES) served as a data source for early government initiatives. In 1985 an extensive Wind Resource Assessment was launched, which also signalled the beginning of concentrated development and harnessing of renewable sources of energy and, more specifically, of wind energy. The Assessment has now become the world's largest such programme and to date five volumes of the *Handbook on Wind Energy Resource Survey*, containing a huge volume of accumulated wind data, have been published.

Initial estimates of the Indian wind resource had put it at 20 000 MW (at the micro level) but recent studies have revised this figure to 45 000 MW (at 50 m hub height). Potential locations with abundant wind have been identified in the flat coastal terrain of southern Tamil Nadu, Kerala, Gujarat, Lakshadweep, Andaman & Nicobar Islands, Orissa and Mamarashtra. Other favourable sites have also been identified in some inland areas of Karnataka, Andhra Pradesh, Madhya Pradesh, West Bengal, Uttar Pradesh and Rajasthan. With the assumption of a 20% grid penetration, it has been estimated that 9 000 MW of potential is already available for exploitation in such states.

In terms of currently installed wind turbine capacity, India now ranks 5th in the world behind Germany, USA, Denmark and Spain. At end-1999 the figure stood at 1 081 MW, of which 55 MW represented demonstration projects and 1 026 MW commercial projects. Tamil Nadu possessed 72% of the commercial plants. By mid-2000, total installed capacity had already grown to 1 175 (57 MW demonstration projects and 1 118 MW commercial projects).

The demonstration projects, which began in 1985, are being implemented through the State Governments, State Nodal Agencies or State Electricity Boards. They, together with extremely favourable financial incentives, have created the conditions that have allowed the wind energy market to expand from just 32 MW of installed capacity in early-1990. The Indian Renewable Energy Development Agency (IREDA) has played a significant role in the promotion of wind energy, attracting bilateral and multilateral financial assistance from world institutions and the private sector. The newly-established Centre for Wind Energy Technology (C-WET) based in Tamil Nadu will act as a technical focal point for wind power development in India.

IRELAND

Ireland's prevailing south-westerly winds from the Atlantic Ocean give a feasible wind resource that has been estimated to be as high as 179 GW, or some 40 times the country's current generating capacity. However, the accessible resource is about 2 190 MW and, in reality, the practicable resource is estimated to be 812 MW.

This abundant wind supply began to be utilised, albeit rather poorly, in the early 1980's with several demonstration schemes. The detailed investigations that followed included the establishment of the Irish Wind Atlas and, in the mid-1990's, the Government's Alternative Energy Requirement (AER I) competition. Under AER I, prospective generators competed for Power Purchase Agreements (PPA's) to sell electricity to the Electricity Supply Board (ESB). The competition was open to a range of renewable energies for contracts of 10-15 years' duration, not extending beyond 2010 (all projects were to completed near end-1997). Wind energy gained ten contracts for 73 MW: seven were eventually built.

The second competition (AER II) excluded wind energy but AER III, launched in March 1997, included a target of 90 MW for new wind energy projects. The results, announced in April 1998, granted PPA's to 17 projects with a combined capacity of 137 MW, to be located in Counties Cork, Donegal, Kerry, Roscommon and Sligo. The PPA's were for 15 years' duration, not extending beyond 2014.

A Government green paper on sustainable energy released in September 1999 not only reiterated Ireland's determination to promote renewable energies and, in particular, the utilisation of wind power, but also dramatically increased the target figures for the period to 2005. It is now expected that wind energy will contribute the bulk of 500 MWe of additional generating capacity (replacing an earlier target of 155 MWe). If this target is met, wind energy will then account for 10.7% of projected total installed electricity generating capacity.

The first commercial wind plant at (Bellacorick, County Mayo) was commissioned in 1992. The 21 turbines have a combined capacity of 6.45 MW. It remained the only windfarm supplying the grid until 1997, when a further six were commissioned (under AER I and the EU's Thermie Programme), with a combined generating capacity of 44 MW. Since then a further five have been constructed, including the 4.62 MW Curabwee plant in County Cork, the first under AER III. By mid-2000, the 12 operating Irish windfarms had a combined capacity of 69 MW, representing 1.4% of total installed electricity generating capacity.

Of the 17 projects awarded under AER III (excluding the Curabwee plant) nine have secured planning, three have failed at the planning stage and the remaining four are at various stages of the planning process.

It was expected that the eight stations under construction in 2000 would bring the end-2000 total installed capacity to 117 MW.

ITALY

Since 1998 the Italian Government has reviewed its policies concerning renewable energies to the extent that wind power plants in particular are now favoured (conditional on suitable circumstances being established). As long ago as 1988 the National Energy Plan had set a wind-power target of 300 MW (600 MW if large machines should become commercially available) to be installed by 2000, and by end-1999 installed capacity had reached 232 MW. In the mid-1990's nearly 700 MW of capacity had received preliminary agreements to be built, but these projects await construction.

In August 1999 the Government approved a white paper on the Exploitation of Renewable Energy Sources. It was drawn up by the National Agency for New Technology, Energy and the Environment (ENEA) and contained guidelines and measures for reducing greenhouse gas emissions. It calculated that if an average of 200 MW new capacity could be brought on line each year for 10 years, then a total wind power capacity of some 2 500 MW by 2008-2012 could contribute to reducing emissions. It is expected that this rate can at least be attained for the years 2000 and 2001, encouraged by the payment of premium tariffs.

As part of new government legislation, the electricity industry is being restructured and from 2002 onwards, any operator who (in the previous year) has produced or imported more than 100 GWh of electricity generated from non-renewable sources, must feed into the grid at least 2% of that figure from new or re-powered renewables. In addition, a system of tradable "Green certificates", similar to that in the UK, is being introduced. Green certificates will be awarded by the Transmission System Operator for the output from renewable plants for a maximum of eight years. Plant owners are expected to gain income by selling these certificates to other companies bound by the 2% renewables quota.

During 1999, 183 wind turbines with a total capacity of 104 MW were installed at ten sites. Italian wind turbines are mostly located in the Apennines range of mountains in the south of the country. More than 80% of installed capacity is in the regions of Apulia and Campania. Research is also being conducted into the possibilities of offshore wind plants.

JAPAN

The Japanese Government instituted its Sunshine Project in answer to the problems created by the oil crises of the 1970's. In 1993, as a way of efficiently overcoming barriers related to new energy, the New Sunshine Program (NSS) was launched; it has been conducted under the aegis of the Agency of Industrial Science and Technology (AIST) in the Ministry of International Trade and Industry (MITI) and has included a renewable energy R&D programme that has directed development of wind power in Japan. Between 1990 and 1994 the New Energy and Industrial Technology Development Organization (NEDO) carried out a wind resource measurement study, and between 1991 and 1998 it undertook a MW-class demonstration wind farm on Miyako Island in Okinawa Prefecture.

The IEA reports that Japanese installed wind power capacity was at a low level until, in 1995, the Government launched a Field Test Program in order to stimulate the introduction of wind plants. At that time capacity stood at 10 MW, but 1996 and 1997 saw growth of 42% and 27% respectively. In mid-1997 the New Energy Law was passed, which aimed to further stimulate the interest in wind power and 1998 showed an increase of 84% over 1997. By end-1999 nearly 44 MW of capacity had been added bringing the total to 75 MW, an increase of 138% over 1998. However, the WEC Member Committee reports an end-1999 installed capacity figure of 83 MW.

To help in achieving the target of 300 MW installed wind capacity by 2010, as quoted in the Primary Energy Supply Plan, the Government has added two incentive schemes to the Field Test Program. One is the New Energy Local Introduction Supporting Program that provides subsidies to new public-sector energy projects and the other, the New Energy Business Supporting Program, which provides subsidies to private-sector wind businesses.

In 1999 NSS/NEDO put in place two R, D&D programmes. The first is the Development of Advanced Wind Turbine Systems for Remote Islands, to utilise the wind resource in Japanese islands where fossil fuel-derived electricity is expensive to produce. The second is the Development of Local Area Wind Energy Prediction Model, a model that is able to accurately predict the correct siting for wind projects in the complex Japanese terrain. Lastly, with oceans surrounding Japan, research has begun into the feasibility of siting wind turbines offshore.

NETHERLANDS

The Third Energy Memorandum of 1995 stated that the Dutch Government intended to meet 10% of the nation's fossil fuel use with renewable energy by 2020, and that wind energy would play an integral part in this strategy.

In 1999 the Government published *Renewable Energy in Progress* – a report on the progress of the strategy. It noted that at the beginning of the year, Novem (the Netherlands Agency for Energy and the Environment) had been awarded a new two-year programme for implementation in 1999/2000 as part of the Multi-year Programme for the Application of Wind Energy in the Netherlands (TWIN). The report on the TWIN programme for 1997/1998 concluded that the improvement in the price-performance ratio for wind turbines in the Netherlands was proceeding on schedule, but that the rate of installation was lagging behind. Both in 1997 and 1998, wind capacity grew by approximately 40 MW. Formerly this low growth could be explained by a combination of factors, including those of a financial nature, but latterly the main problem has been that locations are not being provided at a fast enough rate. Developing locations is a key theme of the TWIN progamme and will help prepare and develop near-shore and offshore wind energy.

By end-1999 the total operational wind capacity in the Netherlands was 408 MW, with 1 258 turbines. At this disappointingly low level, the target of 750 MW by 2000 seemed unlikely to be attained. The underlying cause of the problem is lack of public support at local level. By applying a broad range of activities under the aegis of the information campaign 'Room for Wind Energy', Novem and the Project Agency for Sustainable Energy are attempting to increase public acceptance of wind energy.

Although there is some utility ownership of wind turbines, the majority of Dutch wind turbines are in private ownership, often with shares held by farmers on whose land the turbines stand.

SPAIN

Like many countries with limited fossil-fuel resources, the oil crises of the 1970's provided Spain with the impetus for investigating indigenous renewable energy resources. During the 1980's the Spanish wind resource was assessed, the relevant technology developed and a Demonstration Program launched by the Institute for Diversification and Saving of Energy (IDAE). Thereafter the establishment of several small demonstration wind farms and the enactment of a law in 1994 (guaranteeing the electricity price to be paid by utilities to wind power plants) resulted in the wind energy sector being ready to utilise the considerable potential that exists in both continental Spain and in the Canary Archipelago.

From an installed capacity of just 73 MW in 1994, the figure had increased to 1 539 MW by end-1999 with annual growth rates of 100%, 95% and 85% in the years 1997, 1998 and 1999. Wind turbines have been installed in nine of Spain's provinces, the northern provinces of Galicia and Navarra having 55% of total capacity. In addition to federal energy laws, most Spanish provinces have their own wind energy programmes These have been aimed at stimulating local markets as the structure of the economy has changed. Both Navarra, which had experienced high unemployment, and Galicia have invested heavily in turbine manufacturing plants.

The installed wind power plants are mainly owned by consortiums formed by utilities, regional institutions involved in local development, private investors, and in some cases the manufacturers. Private individuals are not taking an important role in the development of wind energy in Spain.

At the end of 1999 the Spanish Ministry of Energy and Industry prepared the “Program for Promotion of Renewable Energies”. This seeks to maintain the provisions of an earlier law passed in December 1998. In addition, it will be complemented by the new “National Plan for Scientific Research, Development and Technological Innovation (2000-2003)”. The legislation seeks to ensure the continuance of favourable economics for power produced by renewable energy plants. The strategy embodied in the 1998 law is that at least 12% of Spanish energy demand will be met by renewable energies by 2010. To this end, it is expected that further utilisation of the wind resource will result in some 10 800 MW of wind capacity being in place by 2012. Galicia, the most north-westerly province, taking full advantage of the Atlantic winds, will account for 2 800 MW of the total.

SWEDEN

Sweden was one of the early pioneers in modern wind power development, embarking on a wind energy programme in 1975. In 1997, following a statement made in 1995 regarding national energy policy, a new long-term transformation programme to develop an ecologically sustainable energy supply system was agreed upon. The Swedish National Energy Administration, which came into existence at the beginning of 1998, manages the system. In mid-1999 a government commission concluded that in order for there to be a major expansion in the Swedish wind sector, it was necessary to undertake wind surveys and resource planning, especially in offshore and mountain areas. The Energy Administration oversees the Government’s three programmes for supporting the development and installation of wind turbines:

- a three-year (1998-2001) programme investigating all aspects of wind power research;
- a development and demonstration programme for wind systems, with a maximum 50% support;
- an investment subsidy programme.

During 1999 there was a 24% increase in capacity, bringing the installed wind power capacity as at end-1999 to 215 MW. Wind power generation also increased significantly in 1999 to 369 GWh (+18% over 1998), representing 0.25% of the total electricity generation.

During the 1990’s research was carried out on the feasibility of offshore wind plants. A 220 kW plant at Nogersund was followed by the Bockstigen-Valar project (5 plants each of 500 kW). In mid-2000, it was announced that a 10 MW offshore installation on the Utgrunden shoal in south-eastern Sweden had received governmental approval. Other offshore projects are planned for the period to 2005, but as in other north-west European countries there is public resistance to the ever-increasing deployment of wind turbines, and research is being undertaken in an attempt to change attitudes.

UNITED KINGDOM

To ensure the diversity of electricity generating capacity, the UK Government instituted the Non Fossil Fuel Obligation Orders (NFFO) for England and Wales and for Northern Ireland (NI NFFO) and the Scottish Renewables Obligation (SRO). The orders were collectively known as the Renewables Obligations. Four Orders were made in England and Wales (1990, 1991, 1995, 1997), two in Scotland (1994, 1997) and two in Northern Ireland (1994, 1996).

The Utilities Act 2000 makes substantial changes to the regulatory system for electricity in Great Britain. The Act replaces the existing NFFO, but contains provisions to preserve existing NFFO contracts for the rest of their term. The Government will be able to impose an obligation on suppliers that a specified proportion of the electricity they supply must be generated from renewable sources. This obligation will be supported by a system of tradable “Green certificates” (e.g. a supplier which is unable to fulfil its obligation itself can do so by purchasing a certificate from a supplier which has over-achieved). It is expected that the obligation imposed will increase gradually year-by-year to enable the Government’s targets for renewables - 5% of electricity by 2003, and 10% by 2010 – to be achieved.

At the end of 1999, 281 wind-power projects representing 2 676 MW of capacity had been contracted for under NFFO. However, only 19 MW of new capacity was commissioned during the year, bringing the total operational capacity to 60 wind schemes (both windfarms and single turbines), with 779 turbines representing 344 MW. The low deployment rate reflects the difficulties encountered by developers in gaining planning consent.

In December 2000, the UK’s first offshore wind turbines off the coast of north-east England were officially opened. The Blyth windfarm has two 2 MW turbines and is expected to have an annual output of 10 000 MWh. It is linked with the existing 2.7 MW windfarm (9 x 300 kW) turbines lined along the Blyth harbour wall.

As part of its consultation document: *New and Renewable Energy – Prospects for the 21st Century*, the Government has announced its intention that each of the 11 regions of the UK will take a percentage share of the target for renewables (8 regions, excluding London, in England totalling 44%, plus Wales at 8%, Scotland at 39% and Northern Ireland at 9%). It has been prescribed that suitable sites should have a wind speed of at least 7 m/s, but exact locations for turbines will not be centrally determined. Rather, each region’s local governments will take the decision of where to locate the installations, with the anticipation that the wind energy programme can move ahead more positively.

UNITED STATES OF AMERICA

The development of the wind sector in the USA has, since the early 1980’s, reflected the wind-related Federal legislation in place at the time. Federal tax credits in favour of wind energy assisted the development, and the expiry of such credits dampened the incentive to construct capacity.

The Energy Policy Act of 1992 (EPACT) established production tax credits (PTC) for projects brought on line between 1994 and 1999, and there was a consequent growth in the market in 1999 prior to the cessation of PTC. As at end-1999, total capacity stood at 2 251 MW, installed in half of the 50 States. The wind capacity installed in California, Minnesota, Iowa and Texas constituted over 90% of total US capacity. Energy production from all wind systems during 1999 is estimated to have been in the order of 4.5 TWh but wind energy currently supplies only a minute percentage of the national electricity supply.

At the end of November 2000, the American House and Senate granted an extension of the PTC for 30 months to end-2001 (effective retroactively from end-June 1999). This will induce the further development of wind power in the short term: some 2 400 MW of additional capacity is planned. Aided by the state’s restructured electricity legislation (allowing for a ten-year tax credit of 1.5 cents per kWh, adjusted for inflation for plants completed before end-2001), 731 MW of capacity is planned for Texas. By end-2001 it is expected that Texas will become the state with the second-largest installed wind energy generating capacity. However, it is the Great Plains states that hold the greatest potential for wind power: a 1991 Pacific Northwest Laboratory assessment of US wind potential gave

North Dakota, Texas, Kansas, South Dakota, Montana, Nebraska, Wyoming, Colorado and New Mexico 82% of the approximately 1.1 million MW total US potential.

Under the aegis of its Wind Program, the US Department of Energy (DOE) has put in place a *Wind Powering America* initiative. The role of the DOE is to assist with all developmental aspects of wind energy, especially helping to move the technology from the industry to the market place. The Wind Powering America initiative states that the following targets should be achieved:

- wind to provide at least 5% of US electricity by 2020;
- 5 000 MW on line by 2005, 10 000 MW by 2010 and 80 000 MW by 2020;
- double the number of states with more than 20 MW installed (from eight to 16) by 2005, and increase to 24 by 2010;
- provide 5% of electricity used by the federal government (the largest single consumer of electricity in the US) by 2010 (1 000 MW).

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Chapter 14

TIDAL ENERGY

Tides are caused by the gravitational attraction of the moon and the sun acting upon the oceans of the rotating earth. The relative motions of these bodies cause the surface of the oceans to be raised and lowered periodically, according to a number of interacting cycles. These include:

- a half day cycle, due to the rotation of the earth within the gravitational field of the moon
- a 14 day cycle, resulting from the gravitational field of the moon combining with that of the sun to give alternating spring (maximum) and neap (minimum) tides
- a half year cycle, due to the inclination of the moon's orbit to that of the earth, giving rise to maxima in the spring tides in March and September
- other cycles, such as those over 19 years and 1 600 years, arising from further complex gravitational interactions.

The range of a spring tide is commonly about twice that of a neap tide, whereas the longer period cycles impose smaller perturbations. In the open ocean, the maximum amplitude of the tides is about one metre. Tidal amplitudes are increased substantially towards the coast, particularly in estuaries. This is mainly caused by shelving of the sea bed and funnelling of the water by estuaries. In some cases the tidal range can be further amplified by reflection of the tidal wave by the coastline or resonance. This is a special effect that occurs in long, trumpet-shaped estuaries, when the length of the estuary is close to one quarter of the tidal wave length. These effects combine to give a mean spring tidal range of over 11 m in the Severn Estuary (UK). As a result of these various factors, the tidal range can vary substantially between different points on a coastline.

The amount of energy obtainable from a tidal energy scheme therefore varies with location and time. Output changes as the tide ebbs and floods each day; it can also vary by a factor of about four over a spring-neap cycle. Tidal energy is, however, highly predictable in both amount and timing.

The available energy is approximately proportional to the square of the tidal range. Extraction of energy from the tides is considered to be practical only at those sites where the energy is concentrated in the form of large tides and the geography provides suitable sites for tidal plant construction. Such sites are not commonplace but a considerable number have been identified in the UK, France, eastern Canada, the Pacific coast of Russia, Korea, China, Mexico and Chile. Other sites have been identified along the Patagonian coast of Argentina, Western Australia and western India.

Figure 14.1: Prospective sites for tidal energy projects

Country	Country	Mean tidal range (m)	Basin area (km^2)	Installed capacity (MW)	Approximate annual output (TWh/year)	Annual plant load factor (%)
Argentina	San José	5.8	778	5 040	9.4	21
	Golfo Nuevo	3.7	2 376	6 570	16.8	29
	Rio Deseado	3.6	73	180	0.45	28
	Santa Cruz	7.5	222	2 420	6.1	29
	Rio Gallegos	7.5	177	1 900	4.8	29
Australia	Secure Bay	7.0	140	1 480	2.9	22
	Walcott Inlet	7.0	260	2 800	5.4	22
Canada	Cobequid	12.4	240	5 338	14.0	30
	Cumberland	10.9	90	1 400	3.4	28
	Shepody	10.0	115	1 800	4.8	30
India	Gulf of Kutch	5.0	170	900	1.6	22
	Gulf of Khambat	7.0	1 970	7 000	15.0	24
Korea (Rep.)	Garolim	4.7	100	400	0.836	24
	Cheonsu	4.5			1.2	
Mexico	Rio Colorado	6-7			5.4	
UK	Severn	7.0	520	8 640	17.0	23
	Mersey	6.5	61	700	1.4	23
	Duddon	5.6	20	100	0.212	22
	Wyre	6.0	5.8	64	0.131	24
	Conwy	5.2	5.5	33	0.060	21
USA	Pasamaquoddy	5.5				
	Knik Arm	7.5		2 900	7.4	29
	Turnagain Arm	7.5		6 500	16.6	29
Russian Fed.	Mezen	6.7	2 640	15 000	45	34
	Tugur *	6.8	1 080	7 800	16.2	24
	Penzhinsk	11.4	20 530	87 400	190	25

* 7 000 MW variant also studied

Tidal energy can also be exploited directly from marine currents induced by the combined lunar and solar gravitational forces responsible for tides. These forces cause semi-diurnal movement in water in shallow seas, particularly where coastal morphology creates natural constrictions, for example around headlands or between islands. This phenomenon produces strong currents, or tidal streams, which are prevalent around the British Isles and many other parts of the world where there are similar conditions. These currents are particularly prevalent where there is a time difference in tidal cycles between two sections of coastal sea. The flow is cyclical, increasing in velocity and then decreasing before switching to the opposite direction. The kinetic energy within these currents could be converted to electricity, by placing free standing turbo-generating equipment in offshore areas (see Chapter 17: Marine Current Energy).

Different technical concepts for exploiting tidal energy

Most countries which have investigated the potential exploitation of tidal energy have concentrated on the use of barrages to create artificial impoundments that can be used to control the natural tidal flow. Barrage developers in the UK and elsewhere concluded that building a permeable barrage across an estuary minimises the cost of civil structures for the quantity of energy that can be realistically extracted. Construction of barrages across estuaries with high tidal ranges would be challenging but technically feasible. In shallow water armoured embankment would be used, but in deeper water this method would be impractical and too expensive because of the quantity of material required. Complete closure of estuaries would be achieved by emplacing a series of prefabricated sections, or caissons, made from concrete or steel which could be floated and then sunk into position. The technique has been used in the Netherlands to close the Schelde Estuary. A large steel caisson was used in the construction of the Vadalia power station on a tributary of the Mississippi.

Tidal barrages would comprise sluice gates and turbine generators. Large scale structures like the Severn Barrages would also include blank caissons and ship-locks. During the ebb tide water is allowed to flow through the sluices and the turbine draft tubes to ensure the maximum possible passage of water into the impounded basin. At or close to high water the sluice gates are closed. At this stage of the cycle the turbines can be used in reverse as pumps to increase the amount of water within the basin. Although there is an obvious energy demand, the amount of water transferred can provide an additional increase in energy output of up to 10% compared with a cycle where no pumping is used. The actual increase in energy output from pumping depends on the estuary and the tidal conditions.

Retention of water allows a head of water (i.e. difference in vertical height of water levels) to be created as the flood tide progresses seaward of the barrage. Once a sufficient head has been created, water is allowed to flow back through the turbines to generate electricity. In this respect a tidal energy barrage is no different to a low-head hydro-electric dam. The large volumes of water and the variation in head require the use of double regulation, or Kaplan turbines. These turbines have guide vanes and blades that can be moved by hydraulic motors. This allows turbine operation, and therefore energy conversion efficiency, to be optimised through each generation cycle as the reservoir head drops.

Experience from the UK's tidal energy programme revealed that ebb generation (i.e. only on the ebb tide) maximises the amount of energy that can be produced from this type of barrage system. Two-way generation (on both the flood and ebb tides) is technically possible, however less energy would be produced because the head of water created prior to generation is lower compared with an ebb generation cycle. Moreover, Kaplan turbines in a horizontal configuration are optimised for generation with flow in one direction.

As with all other civil engineering and power generation projects, diligent technical appraisal is essential to mitigate against both technical and commercial risk. Barrage design requires a detailed geotechnical site investigation to determine the foundation conditions. The nature of the substrate and the dimensions of an estuary ultimately determined the design options for barrages. Once an optimal design has been identified, it needs to be developed in detail to establish the construction schedule and the costs at each stage of the project to determine both economic and financial viability. A detailed knowledge of the hydraulic flow pattern before and after the barrage has been constructed is of equal importance and for the same reason. Hydraulic flow has to be accurately modelled, using complex mathematical models that can accurately simulate natural flow conditions, so that the effects of progressive closure and environmental changes can be predicted. Hydraulic modelling is also used to determine the energy output from the system during each tidal cycle.

Other concepts based on secondary artificial storage systems have been investigated, and continue to be promoted. The concept enables storage within two or more basins which can increase the control of the water movement and allows the turbines to operate for longer than in single basin schemes. Secondary reservoirs were proposed for the Severn scheme but were discounted because of the cost of the energy produced. The rise in cost is the direct consequence of the substantial additional civil structures required.

Technical status and experience from operating systems

Tide mills were commonplace along the coasts of western Europe from the Middle Ages, until the Industrial Revolution supplanted renewable forms of energy with fossil fuel alternatives. Interest in tidal energy was stimulated by the construction of the French barrage across the Rance estuary in Brittany during the 1960's. A dam was built in-situ between two coffer dams. Consequently the entrapped estuarial waters stagnated, although the ecosystem recovered once the barrage began operation. Most of the structure, which has an installed capacity of 240 MW, is comprised of Kaplan turbines with only a small bank of sluices. The barrage has a ship rock adjacent to the control centre and carries a trunk road. Originally designed for two-way generation, the operators, EDF, predominantly generate on ebb tides. Despite over thirty years of successful operation, EDF have no plans to build other barrage schemes.

Shortly after the completion of the Rance barrage, the Russians built a small experimental system with an installed capacity of 400 kW. The scheme was constructed at Kislogubsk near Murmansk, partly to demonstrate the use of caissons in barrage construction.

The potential for tidal energy at the head of the Bay of Fundy, which extends between the Canadian maritime provinces of Nova Scotia and New Brunswick, has long been recognised. In 1984 a 20 MW plant was commissioned at Annapolis, across a small inlet on the Bay of Fundy's east coast. The barrage was built to demonstrate a large diameter rim-generator (Straflo) turbine. Despite the large tidal energy potential, Canada has relied upon the development of its substantial conventional hydropower reserves.

The UK has invested approximately £20 million in tidal energy R&D. Most of this effort was concentrated on co-funded feasibility and development studies (between the mid-1980's and 1992) with industrial consortia. Two main sites were evaluated: one on the Severn (mean spring tidal range 12 m); and the other on the Mersey Estuary (mean spring tidal range 8 m). Despite detailed technical appraisals, coupled with evaluations of the effects to shipping and the environment, neither project progressed beyond an early development stage. The work revealed that tidal energy was less economic compared with other forms of renewable energy. The UK Programme also investigated four smaller-scale projects (ranging in size from 5–100 MW). None of these schemes progressed further than initial feasibility.

Of more recent interest is Western Australia's tidal energy potential that has been actively promoted near the town of Derby, (situated at the head of two adjacent inlets off the King Sound). The inlets would be connected via an artificial channel. By damming each inlet, differences in water levels in each basin could be controlled which would enable flow via the connecting channel. Power take-off would be achieved from a bank of turbines housed in a structure built in this channel. The Derby tidal power project had been assessed by a consortium led by KPMG. The project's promoters submitted this scheme to an independent ministerial advisory committee. The committee compared the scheme with an alternative gas-fired power plant and decided in July 2000 not to proceed with the Derby tidal project. The committee compared the two bids on financial and technical grounds as well as community benefits and environmental impacts.

Interest in multiple basins has been re-activated in the last three or four years by an American company, Tidal Electric. They are promoting the concept in a number of regions with high tidal ranges including Alaska, Chile and the UK. Water would be moved between three bunded reservoirs built on intertidal mud flats thereby enabling continuous generation. None of these schemes has so far progressed to construction.

Economic considerations

Tidal energy projects based on barrages are capital-intensive with relatively high unit costs per installed kilowatt (>£1 500/kW). The long construction period for the larger schemes and low load factors would result in high unit costs of energy, especially given the demands of private-sector investors. The economic performance of tidal energy barrages reflects the influence of site-specific conditions and the necessity for ship locks where access for navigation is required. As barrage construction is based upon conventional technology and site-specific conditions, it is unlikely that significant cost reductions could be achieved. Predicted unit costs of generation are therefore unlikely to change and currently remain uncompetitive with conventional fossil-fuel alternatives.

Some non-energy benefits would stem from the development of tidal energy schemes. However, they would yield a relatively minor monetary value in proportion to the total scheme cost. These benefits are difficult to quantify accurately and may not necessarily accrue to the barrage developer. Employment opportunities would be substantial at the height of construction, with the creation of some permanent long-term employment from associated regional economic development.

Economic prospects for alternative forms of tidal energy remain uncertain, largely because there is little published data on the costs or performance of either marine current generators or bunded reservoir schemes. Until further information is made available it is not possible to make a rational judgement on their prospects. However, without detailed technical information (for investors) and rigorous appraisal of environmental effects no form of tidal energy is likely to be developed. Experience of other forms of renewable energy has highlighted the necessity for credible environmental assessment to ensure endorsement from regulatory authorities and potential objectors.

Environmental aspects

Tidal energy barrages would modify existing estuarine ecosystems to varying degrees. Firstly some pre-barrage intertidal areas would become permanently inundated and although the intertidal zonation would change it would still be present and capable of supporting an estuarine ecosystem. The post-barrage upstream intertidal range would be approximately halved but the effect would progressively diminish upstream of the barrage. Changes to the hydraulic regime will invariably change patterns of sedimentation, eventually leading to a shift in sediment (particle size) distribution. There would be some sediment accumulation upstream of the barrage. The amount will depend on the position of the barrage. In estuaries like the Severn, with high sediment loads, this is an important consideration. For this reason the proposed downstream alignment offers an advantage because it would be less vulnerable to sediment accumulation.

Reduced post-barrage current strengths would lead to a fall in turbidity, higher light penetration and a concomitant increase in phytoplankton productivity. Site-specific work in the Severn Estuary suggests that this effect would be less marked in comparison to other estuaries. Saltmarsh zonation, a feature caused by periodic inundation by saline or brackish water, would change. A model specifically developed for *Spartina* distribution in UK estuaries indicates that the plant's post-barrage distribution could be predicted with a high degree of confidence.

Estuaries are of key importance to migratory species of fish, many of which are the foundation for commercial fisheries. Barrages could act as barriers to migration and damage fish. There is no clear indication from studies on existing hydroelectric stations of the numbers of fish which might be affected. The changes to fish populations are uncertain: levels may fall by 30-50% before the effects of a barrage become evident. Generic R&D has focused on the suitability of acoustic deterrence methods, which will require further refinement.

Much of the site-specific and generic R&D in the UK has concentrated on ornithological studies of migratory birds which use British estuaries in large numbers. Studies have confirmed that bird populations fluctuate between years and within a single winter. Their distribution is also highly uneven, which is partly due to the highly variable distribution of invertebrates. Post-barrage survival rates will depend on the extent of suitable intertidal areas and climatic conditions.

Construction of bunded reservoirs built on intertidal areas would have different environmental effects compared to conventional barrages. Attention to site-specific conditions, notably hydraulic flows, sediment erosion, transport and accumulation would need to be thoroughly understood to prevent souring or adverse accumulation within the basins. If these schemes resulted in permanent inundation of intertidal feeding areas, migratory bird populations would be displaced, although the impact would depend on their original importance.

James Craig
AEA Technology
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COUNTRY NOTES

The Country Notes on tidal energy have been compiled by the editors, drawing upon a wide range of sources. National, international, governmental publications/web sites have all been consulted, together with contributions made by James Craig of AEA Technology.

ARGENTINA

The southern coast between Tierra del Fuego and Golfo San Matías has mean tidal ranges of up to 7.5 m. An assessment of the country's tidal energy potential identified five sites with an estimated potential of 37 TWh per annum. However, development of tidal energy resources is dependent on the further expansion of hydroelectric resources and the construction of a transmission system that could connect tidal power plants with a suitable distribution network.

An investigation has been carried out in the San José Gulf, which has a basin area of 780 km^2 and is connected to the sea by a 7 km long strait. A barrage at this location would be approximately 13.4 km long, have an installed capacity of 5 040 MW and could produce an estimated 9.4 TWh per annum.

AUSTRALIA

Tidal energy potential is particularly prevalent along the north-western coast of Australia, where tidal ranges are amongst the largest in the world. This coastline has numerous inlets and bays that offer promising sites for barrages, such as Walcott Inlet, Secure Bay, St George's Basin and the larger King Sound. The development of tidal energy is disadvantaged, however, by the small range of neap tides, which is too low for power generation, and the impracticality of absorbing large amounts of intermittent power in a remote region without installing costly transmission links.

In the late 1990's Tidal Energy Australia, a Western Australian company, proposed a combination double basin/double flow design for Doctor's Creek, on King Sound near the Kimberley town of Derby. The advantage of their scheme was that it could provide around-the-clock power. One basin retains a high water level and the other a low level. A channel cut between the two holds the turbines used for power generation. At high tide, water is let into the high basin, and at low tide, is let out of the low basin. The plant, with a capacity of 48 MW, would have been the second largest tidal power station in the world and the only one providing continuous power output. This capacity would fully supply the needs of the region (for both residential purposes and exploitation of the Kimberley's abundant mineral resources), the supply being supplemented with diesel generating capacity as necessary. The population of Derby showed great support for the tidal plant but the government of Western Australia favoured a fossil fuel option for generating power. After much debate, the tidal plant was rejected. However, Tidal Energy has reported that it is working towards securing other customers and in particular, is working on the development of a similar (but expanded) plant for a mineral processing company, also in Western Australia.

CANADA

Embayments at the head of the Bay of Fundy between the maritime provinces of New Brunswick and Nova Scotia have some of the largest tidal ranges in the world. The most promising prospects for tidal power have centred on two sites in this region: the Cumberland and Minas Basins. However, the only commissioned tidal power plant is located at Annapolis Royal, further down the Bay of Fundy. The 20 MW plant came into operation in 1984: the barrage was primarily built to demonstrate a large-diameter rim-generator turbine. Annapolis uses the largest Straflo turbine in the world to produce more than 30 million kWh per year.

In view of the large tidal energy resource at the two basins, estimated to be 17 TWh per year, different options for energy storage and integration with the river hydro system have been explored. At present this prospect appears unlikely.

CHINA

The south-eastern coastal areas of Zhejiang, Fujian and Guangdong Provinces are considered to have substantial potential for tidal energy. China's utilisation of tidal energy with modern technologies began in 1956: several small-scale tidal plants were built for pumping irrigation water. Thereafter tidal energy began to be used for power generation. Starting in 1958, forty small tidal power plants stations (total capacity 12 kW) were built for the purpose of generating electricity. These were supplemented around 1970 by much larger stations, of which the 3 MW Jiangxia and the 960 kW Baishakou schemes were the largest. The majority of the early plants have been decommissioned for a variety of reasons, including design faults, being found to be incorrectly located, etc. Currently there are seven tidal power stations (plus one tide flood station) with a total capacity of 11 MW.

Since the end of the 1970's emphasis was placed on optimising the operations of existing plants to improve their performance. Additionally, a feasibility study for a 10 MW level intermediate experimental tidal power station has been undertaken.

FRANCE

Relatively few tidal power plants have been constructed in the modern era. Of these, the first and largest is the 240 MW barrage on the Rance estuary in northern Brittany. The 0.8 km-long dam also serves as a highway bridge linking St. Malo and Dinard. The barrage was built as a full-scale demonstration scheme between 1961 and 1966 and has now completed 34 years of successful commercial operation. Annual generation is some 640 million kWh.

Originally the barrage was designed to generate on both flood and ebb tides; however, this mode of operation proved to be only partially successful. The barrage is now operated almost exclusively on ebb tides, although two-way generation is periodically instigated at high spring tides.

In 1988 the plant became fully automated, requiring the integration of complex operational cycles imposed by variable heads, and the necessity for continuous regulation of the turbines to optimise energy conversion. A 10-year programme for refurbishing its 24 turbines was begun in 1996, on the plant's 30th anniversary.

Despite its successful operation, no further tidal energy plants are planned for France, which is now dominated by generation from nuclear stations.

INDIA

The main potential sites for tidal power generation are the Gulf of Kutch and the Gulf of Khambat (Cambay), both in the western state of Gujarat, and the Gangetic delta in the Sunderbans area of West Bengal, in eastern India.

The tidal ranges of the Gulf of Kutch and the Gulf of Khambat are 5 m and 7 m respectively, the theoretical capacities 900 MW and 7 000 MW respectively and the estimated annual output approximately 1.6 TWh and 15.0 TWh respectively.

A committee has been formed to estimate the present cost of the Gulf of Kutch project by inviting tariff-based bids and to gather the responses of the various agencies interested in the project. The Ministry of Non-Conventional Energy Sources (MNES) has reported that the "Request for Qualification" and "Request for Proposal" being prepared will enable the feasibility of establishing such a project through private sector participation to be tested.

Following a feasibility study for a 3 MW tidal power plant at Durgaduani in the Sunderbans area, a detailed project report is now being drawn up. If the project proceeds, the West Bengal Renewable Energy Development Agency, with MNES assistance, will take it up.

KOREA (REPUBLIC)

The west coast has mean tidal ranges of up to 6 m. Two prospective sites have been considered: Garolim Bay, which has been studied in detail, and the Gulf of Asam. The Korean Ocean Research and Development Institute (KORDI), assisted by a consortium of British companies, reviewed the schemes in the mid-1980's but no projects resulted.

MEXICO

Two areas in the Gulf of California have been examined, one near Isla Montague at the mouth of the Río Colorado, the other at the island of Tiburón further down the Gulf. They each have a tidal range of 6-7 m. The potential annual output of one site in the Colorado estuary has been assessed as 5.4 TWh.

RUSSIAN FEDERATION

Design studies for tidal power development have been conducted in Russia since the 1930's. As part of this work, a small pilot plant with a capacity of 400 kW was constructed at Kislogubsk near Murmansk and commissioned in 1968. The success of this installation led to a number of design studies for much larger tidal plants at sites in the north and east of the country: Lumbov (67 MW) and Mezen Bay (15 000 MW) in the White Sea, Penzhinsk Bay (87 400 MW) and Tugur Bay (6 800 MW) in the Sea of Okhotsk. Eventually the Tugur station emerged as the only feasible major scheme. Preliminary design work began in 1972 but the timescale for further development work remains uncertain.

UNITED KINGDOM

The large tidal range along the west coasts of England and Wales provides some of the most favourable conditions in the world for the utilisation of tidal power. If all reasonably exploitable estuaries were utilised, annual generation of electricity from tidal power plants would be some 50 TWh, equivalent to about 15% of current UK electricity consumption.

Of six identified sites with mean tidal ranges of 5.2-7.0 m, feasibility studies have been completed for two large schemes: Severn estuary (8,640 MW) and Mersey estuary (700 MW) and for smaller schemes on the estuaries of the Duddon (100 MW), Wyre (64 MW), Conwy (33) and Loughor (5 MW). A governmental programme on tidal energy (1978-1994) concluded that given the combination of high capital costs, lengthy construction periods and relatively low load factor (21-24%), none of these schemes is regarded as financially attractive in present circumstances. A future UK tidal energy programme could include construction of a small-scale scheme primarily to demonstrate the technology and its environmental effects, before progressing to very large schemes on the scale of the Severn.

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Chapter 15

WAVE ENERGY

Wave power technologies have been around for nearly thirty years. Setbacks and a general lack of confidence have contributed to slow progress towards proven devices that would have a good probability of becoming commercial sources of electrical power. For example in the UK, arguably one of the world's best locations for establishing wave power, owing to the strength of the resource, no Government funding was available to support R&D for the ten years from 1989 until 1999.

What has made the difference over the last three years since the WEC Survey of Energy Resources in 1998?

This commentary first sets out some of the milestones around the world that have made a contribution: including the issue of climate change and its impact on the thinking of governments and the major multinational energy companies.

The matters of wave resource and updates in technology for wave energy conversion are briefly touched upon. The Country Notes following this commentary give a flavour of worldwide activities in more detail.

Following this, the need for diversification of the offshore hydrocarbons industry is discussed and also the synergies between that industry and the emerging offshore marine renewable energy industry, of which wave power is an important part.

The way forward is outlined in general terms (applicable worldwide) and includes a generic "roadmap" of future R&D requirements for wave energy conversion technologies. Finally the commercial position for electricity from wave is reviewed in the light of recent investment forecasts and the expected unit costs of the leading-edge technologies.

Milestones for Wave Power

There have been several influential events in the last three years:

- **Kyoto Treaty 1997** - has provided the driver for various governments to set targets for increased proportions of renewable energy over the first decade of the new millennium. Major concerns remain that China, the FSU and India are not showing significant commitment to implementing such targets, and more fundamentally, over the announcement in March 2001 that the USA did not intend to implement the terms at all;

- **UK Review of Renewables 1999** - as part of this, wave power RD&D funding was re-introduced for the UK. Some influence for this came from a report from the Marine Foresight Panel Task Force entitled "Energies from the Sea – Towards 2020" (Ref. 1);

- **Increased focus on Climate Change issues over the period** - has become heightened as a growing consensus in the scientific community, owing to real evidence of the climate-altering effects of greenhouse gas emissions. The phenomenon at the Poles of increased numbers of icebergs and larger ice floes breaking away has been a graphic illustration. More recently, reports of an inland Arctic sea area where ice measurements historically showed a thickness of around three metres, have brought matters into the news and focused public attention. The degree of flooding experienced in East Africa, Bangladesh, India and in parts of Europe as well as mudslides in Ecuador has created awareness that there is more to this climatic instability than just scientific speculation;

- **The large increase in the price of oil in 2000 from the very low levels of 1998** - has caused re-evaluation of economic thresholds of conventional energy projects and improved the attractiveness of emerging renewable technologies, including wave energy conversion, when measured against fossil fuel energy sources. Greater effort to maintain the oil price is now being made within the OPEC group of countries. This has meant that existing wave energy technologies are in the present economic regime competitive in, for example, isolated communities currently served by diesel-driven generators.

Source: based on Claesson, (1987)

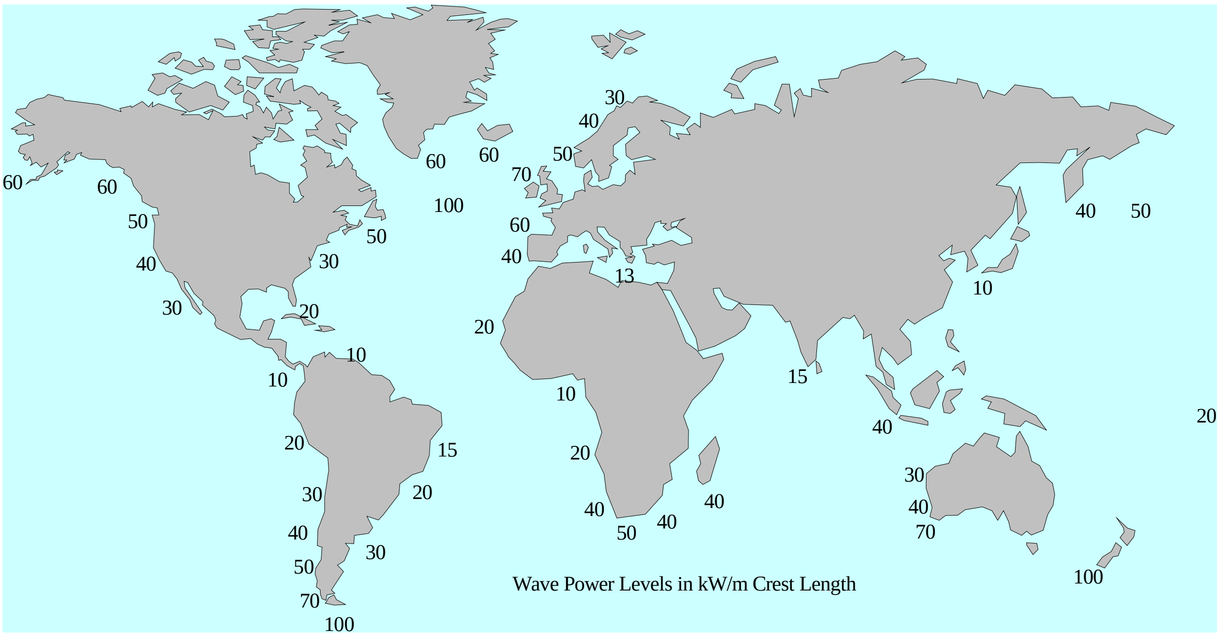


Figure 15.1: Global Distribution of Deep Water Wave Power Resources

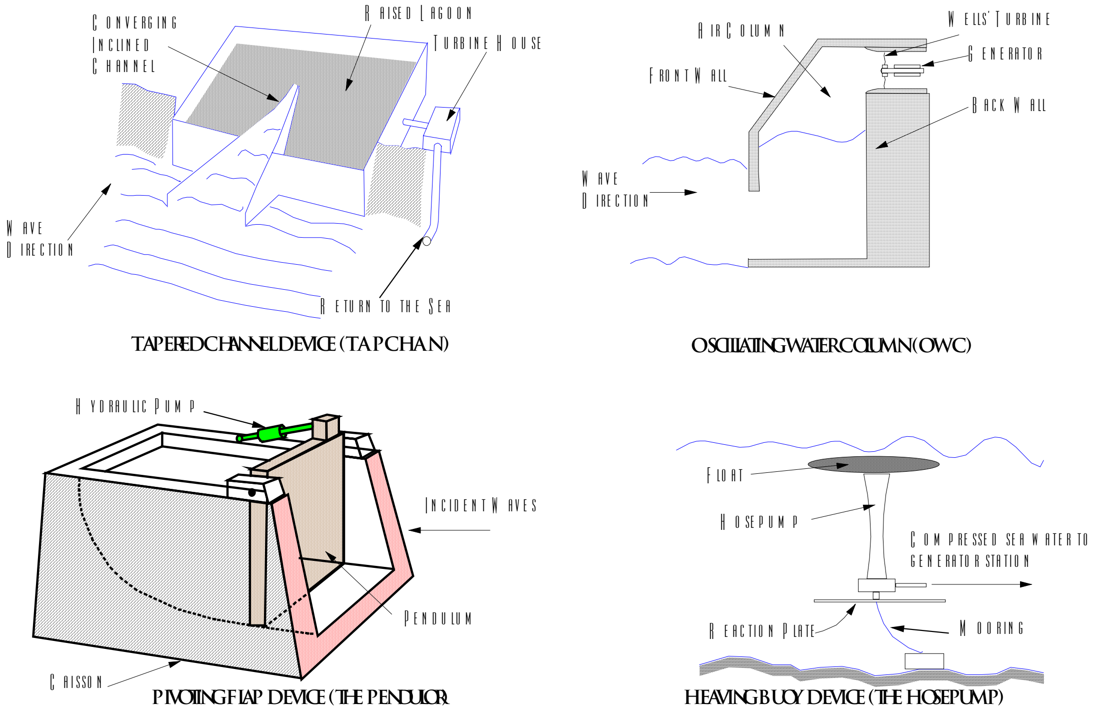
Wave Resource

Despite the climate change phenomena, the world resource for wave remains very much as set out by Dr Tom Thorpe of ETSU (author of the 1998 Wave Energy Commentary) (Ref. 2) The highest energy waves are concentrated off the western coasts in the 40^{o}–60^{o} latitude range north and south. The power in the wave fronts varies in these areas between 30 and 70 kW/m with peaks to 100kW/m in the Atlantic SW of Ireland, the Southern Ocean and off Cape Horn. The capability to supply electricity from this resource is such that, if harnessed appropriately, 10% of the current level of world supply could be provided. Work is still needed to determine how much more may be captured by other products (such as pumped water for desalination or electrolysis), once the storage technology for hydrogen is suitably developed.

Technology Update

Once again, the technologies outlined in 1998 based on Oscillating or Assisted Water Columns (OWC), buoys and pontoons (the Hosepump), flaps and tapered channels (the Pendulor and TAPCHAN) still exist or continue to be developed.

FIGURE 15.2 OUTLINE OF MAIN TYPES OF CURRENTLY DEPLOYED WAVE ENERGY DEVICES



In the recent period, the following new developments have been noted:

- The pelamis (named after a sea-snake), under development by Ocean Power Delivery Ltd in Scotland, is a series of cylindrical segments connected by hinged joints. As waves run down the length of the device and actuate the joints, hydraulic cylinders incorporated in the joints pump oil to drive a hydraulic motor via an energy-smoothing system. Electricity generated in each joint is transmitted to shore by a common sub-sea cable. The slack-moored device will be around 130m long and 3.5m in diameter. The pelamis is intended for general deployment offshore and is designed to use technology already available in the offshore industry. The full-scale version has a continuously rated power output of 0.75MW. Currently a one-seventh-scale prototype is being prepared for deployment in 2001.

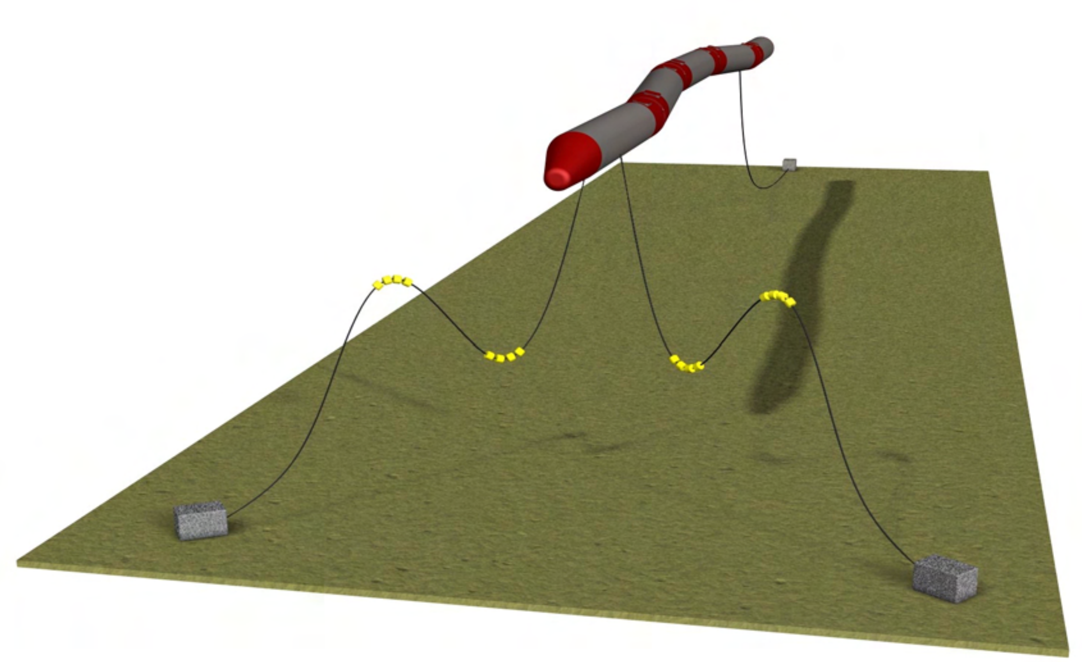


Figure 15.3: The Pelamis Wave Energy Converter (Ocean Power Delivery Ltd.)

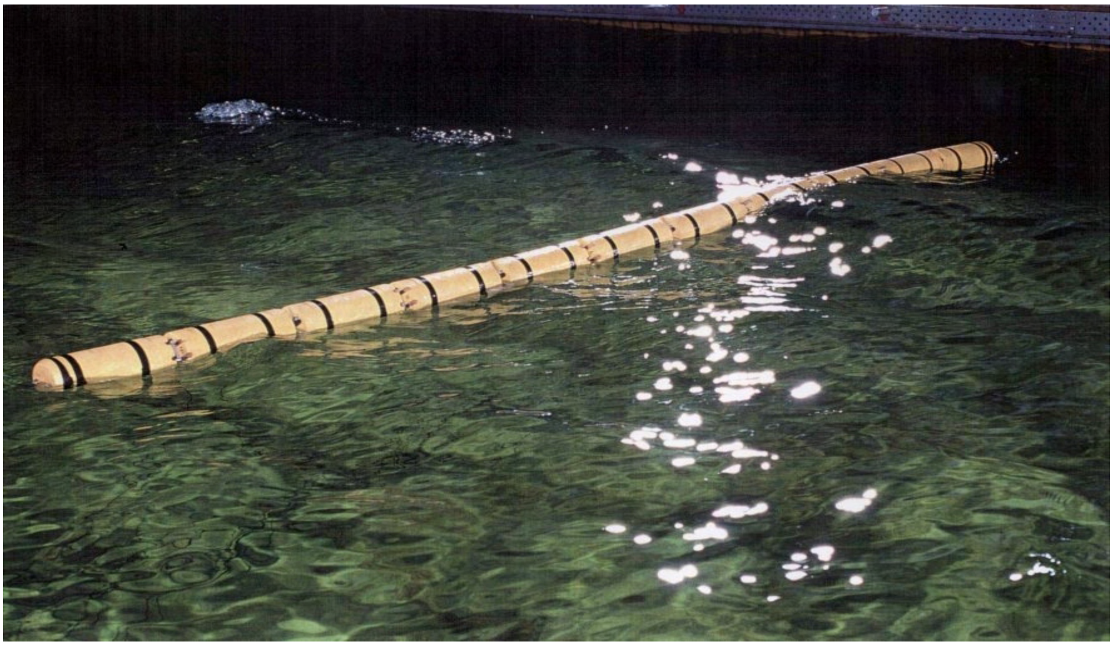


Figure 15.4: Pelamis – prototype (Ocean Power Delivery Ltd.)

- Energetech of Australia has developed a two-way turbine that is claimed to be significantly more efficient than the Wells turbine. This will be utilised in an OWC device that employs a parabolic funnel to focus the wavefronts into the shoreline device for greater power capture;

- Denmark has two recent devices with some innovative elements:

  The Waveplane - is a wedge-shaped structure which channels incoming waves into a spiral trough, this produces a vortex to drive a turbine. A one-fifth-scale model has been on test off Jutland since mid-1999;

The Wave Dragon - is a floating tapchan but using a pair of curved reflectors (of a patented design) to gather waves to overtop a ramped trough where water is released though a low-head turbine. A one-fiftieth-scale model has been tested and a quarter-scale prototype is being designed for deployment in a fjord. The full-size device (estimated to have a generation peak of 4 MW) is large, with a "span" across the reflector arms of 227m;

- In the USA, a company called Ocean Power Technologies (OPT) based in New Jersey is utilising a sheet of piezo-electric polymer material which, when deflected mechanically, produces electricity directly.

The technology scene for wave power is becoming more vibrant as various techniques and devices continue to be developed. It is evident that the range of types of device is far from exhausted, thus providing encouragement for the future.

Synergies with the Offshore Industry

A key fact that emerged from the UK DTI's Marine Foresight Panel Task Force on Energies from the Sea, was the need to transfer technology and knowhow from the existing offshore industry to the new marine renewable energy industry. It is also becoming clear to many companies in the offshore oil & gas industry that their future lies in a capability to diversify their skills and services into future renewable energy sources. This coincidence of needs is becoming a key driver to the development of marine renewables.

The offshore industry is highly skilled in working in construction operations and maintenance in the unforgiving marine environment and has, over the past 25 years, been able to develop equipment with levels of survivability and reliability that the wave energy community cannot yet aspire to. The offshore industry has lost a large part of its manufacturing and fabrication market in NW Europe and is seeking ways to replace the jobs whilst retaining the knowledge and skills of the workforce. Marine renewable energy is an excellent way to begin this process. In the UK in early 2001, a conference and exhibition was held which, for the first time, focused on the opportunities that exist for companies to diversify towards marine renewable energy. The event was attended by more than two hundred people and has set the scene for follow-up activities.

The offshore industry has been involved in several initiatives targeted at cost reduction; this experience will benefit wave energy system economics as developers seek to drive down costs – a key challenge for the next 3 to 4 years. Technology transfer of this type will be vital to wave power developments throughout the world.

R&D – The Way Forward

One effective way of planning future R&D needs is by use of the Roadmap – a diagram with a timeline, showing the main R&D targets and the associated events and activities, set against the timeline as a high-level plan. It displays the generic issues that must be addressed if wave power is to become commercially realisable in the next few years.

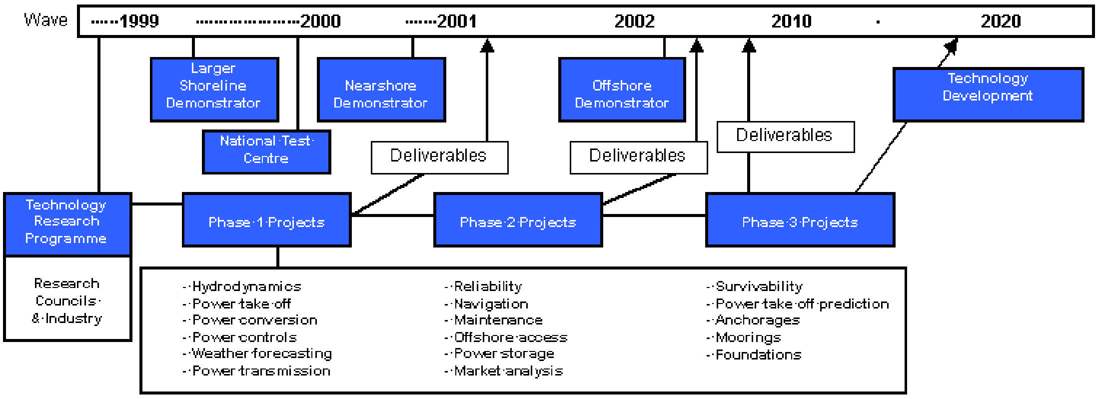


Figure 15.5: Roadmap of R&D targets and associated events and activities

At a more detailed level below this generic indication, there are a large number of topics to be tackled; a few of them are given here for illustrative purposes:

- moorings – long-term fatigue of lines and connections;
- standard couplings for quick-release and re-attachment of moorings and cables;
- standard flexible electrical connectors;
- reduced-cost production of cables, construction and laying offshore;
- modelling of arrays of multiple wave energy devices;
- real-time wave behaviour forecasting;
- environmentally acceptable fluids for hydraulic systems;
- direct-drive power generators;
- power-smoothing systems;
- electrical power storage techniques and devices.

Benefits would undoubtedly be gained from greater international collaboration on as many as possible of the pre-competitive aspects of R&D. At present, the EU funding opportunities provide a major incentive to encourage collaboration, but there is room for other mechanisms to bring the international wave community closer together and avoid duplication and waste.

The Road to Commercial Wave Power

Estimates of the forecast cost per unit of electricity for various wave devices were made by Thorpe (Ref. 2) in 1998. They show offshore and nearshore devices producing power in the 5-7 pence/kWh range (based on 8% discount rate). The trends shown in the same report show a halving in the predicted cost over a period of six or seven years. This is borne out by the experience of onshore wind energy costs, which have been seen to fall by a factor of five over 12 to 15 years. Based on these results, it is reasonable to expect that wave energy unit costs can be made to fall to the 2-3 pence/kWh range within 3 to 5 years.

The success or otherwise of meeting this trend will depend on several factors including:

- the ability of developers, manufacturers and installers to engineer-out cost from devices, especially as greater numbers are manufactured and deployed in arrays;
- the commitment of governments and local authorities to streamline planning and regulatory processes;
- the development of suitable approaches to grid connection, both for smaller "embedded" supplies and major power sources. This requires governments, electricity distributors and the financial community to collaborate in new ways;
- the flow of innovation from R&D on more cost-effective materials, design and construction methods;
- mechanisms being made available (under national electricity regulation regimes) to support specific emerging technologies with access to long-term contracts and/or to include wave power in capital grant mechanisms while the technologies mature;
- the ability of the wave power industry to show good practice in standardised independent testing and performance assessment methods from an early stage;
- the willingness of the financial community to recognise the key role of renewable energy technologies (including wave energy conversion) as a significant future proportion of the energy balance and to seek positively to invest into it.

Having focused on the need for many external agencies to find ways of tackling these challenges, it is incumbent upon the wave power device developers and the companies who will manufacture them and provide support services, to start to collaborate now. There is always more to be gained from collaboration than is ever lost by the "poaching" of ideas between collaborators. The way forward to commercial wave energy installations on a major scale will be highly sensitive to a proper degree of collaborative working. If it can be achieved, some very exciting things will be reported upon in the next WEC *Survey of Energy Resources*.

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COUNTRY NOTES

The Country Notes on wave energy have been compiled by the editors, drawing on a wide range of sources. At the present time the worldwide deployment of wave energy devices is small. Much research is being undertaken by universities, technical institutes and specialist engineering companies and it is these entities that have provided (either via their web sites or by direct communication) the majority of the information. Where available, notes provided by WEC Member Committees have been utilised and, where necessary, information taken from the *Survey of Energy Resources 1998* has been updated. The European Union and governmental organisations have provided the remainder.

AUSTRALIA

Following research undertaken in the early 1990's, Energetech Australia Pty Ltd. modelled and completed the testing phase of its Wave Energy System in 1997 at the New South Wales Water Research Laboratory. The basic concept of the Energetech system is the oscillating water column (OWC) but the company's Denniss-Auld turbine is specifically designed to be used in coastal situations where there is a deep-water harbour breakwater, or where rocky headlands/cliffs occur. It is a shoreline device that uses about 40 m of coastline. In addition to the turbine being suited to the oscillating airflows in OWC's, the system also employs a parabolic-shaped reflector to concentrate the wave resource on the OWC.

Energetech (in a BOO joint venture with commercial partner, Primergy) received a grant of A$ 750 000 under the Government's "Renewable Energy Commercialisation Program". Port Kembla, New South Wales was chosen to be the site for the development of a 300 kW wave generator (capable of operating at 500 kW). It is planned that construction of the first wave power plant using the Energetech technology will commence in early 2001 for completion by October 2001.

The US-based Ocean Power Technologies, Inc. (OPT) has developed a "smart" buoy. It has a computerised system encased in a watertight canister at the top, which allows an internal piston-like device to supply uniform power derived from the motion of the waves. The PowerBuoy is capable of generating about 20 kW of electricity, with the power being carried to shore via an underwater cable. At the beginning of 2001 and in conjunction with

Powercor Australia Ltd. and the Australian Greenhouse Office, OPT was reported to be in the process of installing a PowerBuoy unit off the coast of Victoria.

CHINA

Since the beginning of the 1980's China's wave energy research has concentrated mainly on fixed and floating oscillating water column devices and also the pendulum device. By 1995, the Guangzhou Institute of Energy Conversion (GIEC) of the Chinese Academy of Sciences had successfully developed a symmetrical turbine wave power generation device for navigation buoys (60 W). Over 650 units have been deployed in the past 13 years, mainly along the Chinese coast, with a few exported to Japan.

There are three main projects currently supported by the State Science and Technology Committee aiming to develop onshore wave power stations:

- a shoreline OWC: this is being undertaken by the GIEC. After problems encountered in considering the device for Nan'ao Island, construction was planned at Shanwei in Guangdong province of a two-chambered device with a total width of 20 m, rated at 100 kW_e. Power generation was scheduled to begin in 2000;
- a shoreline pivoting flap device (Pendulor) is being developed by Tianjin Institute of Ocean Technology of the State Oceanic Administration. The 0.05 MW device is reported to be under construction on Daguan Island in Shandong province;
- an experimental 3 kW shoreline OWC was installed on Dawanshan Island in the Pearl River estuary. This supplied electricity to the island community and, following its good performance, was upgraded with a 20 kW turbine. However, following a three month test run, technical problems forced the closure of the power station.

Fundamental research is continually supported by the Nature Science Fund of China and the Chinese Academy of Sciences. The main activities include:

- developing a new turbine for oscillating air flows;
- evaluating safety factors for the design of wave energy devices;
- time-domain modelling and control;
- non-linear hydrodynamic simulation;
- providing an information system for wave energy resources.

DENMARK

In 1998 the Danish Energy Agency launched the Danish Wave Energy Programme 1998-2004. The Programme has a maximum of 80 million Danish Krone at its disposal for broadly supporting development projects initiated by inventors, private companies, universities etc., covering a wide range of possible converter principles. The aim, by the end of the Programme, is to isolate one or several possible wave energy converter concepts as clear candidates for concentrated long-term development. Shallow waters around the Danish coast necessitate venturing offshore: however, at the present time a convincing concept to support this approach does not exist.

The scenario for renewable energy in the Danish Government's 1996 Plan of Action for Energy included the possible full-scale introduction of wave energy on a commercial basis by 2020, depending on the actual costs versus those of electricity from other renewable sources (offshore wind power and photovoltaics).

If a 150 km stretch of the Danish sector of the North Sea were to be covered by wave energy converters with an average efficiency level of 25%, annual net energy production would amount to 5 TWh, corresponding to 15% of the present domestic electricity consumption. To date, and working from a scale model, the Danish Wave Energy Programme has indicated an average efficiency level of up to 10%. However, significant potential exists for improvements in design and power take-off systems.

GREECE

During the 1990's Greece played a role in developing the European Wave Energy Atlas (see Portugal) and has subsequently been involved with the EU DGXII MAST 3 Project: Eurowaves, a computerised tool for the evaluation of wave conditions at any European coastal location.

INDIA

The Indian wave energy programme started in 1983 at the Institute of Technology (IIT) under the sponsorship of the Department of Ocean Development, Government of India. Initial research was conducted on three types of device: double float system, single float vertical system and the oscillating water column (OWC) but it was found that the OWC was the most suitable for Indian conditions: development activities have thus since concentrated on this type.

A 150 kW pilot OWC was built onto the breakwater of the Vizhinjam Fisheries Harbour, near Trivandrum (Kerala), with commissioning in October 1991. The scheme operated successfully, producing data that were used for the design of a superior generator and turbine. An improved power module was installed at Vizhinjam in April 1996 that in turn led to the production of new designs for a breakwater comprised of 10 caissons with a total capacity of 1.1 MW_e. The caissons are designed to be spaced at an optimum distance apart, in order to increase their overall capture efficiency to above that of a single caisson.

The National Institute of Ocean Technology succeeded IIT and continues to research wave energy, although the project on hydrodynamic aspects of the Backward Bent Ducted Buoy (a variant of the OWC design) that was being carried out at IIT has been completed.

INDONESIA

In 1998, following experience gained from Norwave's demonstration plant near Bergen and a feasibility study, a Norwegian team coordinated by Indonor AS and including Norwave AS, Groener AS and Oceanor ASA won a contract to deliver a Tapchan wave power plant.

The site, at Baron on the south coast of Java, utilises a bay with its own natural basin. The 1.1 MW wedge-groove plant will harness power from waves entering the 7-metre wide mouth, flowing down a narrowing channel, being forced over the walls of the basin (reservoir) and being returned to the sea via a conventional low-head turbine.

IRELAND

Wave energy research has been undertaken in Ireland since 1980, much of the work being conducted at University College Cork. In addition to the evaluation of the wave resource, modelling the hydrodynamics of wave energy devices, model testing and device design (primarily OWC's), the College has also co-ordinated the European Wave Energy Research Programme and has collaborated in the development of the European Wave Energy Atlas.

Wave energy funding, originally through the national Government, has latterly come through the EU's JOULE Programme.

In 1996, Hydam Technology deployed a 40 m long prototype McCabe Wave Pump (MWP) off the Irish coast. The device is a hinged-raft wave energy conversion system and having been studied both theoretically and experimentally, a commercial demonstration scheme is expected to be re-launched at Kilbaha, County Clare in early 2001. Funding has been provided by the Irish Marine Institute. This type of device has the advantage of being able to be installed in a variety of locations: it is not dependent on the type of coastline. Hydam Technology hopes that a potential order for two such devices to be sited off the east coast of India will come to fruition prior to end-2001.

During 1998, Wavegen of Inverness was awarded a contract under the Irish Government's Alternative Energy Requirement III (AER III). AER III offered a 15-year power purchase contract and EU infrastructure grant to site the company's near-shore OSPREY 2000 wave energy module off the coast. The funding was subsequently withdrawn and the project remains on hold.

JAPAN

Research into wave energy began in Japan with experiments in the 1940's and became significant during the late 1970's. Extensive research has been undertaken in Japan since then, with particular emphasis on the construction and deployment of prototype devices (primarily OWC's):

- a five-chambered OWC was built as part of the harbour wall at Sakata Port. The device became operational in 1989 but, after a test programme, only three air chambers were used for energy production. A turbogenerator module of 60 kW has been installed and is being used as a power generator unit for demonstration and monitoring purposes. This is expected to be replaced later by a larger and more powerful turbine (possibly 200 kW).
- in 1983, a 40 kW steel and concrete OWC was deployed on the shoreline structure at Sanze, for research purposes. This functioned for several years and was decommissioned and examined to investigate its resistance to corrosion and fatigue.
- a scheme that was operational between 1988 and 1997 comprised 10 OWC's installed in front of an existing breakwater at Kujukuri beach, Chiba Prefecture. The air emitted from each OWC was manifolded into a pressurised reservoir and used to drive a 30 kW turbine.
- a prototype 130 kW OWC was mounted in a breakwater serving the Haramachi coal-fired power station (Fukushima Prefecture) in 1996. This uses rectifying valves to control the flow of air to and from the turbine, in order to produce a steady power output. Experiments were conducted between 1996 and 1998.
- a floating OWC known as the Backward Bent Duct Buoy was deployed in Japan. It was similar to a conventional OWC but the opening faces towards the shoreline.
- the Pendulor wave energy device has been under investigation for over 15 years by the Muroran Institute of Technology. Wave action causes oscillation of the plate ("pendulor"), and the pendulor compresses fluid in a hydraulic power take-off. The second-generation prototype uses active control for efficient energy conversion.
- since 1987 the focus of Japan's wave energy research has been the "Mighty Whale". The 50 m long, 30 m wide, 12 m deep prototype was developed by the Japan Marine Science and Technology Center (JAMSTEC). As the world's largest floating OWC, it was inaugurated in mid-1998 at its mooring position just outside the mouth of Gokasho Bay (off Mie Prefecture). The overall rated power capacity was set at 110

kW and it was planned to test the device for a period of approximately two years. The device serves as a wave breaker: an area of calm water behind it was intended to be beneficial to fisheries and other forms of marine activities.

MALDIVES

The Government of the Maldives has announced that it intends to introduce wave energy power to the islands. Sea Power of Sweden has signed a letter of intent with the government to supply a floating wave power vessel.

If the first installation proves successful, the concept might be extended to cover the electricity requirements of other islands in the Maldives. There are more than 200 inhabited atolls in the group, located fairly far apart, with deep water in between. At present all power in the Maldives is provided by diesel generators: conceptually, a proportion of these might be replaced by floating wave power vessels tailored to the needs of each particular location.

NORWAY

Research into wave energy has, for the past 25 years, been centred on the Norwegian University of Science and Technology (NTNU), Trondheim. Two commercial schemes (a 350 kW_e Tapchan and a 500 kW_e OWC) operated successfully for a prolonged period during the 1980's. Both schemes have ceased to function and subsequently NTNU has conducted extensive theoretical research into optimum control and phase control of wave-energy converters.

Since 1994 NTNU has collaborated with Brødrene Langset AS to develop the Controlled Wave-Energy Converter. In 1998 ConWEC AS was formed to undertake further technical development, demonstration and global marketing.

Oceanor – Oceanographic Company of Norway ASA has played a leading role in the development of Eurowaves, a computerised tool for the evaluation of wave conditions at any European coastal location (see Country Note on Greece).

PORTUGAL

Since 1978 Portugal has played a significant role in wave energy R&D. This work has been undertaken at the Instituto Superior Técnico (IST) of the Technical University of Lisbon and the National Institute of Engineering and Industrial Technology (INETI) of the Portuguese Ministry of Economy. Most of the research on wave energy conversion has been devoted to OWC's. Early work concentrated on theoretical and experimental studies of the device hydrodynamics and the behaviour of Wells turbines (including monoplane and biplane rotors, as well as contra-rotating and variable-pitch designs). This has produced design codes for these turbines and plant control strategies.

In addition to resource assessment studies on a national level, INETI co-ordinated two projects for the European Union:

- development of a common methodology for resource evaluation and characterisation, which led to:
- production of the European Wave Energy Atlas for the deep water resource.

Plans to construct a full-size wave energy plant on the island of Pico in the Azores archipelago were initiated in 1986. This activity was later incorporated into the European Union's JOULE programme in 1991. This led to the development of a 400 kW_e shoreline

OWC, which was completed in 2000 and was expected to be commissioned in March 2001. Apart from being an R&D facility (primarily for testing different turbine designs and control strategies), the Pico plant will supply 8-9% of the island's demand for electricity for the next 25 years.

The Archimedes Wave Swing (AWS) is a system invented by Teamwork Technology BV, which is being developed by AWS BV, a joint venture of the utility NUON, Teamwork Technology and other Dutch interests. The device resembles a buoy, tethered below the surface of the sea. The periodic changing of pressure in a wave causes the upper part (floater) of the buoy to move up and down in the wave while the lower part (basement) stays in position. A full-scale 2 MW pilot project is currently under construction close to Viana do Castelo, a major seaport in the north of the country. Components are being manufactured in Romania and will be floated round to Portugal. Completion is anticipated by end-2001.

SWEDEN

Interproject Service AB of Sweden are working on their IPS/HP WEC Mark VII demonstration project. Following sea trials of the IPS converter in 1980-1981, the new concept is a combination of the IPS buoy and the Hose-Pump converter. The IPS wave power buoy consists of a floating buoy with a submerged vertical tube underneath. The tube is open to the sea at both ends and contains a piston working on the power take-off mechanism in the buoy. In waves, the buoy with the tube and the piston with the enclosed volume of water will oscillate in relation to each other. The H-P Converter consists of a buoy, a Hose-Pump and a damping plate. An H-P Wave Power Plant consists of a large number of converters interconnected via a connecting hose. This hose leads to a turbine/generator station in which the hydraulic power is converted to electric power.

Funding is being sought to finance the three phases of demonstration plants: a 15 kW prototype converter to be installed near Gothenburg in 2001-2002; a 150 kW grid-connected converter to be located in Scotland in 2001-2002 and a second 150 kW grid-connected converter located in Scotland in 2002-2003.

UNITED KINGDOM

At one time the UK had one of the largest government-sponsored R&D programmes on wave energy, covering a wide range of devices. However, this was greatly reduced in the early 1980's and most recent work has centred on a shoreline OWC system at Queen's University, Belfast (QUB).

QUB installed a prototype 75 kW research shoreline gully OWC on the island of Islay (off the west coast of Scotland) in 1990 and subsequently monitored and improved the design. In 1992, with European Union support, QUB, and a newly-formed company, Wavegen (the trading name of Applied Research and Technology [ART] of Inverness), worked jointly to develop the Land Installed Marine Powered Energy Transformer (LIMPET) device. LIMPET, a 0.5 MW OWC with Wells Turbine power take-off, successfully fed electricity into the UK national grid at end-2000. The station has secured a 15-year power purchase agreement with the major Public Electricity Suppliers in Scotland. Further modules will be added in a second stage of development.

Collaborative work between ART, QUB and several commercial companies led to the deployment of a nearshore 1 MW_e OWC called the OSPREY (Ocean Swell Powered Renewable EnergY). In addition to capturing wave energy, the device was specifically designed to serve as a foundation for a 1.5 MW wind turbine, representing an important synergy of renewable energy sources. In mid-1995 the prototype suffered damage and eventual failure before installation was complete. However, further research and re-design led to OSPREY 2000 and the announcement, in 1998, that Wavegen had gained the Irish Government's AER III (Alternative Energy Requirement III). The tender would have resulted in a 15-year power purchase contract but funding has not been forthcoming and the project is presently on hold.

Wavegen has also developed the Wind and Ocean Swell Power (WOSP) device. It is an integrated nearshore wave- and wind-powered station and is designed to operate in much the same way as the OSPREY 2000 device.

As part of the Edinburgh Wave Project, a Wide Wave Tank was constructed for research purposes in 1977 at the University of Edinburgh. Work has continued, primarily with support from the European Commission, and has concentrated on the design and manufacture of high-efficiency, computer-controlled power take-off systems.

Ocean Power Delivery Ltd. (OPD), of Edinburgh, was established at the beginning of 1998. The company was awarded a contract to install two 375 kW pelamis devices within the Scottish Renewables Obligation Third Order (SRO3). The pelamis is a general deployment offshore device (see Commentary above). The two full-scale prototype devices are expected to be installed in 2002 and will be located in Machir Bay, Islay. The electricity will be fed via an undersea cable to shore and grid-connected on shore. OPD is also involved in a feasibility study of the future deployment of the first wave farms.

Early in 1999, Sea Power International AB of Sweden signed a 15-year contract with Scottish Power and Southern Energy for the delivery of electricity to the Shetland Islands. In September 2000, the Swedish arm of Sea Power established Sea Power of Scotland Ltd. in Inverness to facilitate the execution of the project. The system is based on established technology from the shipbuilding and hydro-electric power industries and a fully-functioning but non-commercial pilot system has been demonstrated in Gothenburg. Construction of the island's floating wave energy power station at a site 500 m off Mu Ness, is expected to commence during 2001 with operations beginning in summer 2002.

Sea Power is also studying the possibility of a joint venture to participate in the construction of a wave power station off the coast of Cornwall.

It was reported in mid-2000 that the University of Plymouth (south-west England), on behalf of Embley Energy Ltd., is conducting tests on a unique, free-floating buoy (consisting of multiple water columns) in Plymouth Sound.

UNITED STATES OF AMERICA

At the present time wave energy conversion has not been commercially deployed in the USA. Although several industrial companies have tested a range of prototype devices, activities in recent years have been confined to regional studies by coastal utilities and state government agencies. Several sites for small projects have been identified on the Californian coast but there are currently no firm plans to exploit any of them.

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Chapter 16

OCEAN THERMAL ENERGY CONVERSION

Ocean Thermal Energy Conversion (OTEC) is a means of converting into useful energy the temperature difference between surface water of the oceans in tropical and sub-tropical areas, and water at a depth of approximately 1 000 metres which comes from the polar regions. For OTEC a temperature difference of 20^{o}C is adequate, which embraces very large ocean areas, and favours islands and many developing countries. The continuing increase in demand from this sector of the world (as indicated by World Energy Council figures) provides a major potential market.

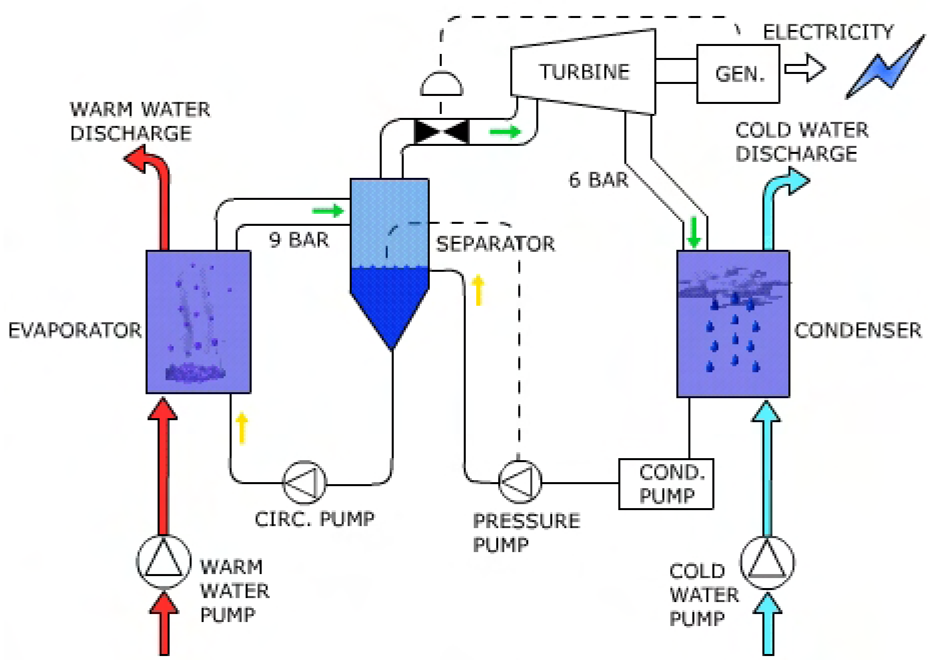

Figure 16.1: Ocean Thermal Energy Conversion (Source: Petroleum Corporation of Jamaica)

Depending on the location of their cold and warm water supplies, OTEC plants can be land-based, floating, or – as a longer term development – grazing. Floating plants have the advantage that the cold water pipe is shorter, reaching directly down to the cold resource, but the power generated has to be brought ashore, and moorings are likely to be in water depths of, typically, 2 000 metres. The development of High Voltage DC transmission offers substantial advantage to floating OTEC, and the increasing depths for offshore oil and gas production over the last decade mean that mooring is no longer the problem which it once was – but still a significant cost item for floating OTEC. Land-based plants have the advantage of no power transmission cable to shore, and no mooring costs. However, the cold water pipe has to cross the surf zone and then follow the seabed until the depth reaches approximately 1 000 metres – resulting in a much longer pipe which has therefore greater friction losses, and greater warming of the cold water before it reaches the heat exchanger, both resulting in lower efficiency.

The working cycle may be closed or open, the choice depending on circumstances. All these variants clearly develop their power in the tropical and sub-tropical zones, but a longer-term development – a grazing plant – allows OTEC energy use in highly developed economies which lie in the world's temperate zones. In this case the OTEC plant is free to drift in ocean areas with a high temperature difference, the power being used to split sea water into liquid hydrogen and liquid oxygen. The hydrogen, and in some cases where it is economic the oxygen too, is offloaded to shuttle tankers which take the product to energy-hungry countries. So, in time, all the world can benefit from OTEC, not just tropical and sub-tropical areas.

A further benefit of OTEC is that, unlike most renewable energies, it is base-load – the thermal resource of the ocean ensures the power source is available day or night, and with only modest variation from summer to winter. It is environmentally benign, and some floating OTEC plants would actually result in net CO_2 absorption. A unique feature of OTEC is the additional products which can readily be provided – food (aquaculture and agriculture); potable water; air conditioning; etc. (see Figure 16.2). In large part these arise from the pathogen-free, nutrient-rich, deep cold water. OTEC is therefore the basis for a whole family of Deep Ocean Water Applications (DOWA), which can also benefit the cost of generated electricity. Potable water production alone can reduce electrical generating costs by up to one third, and is itself in very considerable demand in most areas where OTEC can operate.

The relevance of environmental impact was given a considerable boost by the Rio and Kyoto summits, and follow-up actions have included a much greater emphasis on this aspect by a number of energy companies. Calculations for generating costs now take increasing account of "downstream factors" – for example the costs associated with CO_2 emissions. With such criteria included, OTEC/DOWA is becoming an increasingly attractive option. Even without this aspect, the technological improvements – such as the much smaller heat exchangers now required – have contributed to significantly reduced capital expenditure. On top of these two factors the world-wide trend to whole-life costing benefits all renewables when compared with those energy systems which rely on conventional fuels (and their associated costs), even when the higher initial maintenance costs of early OTEC/DOWA plants are taken into account. When compared with traditional fuels the economic position of OTEC/DOWA is now rapidly approaching equality, and work in Hawaii at the Pacific International Center for High Technology Research has contributed to realistic comparisons, as well as component development.

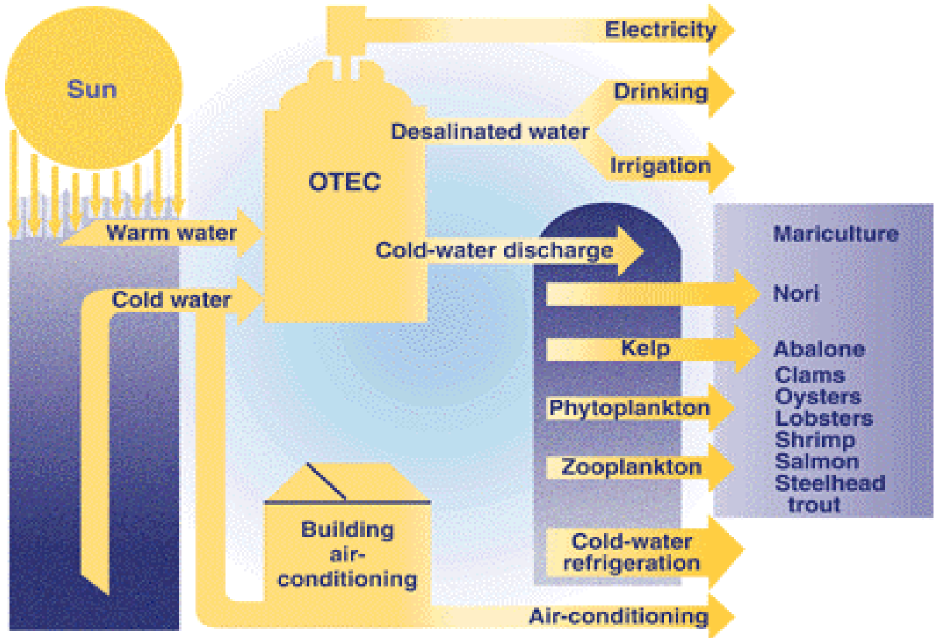

Figure 16.2: OTEC Applications (Source: US National Renewable Energy Laboratory)

Nations which previously might not have contemplated OTEC/DOWA activities have been given legal title over waters throughout the 200 nautical mile Exclusive Economic Zone (EEZ) associated with the UN Convention on the Law of the Sea (UNCLOS). Prior to that no investor – private or public – would seriously contemplate funding a new form of capital plant in such seas and oceans, but since UNCLOS a number of nations have worked steadily to prepare overall ocean policies and recent years have seen a number of these introduced – for example in Australia.

Despite the existence of EEZs, the low costs of many “traditional” energy resources in the recent past had not encouraged venture capital investment in OTEC/DOWA, but the currently higher costs of oil, plus the growing recognition of environmental effects noted above (and the associated costs) of some traditional fuels, are rapidly changing the economics of these in relation to OTEC/DOWA and other renewables. Technology transfer is a major factor in many maritime activities and OTEC/DOWA is no exception, in this case borrowing from the oil and gas industry – again as already noted.

It is *all* these factors which now place OTEC/DOWA within realistic reach of full economic commercialisation early in the 21st century. But, whilst a number of the components for an OTEC/DOWA plant are therefore either available, or nearly so, the inherent simplicity of a number of key elements of OTEC/DOWA still require refinement into an effective system, and this will need further R&D investment. Before OTEC/DOWA can be realised, this R&D must be completed to show clearly to potential investors, via a demonstration-scale plant, that the integrated system operates effectively, efficiently, economically, and safely.

(Source: Luis A. Vega, Ph.D. Project Director)

Figure 16.3: 210kW OC-OTEC Experimental Plant (1993-1998) in Hawaii

Until such a representative-scale demonstrator plant is built and successfully operated, conventional capital funds are unlikely to be available. Whilst, therefore, the establishment of renewable energy subsidiaries of energy companies is important, there is no doubt that the principal hurdle remaining for OTEC/DOWA is not economic or technical, but the convincing of funding agencies – such as the World Bank or the European Development Bank – that these techno-economic values are sufficiently soundly based for the funding of a demonstrator.

Specific national activities are referred to in the Country Notes which follow, but mention should be made here of Taiwan, China, which initiated and still hosts The International OTEC/DOWA Association (IOA), and which among other activities produces a regular Newsletter (Ref. 1) dealing with the subject of OTEC/DOWA. Over a lengthy period Taiwan, China has been extensively evaluating its DOWA/OTEC resource and a number of candidate sites for land-based OTEC and aquaculture were evaluated on the east coast. In 1995 a Master Plan was prepared for an extensive and ambitious floating OTEC programme, again for the east coast, an early stage of which would be a demonstrator, and extensive international review of these concepts was obtained.

In Europe, both the European Commission and the industrially based Maritime Industries Forum examined OTEC opportunities with relevance to DOWA in general rather than just OTEC, and in 1997 the UK published its Foresight document for the marine sector (Ref. 2), looking five to twenty years ahead, and both OTEC and DOWA were included in the energy sector of the paper (Ref. 3). It is significant that the emphasis in the recommendations from all three European groupings has, again, been on the funding and construction of a demonstrator. It is recommended to be in the 5-10 MW range, and remains the highest single priority.

A further indication of the interest in DOWA, rather than OTEC alone, is provided by Japan where the industrial OTEC Association was succeeded by the Japan Association of Deep Ocean Water Applications. More recently there has been joint Indian/Japanese work.

The island opportunities have already been mentioned, and in addition to Japan and Taiwan, the European work has stressed these as the best prospects, and it is noteworthy that both Japanese and British evaluations have identified Fijian prime sites, one each on the two largest islands of that group.

The worldwide market for renewables has been estimated (Ref. 4) for the timescales from 1990 to 2020 and 2050, with three scenarios, and all show significant growth. Within those total renewable figures, opportunities exist for the construction of a significant amount of OTEC capacity, even though OTEC may account for only a small percentage of total global electricity generating capacity for some years. Estimates have been made by French, Japanese, British and American workers in the field, suggesting worldwide installed power of up to 1 000 OTEC plants by the year 2010, of which 50 % would be no larger than 10 MW, and less than 10 % would be of 100 MW size. On longer timescales the demand for OTEC in the Pacific/Asia region has been estimated at 20 GW in 2020 and 100 GW in 2050 (Ref. 5). But, again, realisation of all these numbers depends on the operation of the demonstrator at an early date.

In short, the key breakthrough now required for OTEC/DOWA is no longer technological or economic, but the establishment of confidence levels in funding agencies to enable building of a representative-scale demonstration plant. Given that demonstrator, the early production plants will be installed predominantly in island locations where conventional fuel is expensive, or not available in sufficient quantity, and where environmental impact is a high priority. Both simple OTEC and OTEC/DOWA combined plants will feature, depending on the particular requirements of each nation state.

It can now realistically be claimed that the economic commercialisation of OTEC/DOWA is close – the demonstrator plant is likely to be built in the early years of the new century, and the higher profile of the IOA since 1995 is an indication of the "coming of age" of OTEC/DOWA resource recovery and exploitation.

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COUNTRY NOTES

The Country Notes on OTEC compiled for the WEC *Survey of Energy Resources 1998* have been revised, updated and augmented by the editors, using national sources and other information. Valuable inputs were provided by Don Lennard of Ocean Thermal Energy Conversion Systems Ltd. and by the International OTEC/DOWA Association (via its *Newsletter*).

COTE d'IVOIRE

A French project to build two open-cycle onshore OTEC plants of 3.5 MWe each in Abidjan (Côte d'Ivoire, at that time a French possession) was proposed in 1939. The experimentation was eventually undertaken after World War II, with the main research effort occurring during 1953-1955.

The process of producing desalinated water via OTEC proved to be uneconomic and the project was abandoned in 1958.

CUBA

This was the site of the first recorded installation of an OTEC plant and the island remains a very desirable location in terms of working temperature difference (in excess of 22°C). Georges Claude, a French engineer, built an experimental open-cycle OTEC system (22 kW gross) at Matanzas in 1929-1930. Although the plant never produced net electrical power (i.e. output minus own use) it demonstrated that the installation of an OTEC plant at sea was feasible. It did not survive for very long before being demolished by a storm.

FIJI

This group of islands has been the subject of OTEC studies in the UK and in Japan. In 1982 the UK Department of Industry and relevant companies began work on the development of a floating 10 MW closed-cycle demonstration plant to be installed in the Caribbean or Pacific. The preferred site was Vanua Levu in Fiji.

At end-1990 a Japanese group undertook an OTEC site survey on the Fijian island of Vitu Levu. Design work on an integrated (OTEC/DOWA) land-based plant was subsequently undertaken.

The studies have not given rise to any firm construction project. However, when the tourist industry resumes (following the political problems of recent years), the Vanua Levu site will again be ideal, with cold deep water less than 1 km from shore. The development of the tourist industry will require substantial electrical power, potable water and refrigeration.

FRENCH POLYNESIA

Feasibility studies in France concluded that a 5 MW land-based pilot plant should be built with Tahiti as the test site. An industrial grouping, Ergocean and IFREMER (the French institute for research and exploitation of the sea) undertook extensive further evaluation (of both closed and open cycle) and operation of the prototype plant was initially expected at the end of the 1980's, but the falling price of oil caused development to be halted. IFREMER continues to keep the situation under review and has been active in the European Union.

Specifically, IFREMER with various partners has examined DOWA desalination, since a much smaller (1 metre diameter) cold water pipe would be needed. Techno-economic studies have been completed but further development is on hold.

GUADELOUPE

Experimental studies on two open-cycle plants were undertaken by France between the mid-1940's and the mid-1950's in Abidjan, Côte d'Ivoire - at that time a French possession. The results of these studies formed the basis of a project to build an OTEC plant in Guadeloupe (an Overseas Department of France) in 1958. This onshore 3.5 MWe OTEC plant was intended to produce desalinated water but the process proved to be uneconomic and the project was abandoned in 1959.

INDIA

Conceptual studies on OTEC plants for Kavaratti (Lakshadweep islands), in the Andaman-Nicobar Islands and off the Tamil Nadu coast at Kulasekharapatnam were initiated in 1980. In 1984 a preliminary design for a 1 MW (gross) closed Rankine Cycle floating plant was prepared by the Indian Institute of Technology in Madras at the request of the Ministry of Non-Conventional Energy Resources. The National Institute of Ocean Technology (NIOT) was formed by the governmental Department of Ocean Development in 1993 and in 1997 the Government proposed the establishment of the 1 MW plant of earlier studies. NIOT signed a memorandum of understanding with Saga University in Japan for the joint development of the plant near the port of Tuticorin (Tamil Nadu).

It has been reported that following detailed specifications, global tenders were placed at end-1998 for the design, manufacture, supply and commissioning of various sub-systems. The objective is to demonstrate the OTEC plant for one year, after which it could be moved to the Andaman & Nicobar Islands for power generation. NIOT's plan is to build 10-25 MW shore-mounted power plants in due course by scaling-up the 1 MW test plant, and possibly a 100 MW range of commercial plants thereafter.

INDONESIA

A study was carried out in the Netherlands for a 100 kW (net power) land-based OTEC plant for the island of Bali, but no firm project has resulted.

JAMAICA

In 1981 it was reported that the Swedish and Norwegian Governments, along with a consortium of Scandinavian companies, had agreed to provide the finance required for feasibility studies towards an OTEC pilot plant to be located in Jamaica.

In a reference to OTEC, the National Energy Plan (circa 1981) stated that "a 10 MW plant was envisioned in the late 1980's". Although this project never came to fruition, a plan remains in place for an offshore 10 MW plant producing energy and fresh water. For implementation to take place, purchasing agreements from the power and water utility companies need to be in place.

JAPAN

Research and development on OTEC and DOWA has been carried out since 1974 by various organisations (Ocean Thermal Energy Conversion Association of Japan; Ocean Energy Application Research Committee, supported by the National Institute of Science and Technology Policy; Japan Marine Science and Technology Center, Deep Seawater Laboratory of Kochi; Research Institute for Ocean Economics and Toyama prefectural government; Saga University; Electrotechnical Laboratory and Shonan Institute of Technology).

Saga University conducted the first OTEC power generation experiments in late-1979 and in early-1980 the first Japanese experimental OTEC power plant was completed in Imari City.

During the summer months of 1989 and 1990 an Artificial Up-welling Experiment was conducted on a barge anchored on the seabed at 300 m offshore in Toyama Bay.

With the establishment in 1988 of the OTEC Association of Japan, now the Japan Association of Deep Ocean Water Applications (JADOWA), the country has placed greater emphasis on products that use deep ocean water in the manufacturing process. Such products (food and drink, cosmetics and salt) have all proved commercially successful.

In March 1996, a Memorandum of Understanding was signed between Saga University and the National Institute of Ocean Technology of India. The two bodies have been collaborating on the design and construction of a 1 MW plant to be located off the coast of Tamil Nadu in India.

KIRIBATI

During late-1990, an OTEC industrial grouping in Japan undertook detailed research (including the water qualities of the ocean, seashore, lagoon and lakes) on Christmas Island. Following on from this research, the basic concepts were improved but no developments have ensued.

MARSHALL ISLANDS

In the early-1990's the Republic of the Marshall Islands invited proposals from US companies to undertake a detailed feasibility study for the design, construction, installation and operation of a 5-10 MW (net) OTEC power plant to be located at Majuro.

The contracted study was carried out by Marine Development Associates of California between April 1993 and April 1994 but no project resulted.

NAURU

In 1981, the Tokyo Power Company built a 100 kW shore-based, closed-cycle pilot plant on the island of Nauru. The plant achieved a net output of 31.5 kWe during continuous operating tests. This plant very effectively proved the principle of OTEC in practical terms over an extended period, before being decommissioned.

NETHERLANDS ANTILLES

A feasibility study carried out by Marine Structure Consultants of the Netherlands and funded by the Dutch Government for the Netherlands Antilles Government examined the competitiveness of a 10 MW floating OTEC plant. No development ensued.

NEW CALEDONIA

IFREMER (the French institute for research and exploitation of the sea) has re-examined a previous proposal to establish a test site for OTEC/DOWA in New Caledonia.

PUERTO RICO

A resource assessment conducted in 1977 studied the potential for a nearshore OTEC plant. In 1997 a new evaluation concluded that a closed-cycle, land-based OTEC plant of up to 10 MW was feasible, especially with the inclusion of DOWA. The headland of Punta Tuna on the south-east coast of the island satisfied the criteria for such a plant.

SRI LANKA

Interest in OTEC and DOWA has been revived by the National Aquatic Resources Agency in Colombo, in the context of making use of Sri Lanka's Exclusive Economic Zone (EEZ), which is some 27 times its land area.

Three submarine canyons (Panadura, Dondra and Trincomalee) have been identified as highly suitable sites for OTEC plants and the production of electricity. However, despite successful experiments conducted during 1994, a lack of funding has meant that any proposals have stagnated.

ST LUCIA

In 1983, as a part of a commitment to develop alternative energy systems, the Government of St. Lucia welcomed the opportunity to be part of an OTEC initiative that included the design and construction of a 10 MW closed cycle floating OTEC demonstration plant off Soufriere. Hydrographic surveys in 1985 confirmed that the 1 000 metre contour was less than 3 km from shore, with cold water in the volcanic canyon adjacent to Petit Piton and Gros Piton. This landfall was also close to the electrical grids. The surface temperature of the sea on that part of the west coast never falls below 25^{o}C, reaching 27^{o}/28^{o}C in summer.

The UK-designed plant was provided with a fully costed proposal by a merchant bank, which showed that with construction commencing in 1985, and operation from 1989, the OTEC plant would show a cost benefit over oil-fired plant from 1994, the higher capital cost of OTEC being balanced by the "free fuel", whereas there were ongoing fuel costs for the diesel plant. However, the final decision was to go for a diesel plant, with the whole of the capital cost being funded by another country.

TAIWAN, CHINA

The seas off eastern Taiwan are considered to be highly favourable for OTEC development. Following preliminary studies during the 1980's, three near-shore sites were selected and the steeply shelving east coast was thought to be able to accommodate an on-shore OTEC plant. However, only one site (Chang-Yuan) was deemed suitable for further investigation by the Institute of Oceanography.

In 1989, the Pacific International Center for High Technology Research in Hawaii prepared a development plan for the Taiwanese *Multiple Product Ocean Thermal Energy Conversion Project* (MPOP). The intention of the MPOP was to construct a 5 MW closed-cycle pilot plant for generating power and also the development of mariculture, desalinated water, air conditioning, refrigeration and agriculture. It was thought that the operating data obtained from the pilot plant could be used in the building of a 50-100 MW commercial plant. In 1993 it was assumed that six years would be required for site preparation and five years for construction (to be in operation by end-2003), with the plant having a 25-year life cycle.

During the 1990's the concept of MPOP changed to a *Master OTEC Plan for R.O.C.* (MOPR), with the objective of ultimately establishing eight 400 MW floating OTEC power plants.

With its positive interest, Taiwan was the initiator, in 1989, of the International OTEC/DOWA Association (IOA). A permanent Taiwanese secretariat has worked to ensure a higher international profile for OTEC/DOWA, but within the country, plans for OTEC have, at present, somewhat stagnated.

UNITED STATES OF AMERICA

Hawaii remains the focus of US activity in OTEC/DOWA, primarily through work carried out at the Natural Energy Laboratory of Hawaii (NELHA) facility at Keahole Point.

In 1979 "Mini-OTEC", a 50 kW_e closed-cycle demonstration plant, was set up at NELHA. It was the world's first net power producing OTEC plant, installed on a converted US Navy barge moored 2 km offshore: it produced 10-17 kW of net electric power.

In 1980 the Department of Energy constructed a test facility (OTEC-1) for closed-cycle OTEC heat exchangers on a converted US Navy tanker. It was not designed to generate electricity.

In the early 1980's a 40 MW OTEC pilot plant was designed. It was to be sited on an artificial island off the Hawaiian coast. However, funding was not forthcoming and the plant was not constructed.

An experimental 210 kW (gross electrical) open-cycle OTEC plant was designed and operated by the Pacific International Center for High Technology Research (PICHTR) at Keahole Point. It produced a record level of 50 kW of net power in May 1993, thus exceeding the 40 kW net produced by a Japanese OTEC plant in 1982. The plant operated from 1993 until 1998 and its primary purpose was to gather the necessary data to facilitate the development of a commercial-scale design. Following the experiments, the plant was demolished in January 1999.

A further PICHTR experiment at NELHA employed a closed-cycle plant to test specially developed aluminium heat exchangers. It used the (refurbished) turbine from "Mini-OTEC" to produce 50 kW gross power. During initial operation in May 1996, corrosion leaks developed in the heat exchanger modules; the plant had to be shut down and the units re-manufactured. From October 1998, when the new units were received until end-1999 – the end of the project - data were collected on the heat exchange and flow efficiencies of the heat exchangers and thus on the economic viability of competing types of heat exchangers.

In addition to research into ocean thermal energy, NELHA has established an ocean science and technology park at Keahole Point. Cold deep seawater is pumped to the surface and utilised for the production of energy, air-conditioning, desalination, fish farming, agriculture, etc. A new seawater system to serve the park is scheduled for completion in December 2001. The pipelines will primarily serve the park's companies involved in aquaculture and pharmaceutical manufacture but two companies are preparing proposals to construct an OTEC plant that will provide electricity to power the pumps.

US VIRGIN ISLANDS

The island of St Croix has been found to be a suitable site for the development of OTEC-produced electricity and desalinated water.

In the early 1990's an agreement was drawn up between the US company GenOtec and the Virgin Islands Water and Power Authority (WAPA). The plan was to obtain 5 MW of OTEC-produced electricity and 1.5 million gallons/day of desalinated water from a land-based, closed-cycle OTEC plant. Additionally, various mariculture industries were planned. The project did not come to fruition.

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Chapter 17

MARINE CURRENT ENERGY

Resources

The global marine current energy resource is mostly driven by the tides and to a lesser extent by thermal and density effects. The tides cause water to flow inwards twice each day (flood tide) and seawards twice each day (ebb tide) with a period of approximately 12 hours and 24 minutes (a semi-diurnal tide), or once both inwards and seawards in approximately 24 hours and 48 minutes (a diurnal tide). In most locations the tides are a combination of the semi-diurnal and diurnal effects, with the tide being named after the most dominant type.

The strength of the currents vary, depending on the proximity of the moon and sun relative to Earth. The magnitude of the tide-generating force is about 68% moon and 32% sun due to their respective masses and distance from Earth (Open University, 1989). Where the semi-diurnal tide is dominant, the largest marine currents occur at new moon and full moon (spring tides) and the lowest at the first and third quarters of the moon (neap tides). With diurnal tides, the current strength varies with the declination of the moon (position of the moon relative to the equator). The largest currents occur at the extreme declination of the moon and lowest currents at zero declination. Further differences occur due to changes between the distances of the moon and sun from Earth, their relative positions with reference to Earth and varying angles of declination. These occur with a periodicity of two weeks, one month, one year or longer, and are entirely predictable (Bernshtein et al, 1997).

Generally the marine current resource follows a sinusoidal curve with the largest currents generated during the mid-tide. The ebb tide often has slightly larger currents than the flood tide. At the turn of the tide (slack tide), the marine currents stop and change direction by approximately 180°.

The strength of the marine currents generated by the tide vary, depending on the position of a site on the earth, the shape of the coastline and the bathymetry (shape of the sea bed). Along straight coastlines and in the middle of deep oceans, the tidal range and marine currents are typically low. Generally, but not always, the strength of the currents is directly related to the tidal height of the location. However, in land-locked seas such as the Mediterranean, where the tidal range is small, some sizeable marine currents exist.

There are some locations where the water flows continuously in one direction only, and the strength is largely independent of the moon's phase. These currents are dependent on large thermal movements and run generally from the equator to cooler areas. The most obvious example is the Gulf Stream, which moves approximately 80 million cubic metres of water per second (Gorlov, 1997). Another example is the Strait of Gibraltar where in the upper layer, a constant flow of water passes into the Mediterranean basin from the Atlantic (and a constant outflow in the lower layer).

Areas that typically experience high marine current flows are in narrow straits, between islands and around headlands. Entrances to lochs, bays and large harbours often also have high marine current flows (EECA, 1996). Generally the resource is largest where the water depth is relatively shallow and a good tidal range exists. In particular, large marine current flows exist where there is a significant phase difference between the tides that flow on either side of large islands.

There are many sites world-wide with velocities of 5 knots (2.5 m/s) and greater. Countries with an exceptionally high resource include the UK (E&PDC, 1993), Ireland, Italy, the Philippines, Japan and parts of the United States. Few studies have been carried out to determine the total global marine current resource, although it is estimated to exceed 450 GW (Blue Energy, 2000).

Status of Technology

Useful energy can be generated from marine currents using completely submerged turbines comprising of rotor blades and a generator. Water turbines work on the same principle as wind turbines by using the kinetic energy of moving fluid and transferring it into useful rotational and electrical energy. The velocities of the currents are lower than those of the wind, however owing to the higher density of water (835 times that of air) water turbines are smaller than their wind counterparts for the same installed capacity.

The power that is able to be extracted from the currents is dependent on the velocity of the water flow and the area and efficiency of the water turbine, and can be calculated as follows:

$$Power = \frac{1}{2}\rho \mathrm{A} v^3 C_p$$

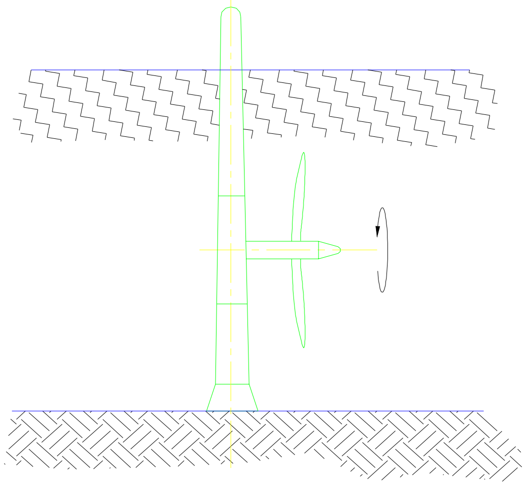
where ρ is the density of sea water (1025 kg/m^3)
A is the area of the rotor blades (m^2)
v is the marine current velocity (m/s)
C_p is the power coefficient, a measure of the efficiency of the turbine

Marine current energy is at an early stage of development, with only a small number of prototypes and demonstration units having been tested to date. There are no commercial grid-connected turbines currently operating. A number of configurations have been tested on a small scale that are essentially marinised wind turbines. Generally speaking, turbines are either horizontal axis or vertical axis turbines. Variants of these two types have been investigated, including turbines using concentrators or shrouds, and tidal fences.

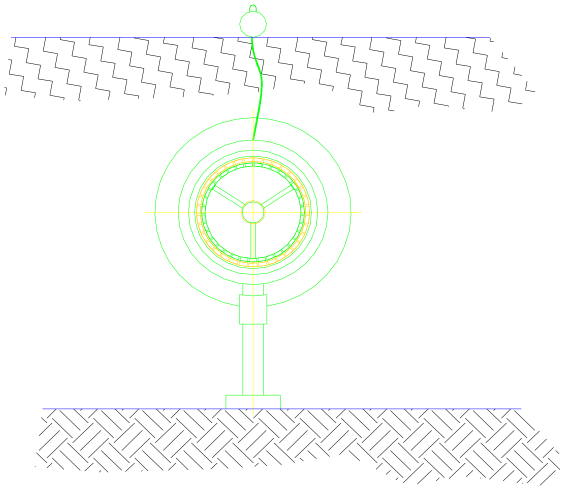
- **Horizontal axis turbines** (axial flow turbine). This is similar in concept to the widespread horizontal axis wind turbine. Prototype turbines of up to 10 kW have been built and tested using this concept. There are currently plans to install a demonstration machine of 300 kW off the south coast of the United Kingdom (MCT, 2000).

  Concentrators (or shrouds) may be used around the blades to increase the flow and power output from the turbine. This concept has been tested on a small scale in a number of countries, including New Zealand (Rudkin, 2001).

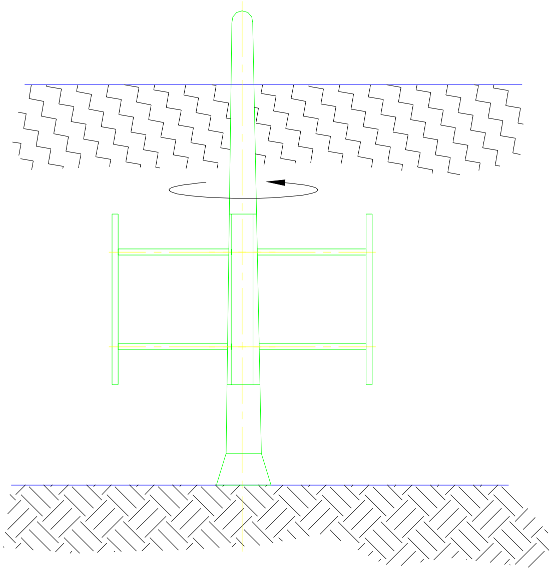
- **Vertical axis turbines** (cross flow turbine). Both drag and lift turbines have been investigated, although the lift devices offer more potential. The best-known example is the Darrieus turbine with three or four thin blades of aerofoil cross-section. Some stand-alone prototypes have been tested, including a 5 kW Darrieus turbine in the Kurushima Straits, Japan. The concept of installing a number of vertical axis turbines in a tidal fence is being pursued in Canada, with plans to install a 30 MW demonstration system in the Philippines (Blue Energy, 2000).



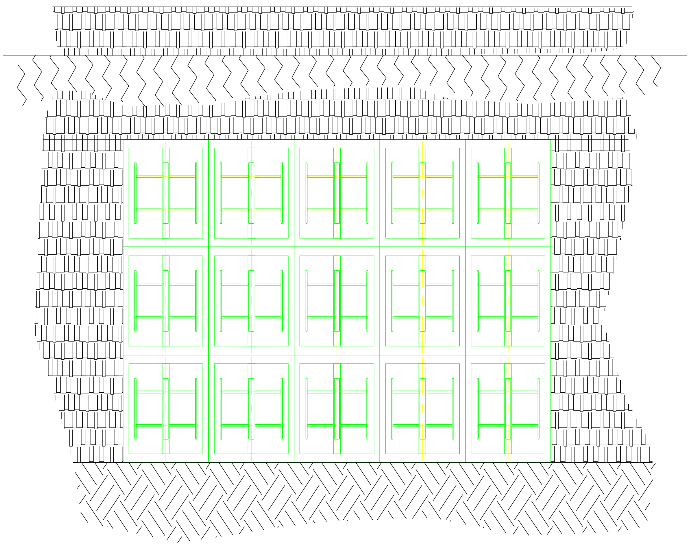
Horizontal axis turbine (axial flow)



Horizontal axis shrouded turbine



Vertical axis turbine (cross flow)



Vertical axis tidal fence

In order for marine current energy to be utilised, a number of potential problems will need to be addressed, including:

- Avoidance of cavitation by reducing tip speeds to approximately 8 m/s. This suggests a turbine with a higher solidity than a wind turbine;
- Prevention of marine growth building up on the blades or ingress of debris;
- Proven reliability, as operation and maintenance costs are potentially high;

- Corrosion resistance, bearing systems and sealing;

Turbines may be suspended from a floating structure or fixed to the sea bed. In large areas with high currents, it will be possible to install water turbines in groups or clusters to make up a marine current farm, with a predicted density of up to 37 turbines per square km. This is to avoid wake-interaction effects between the turbines and to allow for access by maintenance vessels (DTI, 1999).

As there are currently no commercial turbines in operation, it is difficult to assess the cost of energy and competitiveness with other energy sources. Initial studies suggest that for economic exploitation, velocities of at least 2 m/s (4 knots) will be required, although it is possible to generate energy from velocities as low as 1 m/s. As the technology matures and with economies of scale, it is likely that the costs will reduce substantially.

Future of Marine Current Energy

Compared with other renewable technologies, there has been little research into utilising marine current energy for power generation. However, in principle marine current energy is technically straightforward and may be exploited using systems based on proven engineering components (FMP, 1999). In particular, knowledge gained from the oil and gas industry, the existing hydro industry and the emerging wind energy industry can be used to overcome many of the hurdles facing marine current energy.

The global marine current energy resource is very large, and it has a number of advantages over other renewables. Figure 17.1 shows a comparison of the marine current energy resource with other renewables and conventional energy sources. It is clear that there are many benefits to utilising marine current energy, including:

- The resource has four times the energy density of a good wind site, so the diameter of water turbines can be less than half that of a wind turbine for the same energy output;
- The water velocities and therefore power outputs are completely predictable, once accurate site measurements have been taken;
- Water turbines will not need to be designed for extreme atmospheric fluctuations as required with wind turbines, meaning that the design can be better cost-optimised;
- With increased conflicts over land use, water turbines offer a solution that will not occupy land and has minimal or zero visual impact;
- The greatest resource is in close proximity to coastlines and many areas with high population densities;
- The technology is potentially modular and avoids the need for large civil engineering works.

The environmental impact resulting from marine current energy use is likely to be minimal. Project planning will need to be cognisant of species protection including fish and marine mammals, although since the blade velocities and pressure gradients are low this is unlikely to cause any serious problems (Fraenkel, 1999). In siting turbines, consideration of shipping routes and present recreational uses such as fishing and diving will be required. It may be necessary to establish fishery exclusion zones.

Figure 17.1: Comparison of marine current energy with other energy resources

	Renewable resource	Low capital cost	Low running cost	Minimal environmental impact	Predictable	Minimal visual impact	Modular
Fossil	✘	✔	✘	✘	✔	✘	✘
Nuclear	✘	✔	✘	✘	✔	✘	✘
Wind	✔	✘	✔	✔	✘	✘	✔
Solar	✔	✘	✔	✔	✘	✘	✔
Hydro	✔	✔	✔	✘	✔	✘	✘
Wave	✔	✘	✔	✔	✘	✔	✔
Marine Current	✔	✘	✔	✔	✔	✔	✔

The table shows that marine current energy is one of the most promising new renewable energy sources, and is deserving of further investment. Furthermore, the know-how is now available to combine existing technologies to utilise marine current energy for power generation.

It is likely that water turbines will initially be deployed in island or coastal communities with strong marine currents and which are isolated from national grid systems, where they are most likely to offer a cost-effective alternative. However, marine currents have the potential to supply significant quantities of energy into the grid systems of many countries. As interest grows, marine current energy is likely to play an increasing role in complementing other energy technologies and contributing to the future global energy supply mix.

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ABBREVIATIONS AND ACRONYMS

10^3	kilo (k)
10^6	mega (M)
10^9	giga (G)
10^{12}	tera (T)
10^{15}	peta (P)
10^{18}	exa (E)
AC	alternating current
API	American Petroleum Institute
b/d	barrels/day
bbl	barrel
bcm	billion cubic metres
billion	10^9
BOO	build, own, operate
BOT	build, operate, transfer
bscf	billion standard cubic feet
Btu	British thermal unit
BWR	boiling light-water-cooled and moderated reactor
CHP	combined heat and power
CIS	Commonwealth of Independent States
cm	centimetre
CNG	compressed natural gas
d	day
DC	direct current
DOWA	deep ocean water applications
ECE	Economic Commission for Europe
EIA	US Energy Information Administration
ETBE	ethyl tertiary butyl ether
FAO	UN Food and Agriculture Organisation
FBR	fast breeder reactor
FSU	former Soviet Union
GHG	greenhouse gas
IBRD	International Bank for Reconstruction and Development
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPP	independent power producer
J	joule
kcal	kilocalorie
kg	kilogram
km	kilometre
km^2	square kilometre
kW_e	kilowatt electricity
kWh	kilowatt hour
kW_p	kilowatt peak
kW_t	kilowatt thermal
lb	pound (weight)
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LWGR	light-water-cooled, graphite-moderated reactor
LWR	light water reactor
m	metre
m/s	metres per second
m^2	square metre
m^3	cubic metre
mb	millibar
MJ	megajoule
Ml	megalitre
mm	millimetre
MPa	megapascal
mPa s	millipascal second
mt	million tonnes
mtoe	million tonnes of oil equivalent
MW	megawatt
MW_e	megawatt electricity
OAPEC	Organisation of Arab Petroleum Exporting Countries
OECD	Organisation for Economic Co-operation and Development
OPEC	Organisation of the Petroleum Exporting Countries
OTEC	ocean thermal energy conversion
OWC	oscillating water column
PBMR	pebble bed modular reactor
PHWR	pressurised heavy-water-moderated and cooled reactor
ppm	parts per million
PV	photovoltaic
PWR	pressurised light-water-moderated and cooled reactor
R&D	research and development
R,D&D	research, development and demonstration
R/P	reserves/production
rpm	revolutions per minute
SER	Survey of Energy Resources
t	tonne (metric ton)
tC	tonnes of carbon
tce	tonne of coal equivalent
tcf	trillion cubic feet
toe	tonne of oil equivalent
tpa	tonnes per annum
trillion	10^{12}
ttoe	thousand tonnes of oil equivalent
tU	tonnes of uranium
TWh	terawatt hour
U	uranium
UN	United Nations
UNDP	United Nations Development Programme
W	watt
WEC	World Energy Council
W_p	watts peak
wt	weight

GW_e	gigawatt electricity
GWh	gigawatt hour
h	hour
ha	hectare
HWR	heavy water reactor
Hz	hertz
IAEA	International Atomic Energy Agency
MWh	megawatt hour
MW_p	megawatt peak
MW_t	megawatt thermal
N	negligible
NEA	Nuclear Energy Agency
NGL's	natural gas liquids
Nm^3	normal cubic metre
NPP	nuclear power plant
WWER	water-cooled water-moderated power reactor
yr	year
—	unknown or zero
~	approximately
<	less than
>	greater than

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CONVERSION FACTORS AND ENERGY EQUIVALENTS

Basic Energy Units

1 joule (J)	=	0.2388 cal		
1 calorie (cal)	=	4.1868 J		
(1 British thermal unit [Btu]	=	1.055 kJ	=	0.252 kcal)

WEC Standard Energy Units

1 tonne of oil equivalent (toe)	=	42 GJ (net calorific value)	=	10 034 Mcal
1 tonne of coal equivalent (tce)	=	29.3 GJ (net calorific value)	=	7 000 Mcal

Note: the tonne of oil equivalent currently employed by the International Energy Agency and the United Nations Statistics Division is defined as 10^7 kilocalories, net calorific value (equivalent to 41.868 GJ)

Volumetric Equivalents

1 barrel	=	42 US gallons	=	approx. 159 litres
1 cubic metre	=	35.315 cubic feet	=	6.2898 barrels

Electricity

1 kWh of electricity output	=	3.6 MJ	=	approx. 860 kcal

Representative Average Conversion Factors

1 tonne of crude oil	=	approx. 7.3 barrels		
1 tonne of natural gas liquids	=	45 GJ (net calorific value)		
1 000 standard cubic metres of natural gas	=	36 GJ (net calorific value)		
1 tonne of uranium (light-water reactors, open cycle)	=	10 000 – 16 000 toe		
1 tonne of peat	=	0.2275 toe		
1 tonne of fuelwood	=	0.3215 toe		
1 kWh (primary energy equivalent)	=	9.36 MJ	=	approx. 2 236 Mcal

Note: actual values vary by country and over time

Because of rounding, some totals may not agree exactly with the sum of their component parts

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