SUSTAINABLE
GLOBAL ENERGY DEVELOPMENT:

THE CASE OF COAL

LE DÉVELOPPEMENT
ÉNERGÉTIQUE MONDIAL DURABLE:

LE CAS DU CHARBON

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FOREWORD

This study on global coal is a result of the initiative taken by the WEC Polish Member Committee, which also provided much support for its implementation. I would like to thank the study Chair, Mr. Bicki and other Polish members of the study group: Mr. Solinski, Mrs. Gawlik and Mr. Borkowski for all the work they have done to make this study possible, but also for their traditional Polish hospitality in hosting the meetings of the study group.

The study group reported to the WEC Programme Committee, and as the Chair of this Committee, I have been following their work on the report over the past three years. The final result is impressive. The wealth of information on various aspects of coal production and use, and numerous country case studies demonstrate the real scale and the importance of this fuel to the world.

Coal is often taken for granted, perhaps because people have been using it for thousands of years. Coal is the most abundant and widely distributed fossil fuel, and it can provide an affordable, reliable and safe supply of energy for hundreds of years. However, today coal is often dismissed as a part of the sustainable energy future due to its “poor” environmental credentials. Advanced clean coal technologies, which significantly reduce emissions from coal-fired power generation plants can help address this issue. Their costs are high though, and therefore make the wider deployment of these technologies in regions and countries where the use of coal is expected to grow most, practically unfeasible. This is just one of the messages coming out of the study. There are many more, and they all need to be taken into consideration by energy decision-makers, as the stakes are high, given coal’s share of 20% in the world total primary energy supply and 40% in the world electricity generation.

The study group has done a tremendous job, and I would like to thank all members for their contributions. Finally, my special thanks go to Dr. Klaus Brendow who guided and supported the study through its various stages.

Norberto de Franco Medeiros

Norberto de Franco Medeiros, Chair
WEC Programme Committee
Rio de Janeiro, July 2004

FOREWORD AND ACKNOWLEDGEMENTS

Background

The World Energy Council (WEC), under the auspices of its East-West European Energy Programme, published in Summer 2000, a study on "Restructuring and Privatisation of the Coal Industry in Central and Eastern Europe". At a related meeting in Katowice, Poland in January 2000, the delegations of Poland and Russia requested that a similar, but global, study be undertaken by the WEC, in cooperation with other competent international organisations. Following consultations with the WEC Studies Committee, Programme Committee and Cleaner Fossil Fuels Systems Committee during 2001, the Executive Assembly of the WEC decided at its session in Buenos Aires in October 2001, to include in its Technical Programme a study on "Sustainable Global Energy Development: the Case of Coal".

Objective

The study was intended to form an internationally consistent view to answer the question whether and to what extent coal use could be economic and sustainable in meeting global energy demand to 2030 and beyond, and cover markets, trade and demand, mining and combustion technologies, restructuring and international policies, and perspectives. It would consider both, the contribution that coal could make to economic development as well as the need for coal to adapt to the exigencies of security of supply, local environmental protection, mitigation of climate change, and quality of service in a context of global competition. Finally, the study would make an important contribution to the 19th WEC World Energy Congress to be held in Sydney from 5 to 9 September 2004.

Organisation

A study group was set up on 18 February 2002 composed of some 40 participants from 22 WEC Member Committees and four international organisations. I served as Chair, Mr. Zygmunt Borkowski as Project Director, Dr. Klaus Brendow as WEC Liaison and Dr. Jan Solinski as adviser. We developed a study approach and agreed on a structure, assignments and a schedule. We held meetings in Warsaw, Cairo, Brussels, Cologne, Cracow and again in Warsaw, where on 28 January 2004, we agreed the final draft of the study.

Message

The message of the study is reflected in the Executive Summary. Our conclusion is clear: coal will continue to be an expanding, affordable foundation for economic and social development worldwide. Moreover, backed by its vast and well-distributed resource base, it will make a significant contribution to eradicating energy poverty and to energy security. In addition, coal can and will become increasingly clean, - at a reasonable cost in terms of technological sophistication, and at minimal cost in terms of international technology transfer, research and development. For this to happen, we need balanced energy and environmental policies. We need a more pro-active involvement of the coal and associated industries in "globalising" best technical and managerial practices. And finally, coal's credentials must be more effectively advocated to decision makers and the general public.

Acknowledgements

It is my privilege and pleasure to express my sincere thanks to the members of the study group and the authors of over twenty case studies, which formed the basis of the overview chapters and the Executive Summary. I am particularly indebted to the primary drafters of:

Chapter 1: Christine Copley, World Coal Institute
Chapter 2: Zygmunt Borkowski, Kompania Wcglowa S. A.
Chapter 3: Martin Wedig & Michael Schütze, RAG Coal International AG, Eckart C. Günther & Hans-Wilhelm Schiffer, RWE Power AG, and Günter Dach, German Hard Coal Association
Chapter 4: Wolfgang Benesch, Steag Encotec GmbH, Eckart C. Günther & Hans-Wilhelm Schiffer, RWE Power AG
Chapter 5: Léopold Janssens, & Christopher Cosack, Euracoal
Chapter 6 and Executive Summary: Klaus Brendow, WEC Liaison
Statistical Annex: Jan Solinski, WEC, Poland

As the two-year effort has been concluded, I would like to:

- Firstly, express my hope that this study contributes to a more balanced approach to the role which coal could play in meeting the aspirations of nations for economic development and sustainability;
- Secondly give my gratitude to the WEC. The competence and cost-effectiveness, with which the WEC community responded to such a complex task as assessing the global future of coal, proved (once more) an undeniable asset. This appreciation includes the WEC London Office, in particular Elena Nekhaev, who supported the study on substance and logistics and secured its editing, formatting and reproduction.
- Lastly, request the study participants and the WEC to promote the study as widely as possible, to the benefit of all.

Zbigniew Bicki

Zbigniew Bicki
Chair
Warsaw, July 2004

Executive Summary

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Introduction

During the last century, the world has witnessed an accelerating technological development in almost all aspects of the human life, resulting in rapidly improving living standards in the vast majority of countries. This development would have been impossible without energy, and the growing demand for energy services has led both to the discoveries of new energy sources and the development of new energy technologies. While the world's attention was shifting between the "Oil Era" and the "Nuclear Age", the "Dash for Gas" and the "Renewable Future", coal had firmly stayed in the background playing a vital role, in particular, in conferring supply security and price stability. Price stability in fuel supplies is fundamental to world economic prosperity and political stability.

The geopolitical events of 2003-2004 highlight the fragility of the world's energy supply system and once more pose concerns over supply disruptions of energies and volatility of prices. Coal can provide a crucial contribution to energy security. The options for expanded coal utilisation are numerous and they can considerably reduce threats of supply disruptions of other energy carriers. The global energy supply context is often not understood well enough, and should be explored in more depth in the development of any energy strategy. The facts are simple and they speak for themselves: 65% of global oil resources are located in the Middle East (20% in Saudi Arabia alone); 34% of natural gas resources are located in the former Soviet Union (FSU) and another 36% in the Middle East.

Unlike oil and natural gas, coal is widely distributed around the world. The global reserves of coal are spread in significant amounts in more than 75 countries, however, over 75% of global coal reserves are concentrated in six countries: the US, Russia, China, Australia, India and Germany. Coal is most often both produced and used in the region of origin. This accounts for the small world trade in coal compared with the massive trade in oil. In 2000, coal supplied some 24% of global primary energy demand and was used to produce 38% of the world's electricity.

Overall, it seems probable that the dominance of the main commercial fossil fuels, including coal would continue into the foreseeable future, while several key `new' renewable energies (e.g. wind, solar, modern biomass etc.) seem set on the path of rapid growth and declining cost. Renewable energy will undoubtedly become an integral and important component of the future energy mix, but major expansion will take time. In the foreseeable future, renewables can only complement conventional energies.

Energy market liberalisation, reform and competition place the emphasis on the economics of energy supplies. Today, neither energy security nor environmental aspects of energy supplies and use are a part of the economic equation. Decision-making in a market is often based on the short-term planning and performance, whereas to ensure sustainable energy development in the long-term, greater emphasis on full life-cycle analysis is required. Politically motivated decisions forming the future energy sector should be based on sound and comprehensive research and facts, not wishful thinking. Coal, the most affordable fuel, has, however, an incredible potential to become the most reliable and easily accessible energy source.

1. Sustainable Global Energy Development and Coal: Overview

1.1 The benchmarks

WEC believes[1] that sustainable energy development can be appraised against three benchmarks:

- The continued availability of energy, in sufficient quality and quantity, adapted to the changing needs of customers;
- The growing accessibility of energy, it being understood that the costs of supply and further energy development are covered. WEC recalls that at the beginning of the 21st century, two billion people had no access to commercial energy, while another two billion had access to unreliable and often unaffordable supplies[2]; and
- The acceptability of energy, i.e. its compatibility with societal concerns, whether they are developmental, environmental or social.

1.2 The challenges met

The present study concludes that coal is:

- Available to meet the steeply rising demand for steam coal, while adapting the supply of coking coal to reduced demand. Despite the drain on reserves, coal supplies would remain huge in absolute terms and compared to oil and gas reserves[3];
- Accessible, mostly in the form of electricity, to a growing number of people. Due to significant productivity gains[4], international coal prices would remain stable or increase to a lesser extent than the prices of its competitors. Thus, till 2030, coal would notably contribute to reducing by half, the number of people with no or unreliable access to energy[5]; beyond its use in electricity generation, synthetic gases, liquids and hydrogen from coal emerge as long-term options;
- Acceptable in so far as by 2030, an estimated 72% of coal-based power generation in the world would, under market conditions, use cost-effective clean coal technologies[6]; methane drainage from abandoned or active mines and carbon sequestration would be increasingly practiced[7].

1.3 The issues

However, the present study also notes deficits and advocates remedial measures.

1.3.1 The image of coal

Coal's global image does not reflect the realities of the industry. A worldwide commitment of the coal community is needed to improve the public perception of coal's real performance.

[1] WEC, *Energy for Tomorrow's World – Acting Now!,* London 2000, p. 55; WEC, Living in One World, London 2001, p. 171
[2] WEC, *Living in One World*, ibid., p. 74
[3] Chapters 1 on Coal Demand and Trade, Chapter 2 on Coal Production, Productivity and Profitability and Chapter 6 on Global and Regional Coal Demand Perspectives to 2030 and Beyond
[4] Chapter 2 on Coal Production, Productivity and Profitability
[5] IEA, *World Energy Outlook 2002*, Paris 2002, p. 372 and following
[6] European Commission, Directorate-General Research, World Energy, *Technology and Climate Change Outlook 2030*, Brussels 2003, p. 130; in the following quoted as EU-WETO
[7] Chapter 3 on Coal Mining Technologies

1.3.2 International policies

International policies appear to undervalue the contribution, coal offers to sustainable development, in terms of availability, accessibility and acceptability. Hence there is a need to re-equilibrate international policies.

The present study recommends that international policies should:

- Place emissions from coal into a more balanced perspective. If life cycle analysis was used and other greenhouse gases (GHG) were taken into account, electricity generation from fuels other than coal would show similar or even higher GHG emissions[8];
- Acknowledge that the projected increase in annual emissions of carbon dioxide from coal between 2001 and 2025 of 1.1 Gt of carbon equivalent would be less than the increased amount projected for either natural gas (1.3 Gt) or oil (1.5 Gt)[9];
- Acknowledge the contribution which coal can make to social and economic development and energy security;
- Avoid instruments which discriminate coal; rather encourage a more efficient and clean use of coal in power generation, including through joint implementation (JI), clean development mechanisms (CDM) and emission trading (ET)[10];
- Supplement ongoing information exchanges on carbon sequestration by related funding of research and development (R&D) initiatives;
- Assist developing countries in acquiring clean coal technologies[11]; an expanded contribution of the Global Environmental Facility and of the World Bank's Prototype Carbon Fund under preferential conditions is recommended;
- Encourage the worldwide application of more effective SO_2, NO_x and dust emission standards for new power plants; this would also reduce the regulatory uncertainty affecting the design of clean coal technologies;
- Encourage a transparent and representative reporting system on health and safety practices in coal mining, as a basis for the broad deployment of good practices[12];
- Ratify ILO Convention Nr. 176 on Safety and Health in Mines; and
- Include coal services (consulting, engineering, management) in the attempts underway in WTO-GATS to liberalise access to markets[13].

In addressing these issues, the intergovernmental bodies could rely on the cooperation of non-governmental organisations such as the WEC and its Cleaner Fossil Fuel Systems Committee, the World Coal Institute, the International Energy Agency (IEA) Clean Coal Centre or the International Council on Mining and Minerals[14].

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[8] World Coal Institute, *Sustainable Entrepreneurship – The Way Forward for the Coal Industry*, London 2001, p. 6 and 26; see also a WEC Study on *Life Cycle Analysis*, under preparation

[9] USDOE, International Energy Outlook 2003, Washington, May 2003, p. 79 and 13; in this scenario, coal grows slowest among the fossil fuels

[10] Chapter 5 on Forging Internationally Consistent Energy and Coal Policies

[11] See the paper contributed by D. Chazan, J. Cavalho da Cunha and F. Zancan on "The use of low-grade coals"

[12] See the paper contributed by Christine Copley on "Globalisation and consolidation of the coal industry", as well as 8, p. 42

[13] Chapter 5 on Forging Internationally Consistent Energy and Coal Policies

[14] See footnote 12

1.3.3 Clean coal technologies

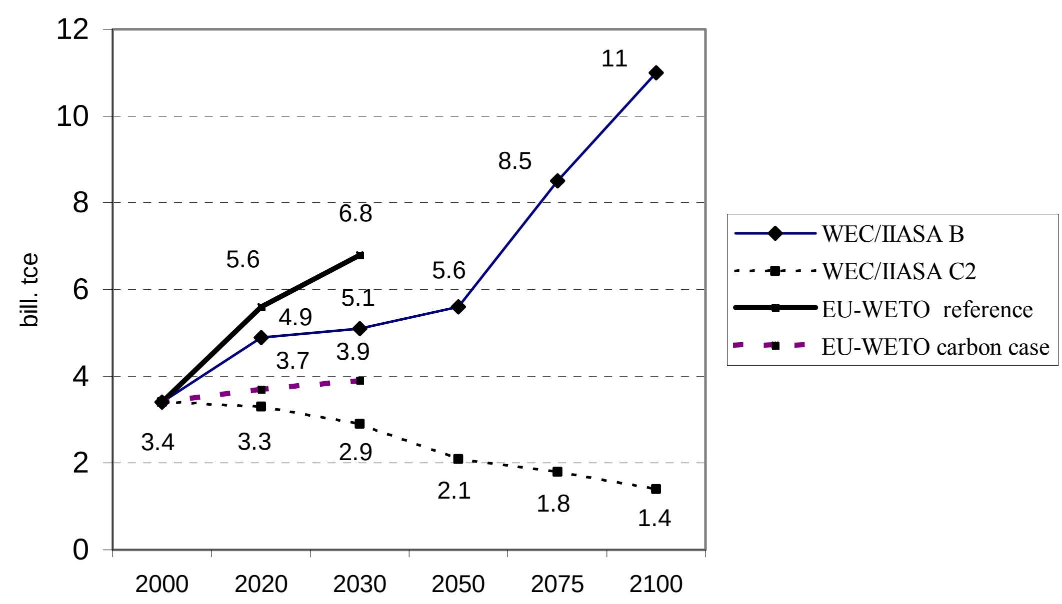
The projected growth of energy demand particularly in developing countries will prompt a significant increase of CO_2 emissions. The coal industry and power equipment manufacturers are making every effort to deploy technologies with higher efficiencies in the short and medium term and to develop carbon sequestration to technical and commercial maturity in the next 15 to 20 years.

2. Availability Of Energy: Coal's Lasting Strength

2.1 World coal demand on the rise

Demand for coal (hard coal, brown coal, lignite) has grown by 62% over the past thirty years[15]. IEA, in its reference scenario, expects coal demand to grow by another 53% up to 2030 and EU-WETO by 100%. WEC/IIASA market-driven scenarios[16] project a continued growth during the remainder of the century. By contrast, carbon constraining policies would lead to a decline of coal demand as of 2030 or slightly before (see Graph 1[17]); this begs the question how relevant such policies could be in addressing the issue of "energy poverty eradication and the role of affordable universal energy access as the principal issues of sustainable development" (World Summit on Sustainable Development).

Graph 1: World coal demand projections



In market-driven scenarios, the share of coal will decline slowly from 26% in 2000 to 24% in 2020 and 22% in 2050.

[15] Statistical Annex, table 1
[16] Also termed business-as-usual, trends-continued or dynamics-as-usual scenarios
[17] Source: Chapter 6 on Global and Regional Coal Demand Perspectives to 2030 and Beyond

2.2 The main driver: power generation

Most of the increase of coal demand will be from power plants, which might absorb in 2030 some 74% of coal supplies, against 66% in 2000[18]. Three decades from now, coal would cover 45%[19]of world power needs, compared with 38% in 2000[20].

2.3 New regional demand and production patterns

During the last thirty years, owing to the rise of demand, production rose steeply in China (with a temporary adjustment recently), India, United States, South Africa, Australia, Canada, Colombia and Indonesia, but declined in Europe with its high-cost deposits[21]. This pattern is expected to continue[22].

2.4 Towards globalisation: international coal trade and services

The coal mining and power generation industry is becoming ever more global. Whereas international sea-borne hard coal trade accounted for only 7.5% of world hard coal production in 1970, by 2000 already 16% of production was internationally traded[23]. At 637 Mt in 2000, international coal shipments are expected to grow to 1051Mt in 2030[24], corresponding to 15 to 16% of projected world coal production.

Trading practices change: short-term contracts and tenders prevail over long-term contracts as a result of strong competition. Mergers, acquisitions and horizontal and vertical integration gain ground. Consolidation allows economies of scale and reduces overheads, hence enables competitive pricing. While in 2001, the five largest private coal companies accounted for 40% of international hard coal trade[25], competition continued as new suppliers entered the market[26].

Sea-borne shipping accounts for about 30% of the delivered cost of coal; a reduction of these costs would contribute to enhancing coal's markets.

2.5 Coal reserves: the benefit of size

Economically recoverable coal reserves are huge[27]. Despite increased production during the next thirty years, only 25% of presently known coal reserves would be depleted, compared with 84% of oil reserves and 64% of gas reserves [28]. Moreover, depletion ratios would slow due to the anticipated increase in power plant efficiency and related fuel savings of as much as 35%[29]. Nevertheless, the industry should remain active in exploration, if only to enhance coal's contribution to energy security.

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[18] IEA, *World Energy Outlook 2002*, p. 121
[19] EU-WETO, ibid., p. 130
[20] Statistical Annex, Table 23, and EU-WETO, p. 130
[21] Statistical Annex, table 6; on restructuring of the European coal industry, see Chapters 2 and 5
[22] Chapter 6 on Global and Regional Coal Demand Perspectives to 2030 and Beyond, graphs 5 and 6; Chapter 2
[23] Statistical Annex, Table 5
[24] IEA, *World Energy Investment Outlook 2003*, p. 277
[25] Paper contributed by H.-W. Schiffer on "Trade in coking coal and steam coal"
[26] Chapter 1 on Coal Demand and Trade; Chapter 2 on Coal Production, Productivity and Profitability
[27] Statistical Annex, Table 4
[28] WEC/IIASA, *Global energy perspectives*, Cambridge 1998, p. 53, 54and 262
[29] Karl A. Theis, *Realistische Chancen durch Technologieoffensive nutzen*, Energiewirtschaftliche Tagesfragen, May 2003, p. 294

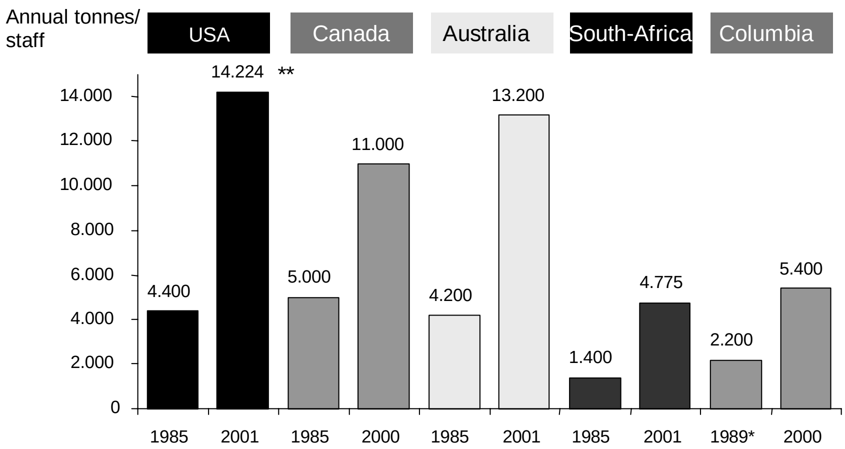
3. Accessibility Of Energy: Coal's Growing Strength

3.1 Income growth versus growth of energy prices

IEA[30] and EU-WETO[31] anticipate world per capita GDP to rise by about 2% per year until 2030. Income growth would be faster in developing (2.8%) and transition economies (3.4%) than in OECD countries (1.6%).

Access to commercial energy would be eased if income growth exceeds the rise of energy prices. It is anticipated that international fossil fuel prices would rise less fast than income, thereby opening access to commercial energy to a growing number of people. IEA estimates that by 2030, this differential and other factors would allow two billion people to have access to electricity and other modern fuels. However, another one billion people would remain in energy poverty[32].

Graph 2: Development of Productivity in the Hard Coal Mining Industry from 1985 to 2000 or 2001*



* 1985 figures not available ** incl. lignite
Source: RWE Power AG

3.2 Coal's growing price competitiveness

After a significant decline of international coal prices during the 1990s[33], coal prices are expected to be stable or to rise only slightly in comparison with oil and gas prices[34]. As a result, coal will lead in terms of price competitiveness and accessibility.

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30 IEA, *World Energy Outlook 2002*, p. 408 and 409
31 EU-WETO, ibid., p. 15
32 IEA, *World Energy Outlook 2002*, p. 372
33 Statistical Annex, Tables 24 and 25
34 IEA, *World Energy Outlook 2002*, p. 49 and figure 1.7; EU, ibid., p. 15; paper contributed by Lidia Gawlik on "Actual and projected coal prices: an interfuel comparison"

3.3 Behind coal's performance: productivity and efficiency gains

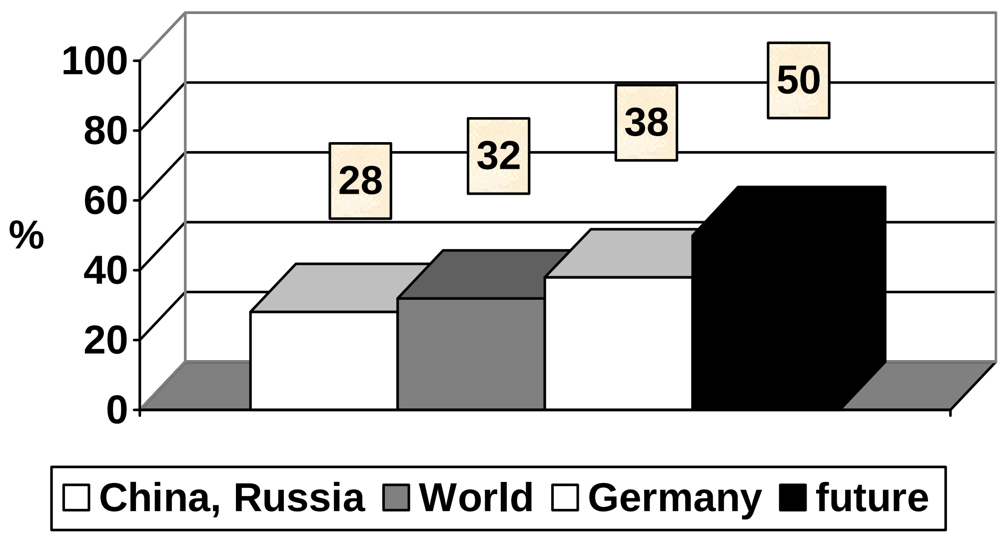
Coal's price performance is in the last instance caused by productivity gains in mining and improved efficiency in power generation.

3.3.1 Productivity growth in mining

According to IEA, productivity per person and year rose between 5 and 10% in the 1980s and by between 10 and 15% in the 1990s[35] (see Graph 2[36]). This growth was not only due to increased labour productivity, but also to the closing of uneconomic or small (and often illegal) mines, the liberalisation and restructuring of coal industries, the transfer of knowledge and technology to newcomers and the expansion of opencast mining versus underground mining. Productivity growth is expected to continue.

3.3.2 Efficiency growth in power generation

At present, average world coal-based power generation efficiency is approximately 32%, while state of the art is 42 to 45%. Advanced clean power generation technologies promise efficiencies of 50 to 53%[37]. As new plants penetrate the market, efficiencies will rise. EU-WETO estimates that by 2030, 72% of world coal-based power plants will use advanced technologies with efficiency at 49 to 50%. EU-WETO also estimates that these plants could potentially reduce gas-fired combined cycles down to 4500 h/year even in regions with access to reasonably priced gas[38].



Graph 3: Efficiency of hard coal power stations, 2000

[35] IEA, *World Energy Outlook 2002*, p. 122

[36] Source: paper contributed by H.-W. Schiffer on "Trade in coking coal and steam coal"

[37] Chapter 4 on Coal-based Power Plant Technology ; Graph 3, source : Gesamtverband des deutschen Steinkohlenbergbaus, Steinkohle 2000, Essen 2000, p. 34

[38] EU-WETO, ibid., 130; p. 75, reference case, and p. 74

3.4 Investments in coal mining and power generation: comparatively low

Coal mining is less capital-intensive than the extraction of oil and gas, but its combustion is associated with a higher environmental policy risk than its main competitor – gas, unless matched by clean coal technologies. Gas, by contrast, seems to face a risk of higher prices, affecting its competitiveness.

3.4.1 Capital requirements

IEA[39] estimates the cumulative investment requirements for coal mining and shipping (including port facilities) during 2001-2030 at US$398 billion. These would support an increase of world coal production from 4595 Mt in 2000 to 6954 Mt (reference scenario). The mining of a ton of coal (in toe equivalent) requires less than US$5, compared with US$22 for the extraction of oil and almost US$25 for gas.

Cumulative global coal investments would be shared equally between developed and developing nations, with China requiring 34%, the United States and Canada 19%, Australia and New Zealand 9%, the transition economies 8%, OECD Europe 7% and India 6%.

If investments for coal-based power stations were added, the total cumulative investment needs would amount to US$1900 billion. This is 12% of the investments required by the world energy supply industries as a whole (US$ 16000 billion). IEA highly values the future role of clean coal technologies and carbon sequestration (subject to cost reduction), but considers their impact “limited” by 2030. This assumption, of course, limits requirements for coal-based power generation. In comparison, EU-WETO estimates in its reference scenario that by 2030, 72% of coal-based power generation (or 45% of thermal power generation) would be with advanced coal technologies. As previously mentioned, those technologies would “noticeably” replace gas-fired combined cycles “even in regions with access to reasonably cheap gas prices”[40].

3.4.2 Financing

According to IEA, total energy sector investment requirements amount to 1% of world GDP and 4.5% of domestic capital formation. Thus, neither the energy sector as whole, nor coal mining, shipping and coal-based power generation should face problems in attracting the necessary capital if profitability matched risk.

3.4.3 Policies and business strategies

However, coal does have to face greater uncertainties than oil and gas as to the impact of potentially more restrictive environmental policies on demand. The IEA alternative scenario estimates that, compared with the reference scenario, such policies could reduce coal demand in 2030 by 8% (to a level of 6430 Mt), investment needs by 6% (to a level of US$373 billion) and international coal trade by 10% (to a level of 938 Mt). Also EU-WETO, in its carbon abatement case, projects world coal demand to be lower in comparison with the reference case. However, both the IEA and EU-WETO anticipate an increase in comparison with 2000 (EU-WETO + 23%, IEA +40%)[41].

The growth perspectives for coal in all the above scenarios, coupled with greater certainties about future environmental protection policies, should constitute a sufficient

[39] IEA *World Energy Investment Outlook*, Paris, 2003, p. 46, 277-338, 349

[40] EU-WETO, ibid., p. 130 and 108; super-critical coal combustion would cover 30% of world coal-based power generation by 2030, IGCC 15%, direct coal-fired combined cycles 15% (p. 73, 74)

[41] EU-WETO, ibid., p. 103, 108, IEA World Energy Investment Outlook, p. 335, figure 6.25

basis for encouraging proactive business and investment strategies in world coal mining, shipping and combustion.

4. Acceptability and Energy: Coal's Technological Agenda

The anticipated growth of coal demand (see Graph 1) will also be driven, and increasingly so, by coal's capability to accommodate societal concerns: economic growth, environmental protection, mitigation of climate change, improved labour safety and health standards, and community development. In the absence of response, these concerns will become the limiting factor to coal's growth.

4.1 Facilitating technology and knowledge transfer to developing countries

4.1.1 Coal: the growth engine

According to IEA and WEC/IIASA, coal demand is expected to increase during the next three decades everywhere in the world, except in Western Europe. The increase would be strongest in the developing countries: China, India, South-East Asia, sub-Saharan Africa and Latin America. Coal demand by developing nations would actually double from 1.5 Gt in 2000 to 3.1 Gt in 2030. By that year, 60% of world coal demand would be generated in developing countries, against 45% in 2000[42].

If the developing countries are the growth engine behind global coal demand, coal remains an important, indeed indispensable, technological development. Despite competition from natural gas, coal would account for 33% of total primary energy supplies in 2030 (against 39% in 2000). More importantly, in developing countries coal would secure 53% of electricity generation in 2030, against 56% in 2000. Between those two years, coal-based power generation would more than triple[43].

4.1.2 Enabling measures and policies

To enable a prospering coal industry of the size and dynamics suggested above requires continued efforts on the part of governments, industry and the international community with regard to:

- **Technology transfer:** financing technology transfer to developing countries meets serious difficulties unless the macro-economic and policy frameworks encourage investors. Cumulative investment needs of developing countries for coal mining and shipping for 2001-2030 amount to US$261 billion[44]. IEA notes that the risk of a shortfall of foreign investments is greatest in developing countries, where ownership remains in government hands[45]. International financial assistance in demonstration projects (mining, liquefaction, preparation plants, methane drainage, waste handling, integrated gasification combined cycle (IGCC), coal slurry pipeline), have proven their value, if coupled with a legal regime attracting foreign investors. The number of such projects needs to be

[42] IEA, *World Energy Outlook 2002*, p. 410 and 458
[43] IEA, *World Energy Outlook 2002*, p. 458 und 459
[44] IEA *World Energy Investment Outlook* 2003, p 279
[45] IEA, *World Energy Investment Outlook* 2003, p. 278

multiplied, until such time as the costs of modern technologies have been brought down.

- **Restructuring:** recent policies of developing countries aim at a greater degree of private sector involvement in mining and power generation, including privatisation. As the foundation of success include a reduced role of governments in operations, the gradual phase-out of price controls, import tariffs and subsidies, and the removal of restrictions such as the use of coal production in captive power plants[46]. The main issue is to supply cheap energy to the poor, i.e. changing the system of producer subsidies to a system of consumer subsidies.
- **Management:** the transfer of efficient management practices, through internationally operating companies or otherwise, enables significant productivity gains. The tools are company-supported education, training and community relations.
- **Standards:** in developing countries, the setting of health, safety, environmental or quality standards has to obey the triple objectives of economic, social and ecological development. This demands a gradual, fine-tuned move from minimum to more constraining standards rather than the application of western-world standards. International financial institutions should recognise such a step-wise strategy as valid, when determining the conditions for loans[47].

4.2 Abating local/regional pollution: a matter of worldwide deployment of proven technologies

Proven technologies exist to reduce the emission of dust, SO_2, and NO_x from coal-based power generation[48], to recycle toxic effluents, by-products and coal bed methane[49], to mitigate subsidence or to reclaim opencasts[50]. The issue is one of the worldwide deployment of best practice, however difficult and time consuming this may be. Stricter national and trans-boundary emission standards and leadership of global players would pave the road.

4.3 Mitigating climate change: clean coal-based power generation and carbon sequestration

4.3.1 Raising efficiency

As pointed out in section 3.3.2, rising efficiencies of coal combustion in power stations reduce fuel use and, hence, CO_2 emissions.

There exist several technological options (with variants) with high and growing efficiencies.

For hard coal, supercritical pulverized coal combustion presently operates at efficiencies of 45% and offers prospects for an increase to 48%; this technology remains the preferred option for large units and for up to 2020. For lignite, supercritical pulverized firing attains

[46] See paper contributed by Shashi Kumar on “Coal as a driver of economic development – a case study relating to India”
[47] See paper on “The use of low-grade coal”, contributed by David T. Chazan, José C. Carvalho da Cunha and Fernando Luiz Zancan
[48] Chapter 4 on Coal-based Power Plant Technology
[49] Chapter 3 on Coal Mining Technologies
[50] See paper contributed by H.-W. Schiffer on ”Lignite: mining technologies”

more than 43% (in the so-called BoA unit of the German plant of Niederaussem), with a target of 50% and more if pre-drying and new materials were used (timeframe 2020). Fluidised bed combustion, suitable for smaller capacities and high ash coals, presently operates at 40% efficiency with prospects for up to 44%. Integrated gasification combined cycles (IGCC) – at demonstration stage – achieves 43%, but may attain 51 to 53% [51].

However, efficiency is only one parameter. The choice of the technology depends on many site-specific criteria such as the size of the unit, the load regime, the fuel used, the marketing or recycling of by-products and environmental legislation.

Nevertheless, the worldwide application of these advanced technologies would theoretically avoid 1.8 Gt of CO_2 per year, equivalent to 7.5% of present world CO_2 emissions[52].

4.3.2 Sequestering carbon

Coal does have every interest to develop carbon capture and disposal technologies to technical and commercial maturity in the next 15 to 20 years. International research is underway, such as the "Zero Emission Coal to Hydrogen Alliance" (ZECA), the US Department of Energy (DOE) "Vision 21" or "FutureGen" Programme. The EU Framework Programmes for Research and Technological Development for 2002-2006 include a chapter on capture and sequestration of CO_2. A Charter on carbon dioxide (CO_2) was signed in June 2003, creating the Carbon Sequestration Leadership Forum; 13 countries and the EU participate. The IEA Clean Coal Centre has long since been active in CO_2 emission analysis and control[53].

4.3.3 Promoting cleaner fossil fuel technologies and universal access to energy

Cleaner coal, indeed fossil fuel technologies appear to be a major possible and feasible long-term means to seriously address the two interrelated issues of reducing energy-related GHG emissions <u>and</u> of enabling universal access to energy. However, related costs have to be brought down and least cost carbon mitigation technologies of all types need to be judged in a competitive market context. By contrast, alternative policies to wean the world of its dependence on fossil fuels require comparatively higher price increases which would be at least equivalent to the two oil shocks of the 1970s, every ten years. This would engender corresponding losses of economic growth, prolong the use of traditional fuels by poor people in developing countries and exacerbate the global level of GHG emissions[54].

4.3.4. Broadening the product range: gases, liquids, and synfuels from coal

Coal needs to accommodate more towards the markets other than electricity generation in power plants. Apart from the gasification of coal, prior to its combustion in IGCC processes mentioned under section 4.3.1, the perspective of comparatively low coal prices aroused renewed interest in its liquefaction. In China, the construction of a coal liquefaction plant has begun in Majiata, Inner Mongolia. In the US, the Gilberton coal-to-power-and-clean-fuel demonstration plant is at its final stage, awaiting a favourable environmental impact statement, tax breaks and a government loan for May 2004. In

[51] Chapter 4 on Coal-based Power Plant Technology
[52] Karl A. Theis, ibid.
[53] Paper contributed by John Topper on "International research on clean coal"
[54] WEC, *Drivers of the Energy Scene*, London 2003, p. 42

Australia, a letter of intent has been signed for a large integrated power-and-liquids plant in Victoria[55]. Regarding underground gasification, a project has started in the United Kingdom, with the ambition to tap coal reserves from beneath the North Sea with minimal environmental impact.

Evidently, these projects are forerunners, driven by a comparatively high price environment and tensions in the Middle East. Also, they benefit from specific favourable conditions. But essentially, they see the 'light of the day' at a time when oil and gas reserves are plentiful.

Ultimately, depending on cost, synfuels and hydrogen emerge as vectors for coal use[56]. The longer-term perspectives of synfuels from coal are clearly related to the depletion of cheap conventional oil reserves, presently too expensive. Synfuels from coal may contribute about 100 Mtoe (or 4% of world liquid fuel demand) in 2020 and up to 660 Mtoe (14%) by 2050 [57].

4.4 Coal's road to public acceptance

Despite public relations campaigns for example in the US and Germany, there is still a striking difference between coal's perceived image and coal's real performance. Regrettably, so far there has not been an industry effort to address this deficit at the global level. Coal clearly has key attributes, however, it is incumbent upon the global industry to take action to market them to the public and policymakers alike so as to ensure that coal provides a sustainable bridge to the future.

The present study proposes such a worldwide action programme around the topic of ***"Sustainable Development from Coal"*** based on a voluntary alliance between the coal mining and trading community, coal users, equipment manufacturers, research institutes, international financial institutions, and intergovernmental organisations. Emphasis should be on local and regional conditions for sustainable coal development[58].

Issues addressed could comprise:

- The replication of good health and safety standards in countries with less rigorous or no legislation. This requires a representative and transparent reporting system, on a world-wide basis[59];
- The ratification of ILO Convention Nr. 176 on Safety and Health in Mines[60] by more governments;
- Non-discrimination of local labour[61];
- Closure of illegal mines or their formalisation[62];
- Promotion of local coal-related projects (retrofitting of boilers[63], electrification schemes, methane drainage, land reclamation, waste recycling);

[55] COALTRANS, May/June 2003, p. 24 and 25
[56] See paper contributed by the IEA Clean Coal Centre: abstracts # 32 and 33
[57] WEC, Global Energy Perspectives to 2050 and Beyond, Report 1995, p. 78;
[58] See papers contributed by Charlotte Griffiths on "The global image of coal " and by J. A. Soraes on "Coal marketing"
[59] WCI, ibid., p. 42
[60] Chapter 5 on Forging Internationally Consistent Energy and Coal Policies
[61] see paper contributed by Allan Shout on "Country case study South Africa"
[62] WCI, ibid., p. 6 and 48
[63] See paper contributed by K. Brendow on "Clean coal combustion in small and medium-sized boilers in central and eastern Europe"

- Promotion of clean coal technologies;
- Quality and environmental certification of mines according to ISO standards[64];
- Awareness campaigns (coal and security of supplies; coal and social development; the “greening” of coal);
- Community development (housing, water supply, medical facilities, road construction, cultural centres, education, resettlement) [65]; and
- Conditions attracting foreign investors[66].

The message: Coal is not part of the problem. Coal is part of the solution to sustainable development and eradication of energy poverty. Coal can, and will increasingly, be clean.

[64] See the paper contributed by Slavko Plazar on “The introduction of management system according to the requirements of the quality standards in the Velenje coal mine”
[65] See the papers contributed by F. L. Zancan on “Brazilian coal – its economic, social and environmental impact” and by Shashi Kumar on “Coal as a driver of economic development – a case relating to India”
[66] See paper contributed by Shashi Kumar, ibid.

Epilogue

This epilogue ventures an – informed – speculation of how the situation and prospects of world energy demand and supply, particularly of coal, might be seen in 2030. This is, of course, not a forecast of what would have happened by then, but a vision of what could have happened if all stakeholders had combined their efforts at rendering coal sustainable in a global economic growth and energy context.

2000-2030: a retrospective

If the WEC should launch in 2030 a mid-century revue of "Energy for the World of 2050", it will certainly applaud the role of coal in social and economic development and the spirit of societal responsibility of the industry. But concerns remain, although earlier concerns about sustainability of coal use might well be surpassed by concerns about the implications of dwindling low-cost oil and gas reserves.

Concerning sustainability, the carbon intensity of world energy use (tC/toe) during 2000-2030 had declined by about 25%[67], due to the deployment of efficient and clean fossil fuel combustion technologies, CO_2 sequestration, penetration of gas and (less) renewables. Indeed, by 2030, 72% of coal-based power generation uses advanced technologies[68]. But energy-related emissions of CO_2 had almost doubled, due to the growth of population and related energy demand in the developing countries. This is why policies to mitigate climate change have remained important in 2030. However, rather than enhancing global and comprehensive action, policies now focus on the fine-tuning of regional and special measures particularly with regard to emissions from transportation and in urban areas. Prospects, as seen in 2030, are that the disadvantages and advantages of global climate change might reach a satisfactory global balance in a not too distant future.

The burning issue in 2030 is the dwindling of low-cost oil and gas reserves. During 2000-2030, the economically recoverable reserves[69] of conventional oil, gas[70] and (less) coal had diminished, despite new discoveries. Supplies of oil and gas had since long peaked. This had led to a general rise of energy prices, with beneficial effects on efficiency. Also, the structure of energy prices had improved, due to the internalisation of environmental and societal cost and the elimination of subsidies and restrictions. Now, in 2030, the energy price differentials between competing fuels tended to better reflect the life cycle costs of energy provision. As a result, least cost planning no longer referred to isolated plants or projects, but to entire energy systems. A case in point was progress in optimising local energy systems: in 2030, half[71] of the world population are urban dwellers, requiring heat, warm water, electricity, air conditioning and transportation in an acceptable environment and at an affordable cost.

[67] EU-WETO, ibid. p. 36
[68] EU-WETO, ibid. P. 130
[69] For a table on global hydrocarbon reserves, resources and occurrences, see N. Nakicenovic, Global prospects and opportunities for methane technologies in the 21st century, in IGU, Seven decades with IGU, London/Hørsholm (Dk), 2003, p. 119
[70] On long-term gas reserves and wellhead costs, see M. A. Adelman and M. C. Lynch, Natural gas supply to 2100, in IGU, Seven decades with IGU, London/Hørsholm (Dk) 2003, p. 81, figure 5
[71] Interpolated from WEC, Living in One World, London 2001, p. 179

Higher prices and efficiencies had resulted in a slowdown of world primary energy demand growth to 1.6% per year during 2020-2030. As during the same period, GDP growth stood at 2.6% per year[72], even in 2030 a full decoupling of world economic and energy demand growth had not materialised. Neither did expectations that new renewables would cover a notable share of supplies. In 2030, fossil energy still covered 88% of world energy demand, with coal covering 22%, compared with 24% in 2000.

2030 – 2050: a perspective

In 2030, the issue is one of resource constraint and opportunity. The concern is not so much the related rise of energy prices (which, as was pointed out earlier, had a beneficial impact on efficiency), or their impact on customers (average world income had doubled between 2000 and 2030 [73]), or a physical scarcity (unconventional fossil fuel resources are plentiful in 2030). Rather, the concern is the inefficient and unprofitable use, i.e. combustion of the valuable organic components of fossil fuels. Experience since the 2020s, had shown that chemical processing, particularly into clean transportation fuels, enabled a fuller and more profitable exploitation of the energy raw material.

The discussion in 2030 centres on what would be the factors shaping such a change of long lasting supply structures. Three factors appear determinant:

- A possible renaissance of nuclear power as a substitute for base-load electricity generation from fossil fuels. New nuclear could replace precious natural gas and coal in the base-load power generation market;
- The viability of chemical processing plants using fossil fuels to produce electricity, synthetic gas and oil substitutes, hydrogen, fertilisers and chemical products. Owing to synergy effects, these plants operate at high conversion efficiencies, reduce cost and minimise effluents and emissions (including carbon removal and storage); and
- A breakthrough of new technologies or renewables.

Chemical processing of coal may emerge as the likely winner, in quantitative terms, due to coal's comparatively favourable resource base, its price competitiveness and familiarity with much of the technical processes. Chemical processing into synfuels and gas could become a growth market for coal. Under market conditions, coal-based synfuels could cover by 2050 some 14% of world transportation fuel consumption. However, the coal industry would have to change: hitherto separate enterprises in coal mining, gasification, liquefaction and coal bed methane drainage, would have to integrate into necessarily globally operating oil and gas refining, product transportation and distribution businesses; the business strategy of coal companies would have to be subdued to the strategies of the processing and delivery conglomerates.

Whether servicing the traditional power generation market or the clean transportation fuel market, coal no longer reaches the end user as "coal". The term "coal" itself is replaced by brand names, which highlight the service rendered (power, mobility) without identifying the raw material (coal). Ironically, concerns expressed at the beginning of the century that the lack of public acceptance might be an obstacle to the growth of coal

[72] EU-WETO, ibid. p. 122
[73] EU-WETO, ibid. p. 130

demand, proved unfounded: there is no direct interface any more between "coal" and the end user except in very rare cases of its direct use as a fuel or … as a piece of art[74].

The message: while confirming the important societal role of coal in meeting the aspirations of nations for development and sustainability, a study undertaken by the WEC in 2030 on "Energy for the World of 2050" is unlikely to conclude on a continuation of the trends which prevailed during 2000-2030. Rather it would point to a significant but challenged role of coal in traditional power generation, and to its comeback, as a derivate in markets, which it had lost with the advent of cheap oil and gas, - some hundred years ago.

[74] Traded as coal ceramics

PART I:

GLOBAL ANALYSIS

Chapter 1:
Coal Demand and Trade: Growth and Structural Change in a Competitive World Market

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Key messages:

- Coal demand has grown steadily over the past thirty years and will continue to grow, in particular from the electric power industry.
- Although coal reserves are vast and widely distributed, demand growth is strongest in countries with limited indigenous resources. There is a significant change in the regional pattern of coal demand, with a shift to Asian markets.
- Coal trade has grown much faster than demand, but is still a small proportion of total demand. Coal trade will also continue to grow, at a faster rate.
- Coal transport costs are relatively high as a proportion of its final price.
- Industry consolidation progresses but does not impede competition as new suppliers enter the market.
- Long-term contracts are increasingly replaced by spot contracts and tender transactions.
- E-commerce is developing, based on standard contracts for steam coal.
- International coal prices have remained stable relative to oil and gas, and are expected to maintain this position, thereby enhancing coal's price competitiveness on the international market.

1. Demand Trends

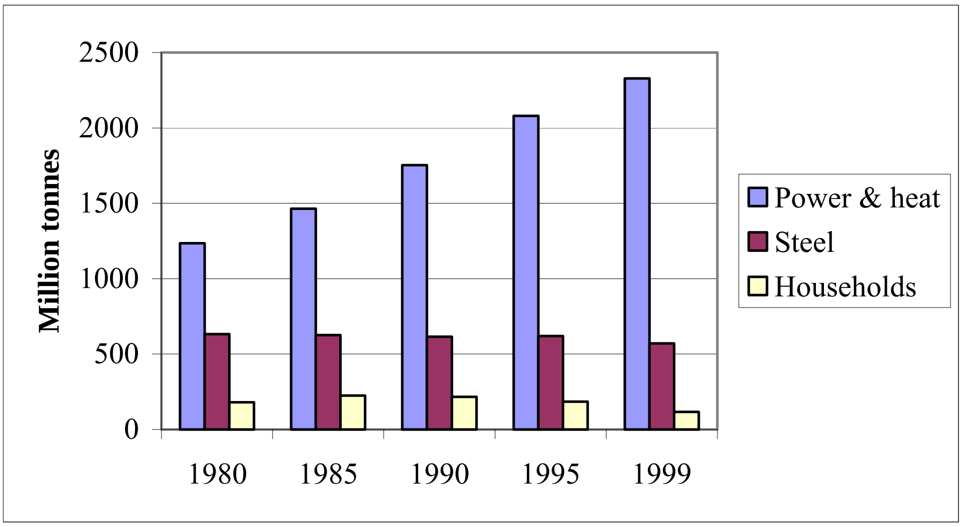
It is not generally considered economically feasible to transport or trade lignite, so for the purposes of this chapter, we will consider hard coal (steam and coking) only. For a broad discussion on the role of lignite in power generation, please refer to the paper ("Markets for Lignite") in Part III of this report[75].

The global trend of hard coal demand has been one of increase over the last thirty years, albeit with a recent slight decline in the latter part of the 1990s – although this is likely to have been heavily influenced by Chinese figures. The International Energy Agency (IEA) figures show an increase in global consumption from just over 2000 Mt in the early 1970s to over 3500 Mt in 2000, an increase of over 38%. Over the same time period, oil use increased by 32% and remains the largest energy source. Gas usage increased by 57% over this time. Regional consumption patterns have also changed over this period, with the bulk of the increased total demand coming from the Asian region. Only a relatively small fraction of this consumption is internationally traded – about 17% - but this has increased much faster than overall demand.

1.1 Sectoral changes in demand

Hard coal is used for two main purposes – electricity generation (steam coal) and coke production for use in steel making (coking coal). Approximately 16% (almost 600 Mt) of total hard coal production is used by the steel industry, with almost 70% of the world's total steel production being dependent on coal. Coal provides over 23% of global primary energy needs, and generates about 38% of the world's electricity.

Graph 1-1: Coal Demand by Sector



Source: IEA

As the chart demonstrates, the increased demand for coal over recent years has been exclusively as a result of increased demand from just one sector – the power and heat sector. Overall consumption within the steel industry has declined slightly, due mainly to

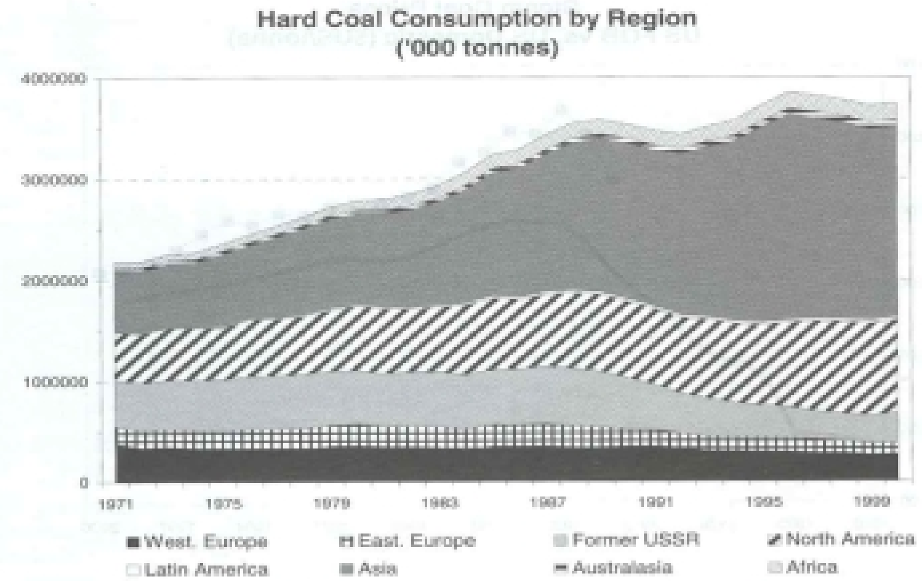
[75] Markets for Lignite, Case Study 9, by Eckart C. Günter

increased use of pulverized coal injection (PCI), although increased use of electric arc furnaces and higher rates of steel recycling may also play a part.

1.2 Regional changes in demand

Significant changes in the location of coal demand have taken place over the last twenty years. In 1980, Europe, FSU and North America consumed roughly equal quantities of hard coal, around 600 Mt. North America's demand, as a percentage of total global consumption, has stayed roughly static at around 25% (in real terms, an increase of 300Mt over the period). However, by 1990, the trends were of decreasing demand in Europe and the FSU. By 2000, European demand had fallen to just 10% of total global hard coal consumption (in physical terms, a decrease from 584 Mt in 1980 to 373 Mt in 2000). Demand in the Asia-Pacific region for hard coal, in contrast, has increased dramatically from 34% (of global demand) to 52% over the same period – an increase equivalent to almost one billion tonnes.

Graph 1-2: Hard Coal Consumption



Source: IEA, 2001

One reason for this is the huge increase in demand for electricity in Asian countries. China's electrification programme, for example, has connected 700 million people over the last fifteen years. As a result of the programme, electricity production in China has increased by nearly 1000 TWh. 84% of this is coal-fired. Forecasts indicate that this regional trend will continue, with the bulk of the projected increase in global coal demand coming from the region.

Japan continues to be the largest importer of hard coal – both steam coal and coking coals – and is projected to account for 24% of total world imports by 2020. Other Asia-pacific countries, such as Malaysia, Philippines, Thailand, are looking to coal to diversify their energy mix and provide a secure supply of affordable energy to meet their growing electricity needs.

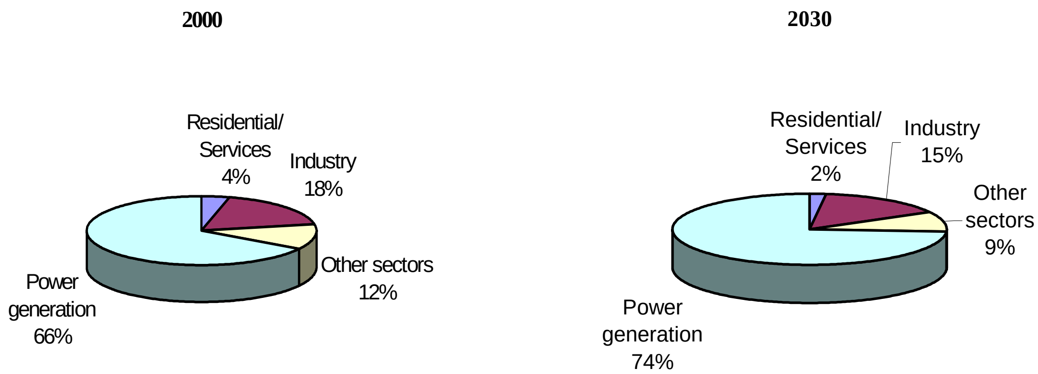
The decline of coal consumption in the EU can be attributed to a number of factors, including more stringent environmental legislation, and the availability of gas from the North Sea, Russia, and North Africa. As older coal-fired plants faced retirement, the capital costs of building combined cycle gas plants were considerably lower than building a new coal-fired plant with the required environmental controls, and at a time when gas prices were relatively low, was the economic option. However, such long-term decisions can be affected by the vagaries of gas prices – as occurred in the UK in 2001, when coal-fired plants were brought back on-line due to sudden increases in gas prices.

The effects of enlargement within the EU will also have an impact on coal demand in the region, as much of the power generation capacity of accession countries is coal-fired. Poland and the Czech Republic, for example, generate 96% and 71% of their electricity demand from coal.

1.3 Demand projections

To be discussed in Chapter 6, there are many projections regarding future coal demand. However, all concur that global coal demand will increase over the relevant projected period.

Graph 1-3: Coal Demand by Sector



In this section, we will consider projections for hard coal and coking coal separately. The IEA World Energy Outlook projections (as seen in the pie charts) suggest that the bulk of the projected increase will take place in the power sector, accounting for 74% of the estimated total demand of 3606 Mtoe by 2030. It is expected that almost 90% of the increase in coal demand between 2000 and 2030 will be as a result of power generation.

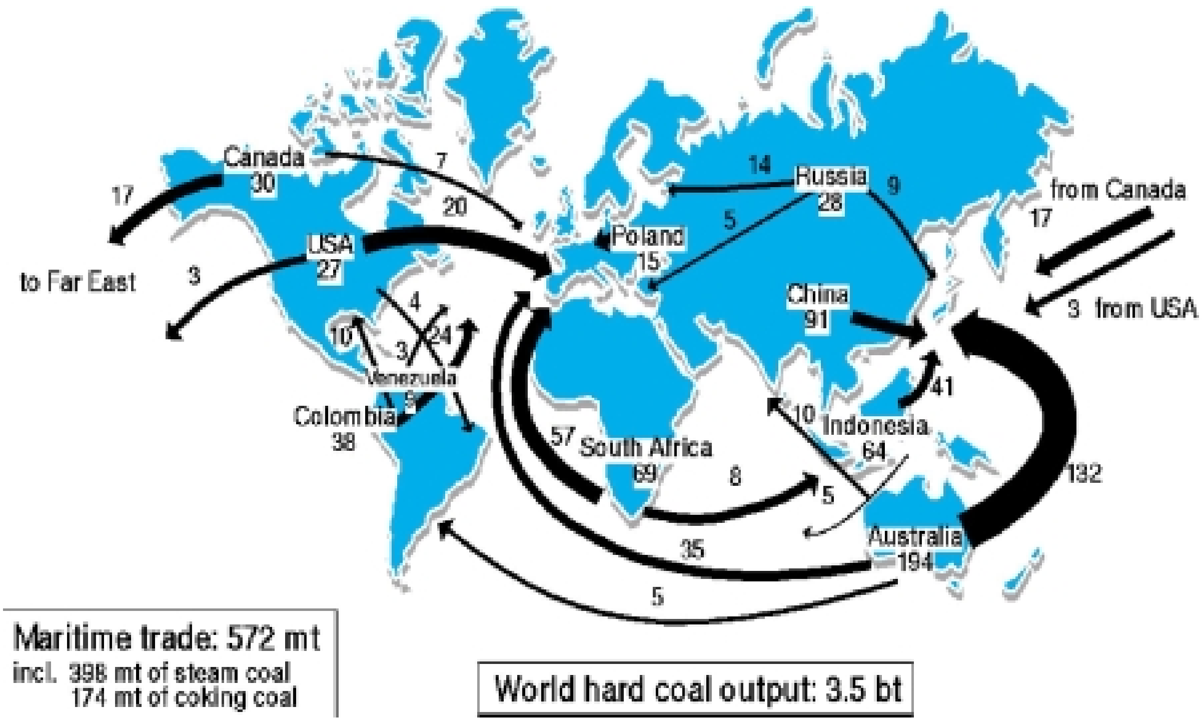
Coal demand is expected to be strongest in the developing world and the transition economies, where local supply is ample and production costs low. It is thought that a lack of gas resources will swell coal's role in several countries, particularly India and China, who will account for over 60% of the increase in world coal use over the next thirty years.

2. Hard Coal Trade

Because of the expense of transportation, most traded coal is hard coal, which has higher value and energy content. Coal trade, especially seaborne trade in hard coal, has on average risen by around 4% a year since 1970, with the growth dominated by the trade in steaming coal (used mainly for electricity generation). The initial growth in coal trade during the 1970s was due to strong growth in steam coal demand as coal widely replaced oil in electricity generation as a result of oil price rises (IEA 1997). More recently, the growth in steam coal trade has been driven by greater imports from Japan, developing Asia and Latin America where there are inadequate domestic reserves to meet growing demand. The largest coal exporters are Australia, South Africa, Indonesia, United States, China and Colombia.

In 2001, hard coal trade continued to expand and grew by 7% to 610 Mt. Thus, the international trade volume has increased by approx. 100 Mt or 20% in the last two years. The share of hard coal trade in the global hard coal output was 17%. Worldwide hard coal trade is divided into maritime trade of 572 Mt and internal trade of 38 Mt.

Fig. 1-1: Key Trade Flows in Hard Coal Traffic by Sea in 2001 (Mt)

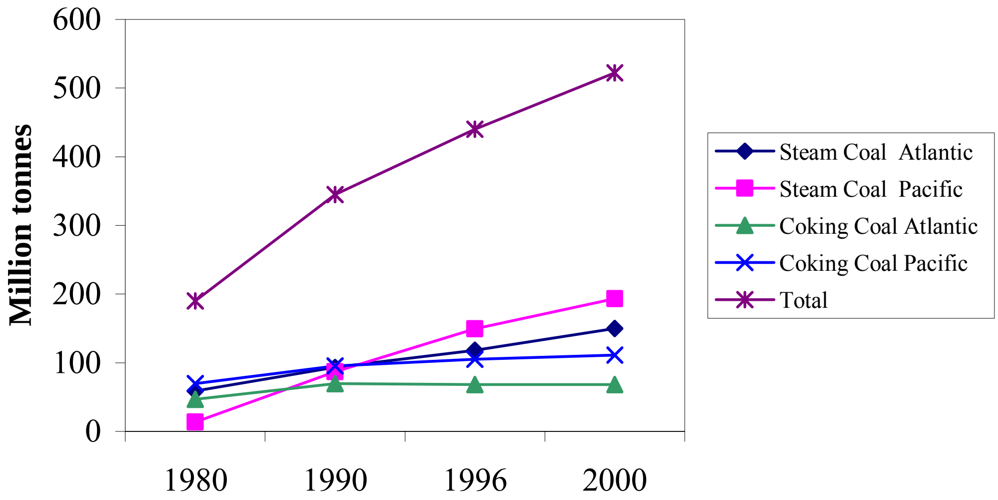


In 2001, international hard coal trade in maritime traffic totalled about 17% of worldwide hard coal output. Thus almost 85% of hard coal output is consumed in the mining country itself – in particular for power generation and, in addition, by some key industries, such as iron and steel, cement and chemicals. This is especially true for the three largest hard coal producers China, US and India.

Of total hard coal overseas seaborne trade in 2001, approx. 398 Mt were accounted for by steam coal and 174 Mt by coking coal. The most important exporting countries in 2001 were Australia, China, South Africa and Indonesia, whose exports totalled 73% of seaborne hard coal trade. The major importing continents are Asia (mostly Japan) and despite a general decline in overall consumption, Europe.

A major determining factor of the export flows from supplier countries is the geographical position of the recipient countries. For example, the hard coal market in Asia is marked by deliveries from Australia, China and Indonesia. Other suppliers for Japan and the newly industrialised countries in the Asian-pacific area – in particular, South Korea, Taiwan and Hong Kong – are South Africa, US, Canada and Colombia. The market leaders for the EU are South Africa, Australia, Colombia, the US and Poland.

Graph 1-4: Development of Seaborne Trade



Source: World Coal Institute, *Coal Facts*, October 2001

The graph clearly shows how Pacific steam coal trade surpassed the Atlantic market in the early 1990s, and by 2000 was more than 20% higher.

Today, international hard coal trade is – to a growing extent – handled directly between producers and consumers. The traditional role of traders was to negotiate business between suppliers and consumers and to close deals, but also to bundle the small amounts which had been ordered by several consumers for delivery as one aggregated shipload and – subsequently – to pass the 'part' shipments on to the respective customers.

Due to the increasing number of direct transactions between the producers/suppliers and the consumers, the scope of functions to be fulfilled by the remaining traders is undergoing change. The traditional trading transactions are moving more and more towards, non-transparent market segments and the handling/distribution area. In addition, traders are increasingly assuming the role of the sales agent acting for big producers, which means rendering assistance in implementing contracts and supporting customers. The ongoing change of coal into a commodity will offer traders a new market segment in the future, if appropriate trading forms are established. Perhaps the largest potential for coal trading will be in the Asian markets, encompassing the large producers and importers.

3. Industry Consolidation

The international hard coal market is characterised by competition among a multitude of suppliers – traditional and new suppliers, which include both mining companies and trading firms. In 2001, more than 100 producers were active on the world market. Within the export-oriented hard coal mining industry, there have been two somewhat conflicting trends. First, there has been significant consolidation at corporate level, among the main companies involved in international coal trade. But at the same time, new exporting countries have significantly expanded their market share, bringing new companies into the international market.

There are a number of reasons for the consolidation at corporate level - by enlarging assets, companies can take advantage of economies of scale, and can reduce their overhead costs. Larger operations bring greater revenues, unproductive activities can be closed, and the increased wealth of the company allows investment in modern mining technologies, increased productivity and reduced labour costs. Functions can be spread between several operations - allowing legal or technical fees to be reduced.

Consolidation is also a result of price decreases. As prices fall, fewer mines are considered economic as sole entities, and are sold off. Mergers and acquisitions increase, resulting in well-run, efficient companies taking the market. Horizontal integration may also come into play - mining companies today are usually conglomerates in the extractive industries, with coal being only one of their products. This goes hand-in-hand with globalisation - as new markets are opened up, companies expand their area, and risks in one geographical or sectoral field can be offset against less risky, more profitable areas of the business. Risk management may also be achieved through vertical integration, seen in a number of producer areas – expansion into transport and power generation, however may be seen as countering the efficacy of the market through reduced competition.

4. Coal Contracts

Between suppliers and demanders in the international hard coal market, both long-term supply contracts and spot transactions are frequent instruments, though the importance of long-term contracts is decreasing. The share of spot transactions in the coal quantities imported by the EU rose from 14% in 1980 to 65% in 2000. The reason underlying these developments is the abundant availability of coal on the world market, and – as a result – the improved security of supply, which in turn entails a reduction in one-sided dependencies.

4.1 Long term contracts and the spot market

Long-term contracts were once concluded for periods of up to ten years. They stipulated the annual delivery quantities, including buyer and seller options, as well as fixed prices for each current purchase year. Today, however, long-term contracts are concluded – if at all – only on domestic markets, e.g., for the supply of mine-mouth power plants or steel mills, and where long-term mutual dependences exist between producer and consumer.

The character of long-term contracts has undergone considerable changes, in view of the growing pressure exerted by spot transactions. They may last for shorter periods (often less than three years) and focus on quantities rather than price, which is negotiated separately. The aim is to secure long-term cooperation between supplier and consumer by selling or purchasing rights (including buyer's options) provided that agreement can be reached upon the purchase price, guaranteed for only three months.

In signing spot contracts, the consumer can respond to the current market in a much more flexible manner. In particular, the following aspects can be the reason for the conclusion of one-time supply or only short-term contracts by the buyers:

- Optimum use made of the trend in prices;
- Purchase of "smaller" quantities on favourable conditions; as well as
- Covering of consumption peaks exceeding the respective time horizon.

Spot prices will respond to the market situation, exceeding long-term contract prices when the market is tight, and undercutting when the market is well supplied. In this way the spot price reflects more accurately the market conditions, thereby also acting on negotiated long-term contract prices.

A variant of spot purchases is the growing number of tender transactions, i.e. purchases which are preceded by an invitation to tender and where the best tender wins the contract. The deliveries agreed in this way usually comprise a larger volume than that of individual transactions, and in most cases the time frame covers one to two quarters.

4.2 E-commerce

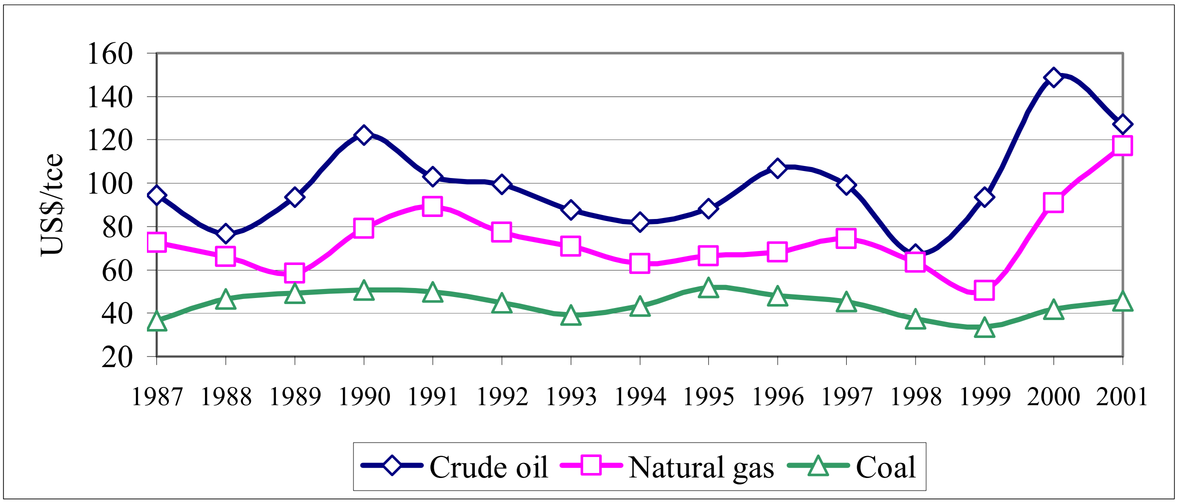
A further development in a changing world coal market is the arrival of e-commerce. GlobalCoal was set up by nine major players in the energy sector – coal suppliers, coal traders and coal users – in 2001, and provides an electronic, on-line trading service for its members. The key aim of the system is to create standards for the trading of commoditised seaborne steam coal, in order to promote a reliable financial trading and risk management system. Standard contracts provide a single set of legal terms and conditions, and standard quality specifications. The service is run on a confidential, independent and neutral basis, and started trading in May 2001. So far over 19 Mt of physical or financial coal has been traded, and the members now total 36.

4.3 Pricing

There is neither a single world market for coal nor a single coal price, although as the chart below indicates, coal has consistently been the most stable and affordable fossil fuel in terms of price trends over the last fifteen years.

The information in this section has been derived from a contributing paper “Actual and projected coal prices: an inter-fuel comparison”, Gawlik, 2001, see Part III of this report.

Graph 1-5: Price development of crude oil, natural gas and coal



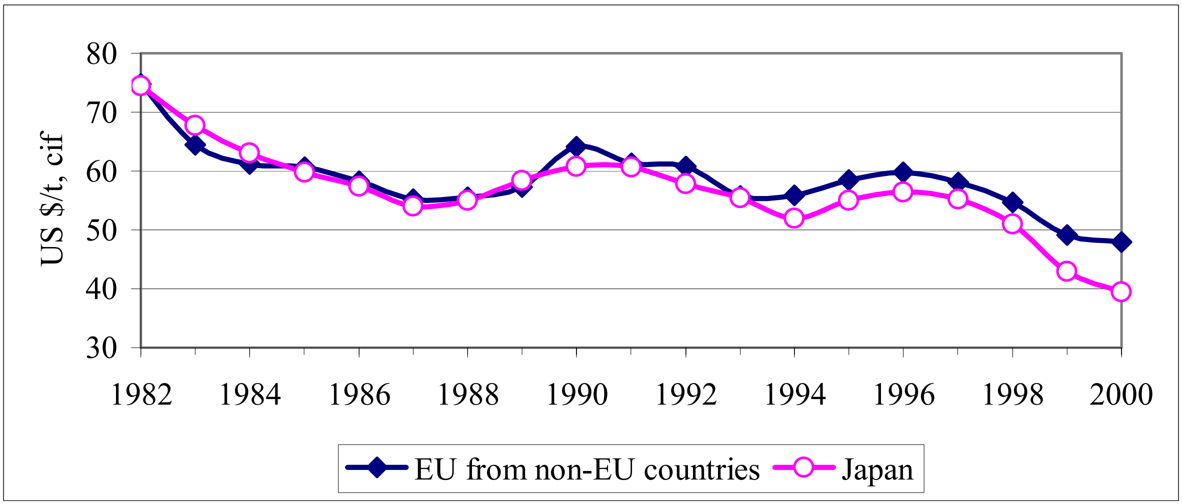
Crude oil - Brent, spot
Natural gas - imported to EU, cif
Coal - MCIS marker price, Northwest Europe, cif
Series recalucluted to tce (tonnes of coal equivalent); 1 tce = 7000 kcal/kg
Data source: *BP, 2002*

In general, separate markets exist for steam coal and coking coal, with the main markets identified on a geographical basis.

Coal price analyses are carried on the base of cif ('cost, insurance, freight') prices paid in the two main importing regions (EU and Japan) or on the base of fob ('free on board') prices in main exporting countries. Cif prices depend very heavily on the cost of transportation both in the country of exporter (between mine mouth and ports) and ocean freights.

The cost of transporting coal represents a sizeable component of the final delivered price to end-users, and as a result, affects the demand for coal and the geographic extent and operation of coal markets. Transport costs (rail and port, ocean freight, port and barge charges) can account for more than 50% of the price of coal – and as ocean transport costs are currently as volatile as the coal market itself, they can have significant impact on the fob prices as the Atlantic and Pacific markets balance supply and demand.

Graph 1-6: Average import unit values, US$/t cif of steam coal imported to European Union from non-EU countries and imported to Japan

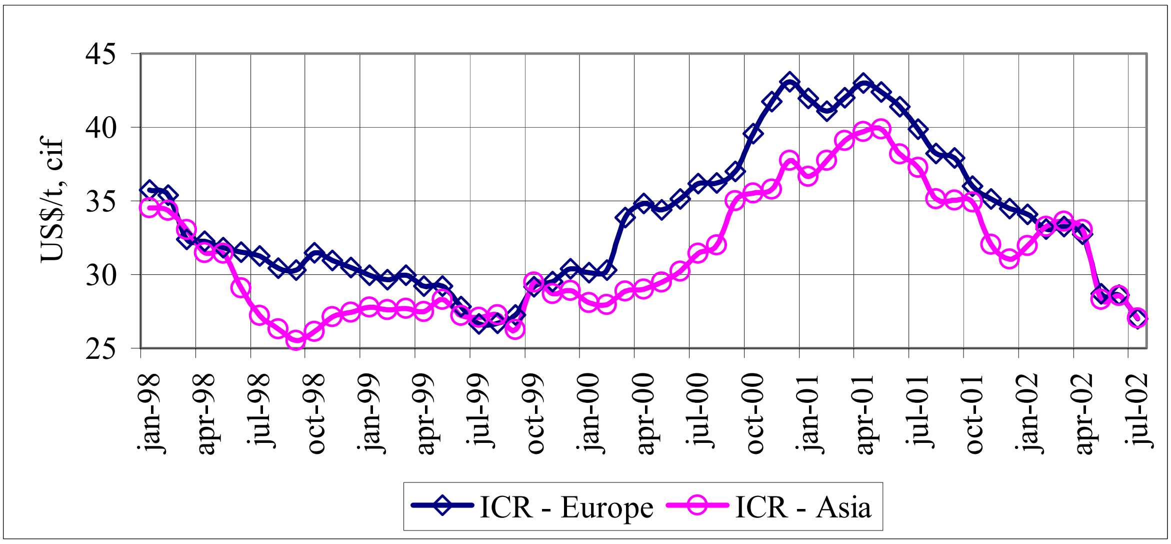


Source: IEA, *Coal Information 2001*

Both European and Asian customers continue shifting out of long-term purchase commitments, relying upon either spot purchases or long-term arrangements covering committed volumes, but with prices renegotiated annually. The contract prices and also custom values of all transactions generally follow the spot prices with a lag of up to one year.

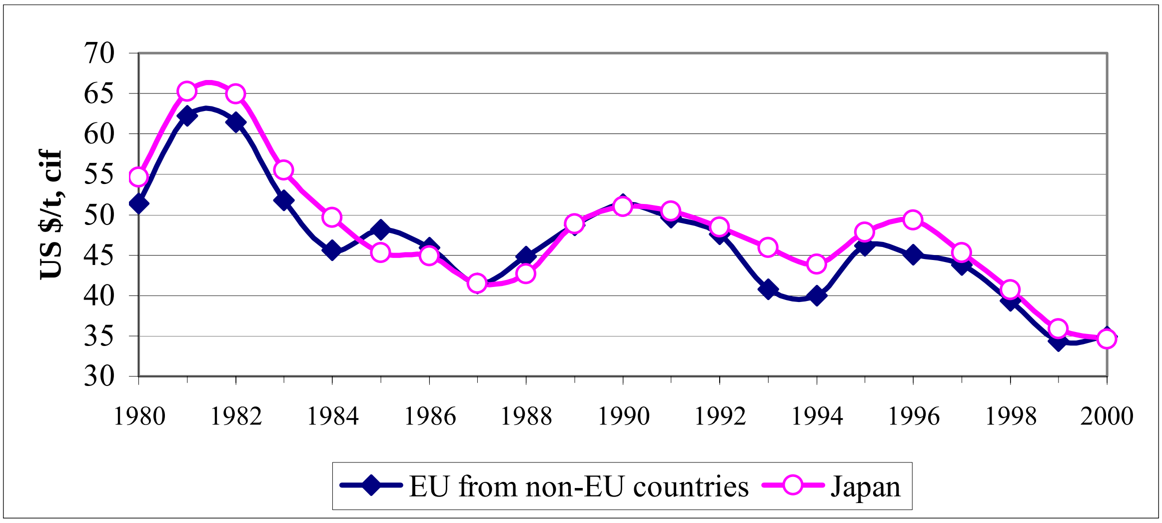
Various indices have been developed to report the current trends in coal prices. They take into account different coals and different sets of transactions. The representative spot prices for steam coal in both the European and Asia – Pacific markets are shown in the following graph. These are averaged quarterly prices recalculated into prices of coal equivalent (7000 kcal/kg).

Graph 1-7: International Coal Report Steam Coal Market Price in Europe and Asia



Source: ICR, selected issues

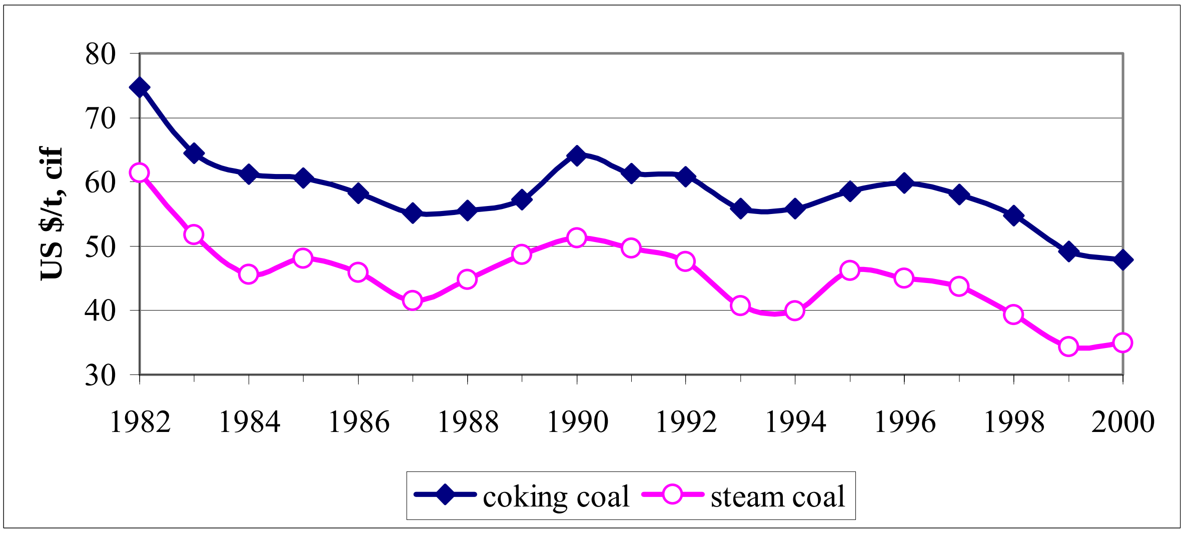
Graph 1-8: Average import unit values, US$/t cif of coking coal imported to European Union from non-EU countries and imported to Japan



Source: IEA, *Coal Information 2001*

Thus it may appear that the overall trends are very similar in the two markets. It should however be noted, that the lower average import unit values recorded in recent years in Japan, are the results of accounting by custom officials, the Indonesian coal as coking coal even though it is not generally used in the metallurgical industry. Japan is the largest coking coal importer, and thus has a significant influence on world prices.

Graph 1-9: Comparison of coking coal and steam coal prices in Europe (measured by import unit values US$/t cif)



Source: IEA, *Coal Information 2001*

5. Exports

In this section, we consider the emergence of relatively new players on to the export scene, although the traditional exporters of Australia, South Africa will continue to dominate for some time.

5.1 The emergence of China and its impact on world markets

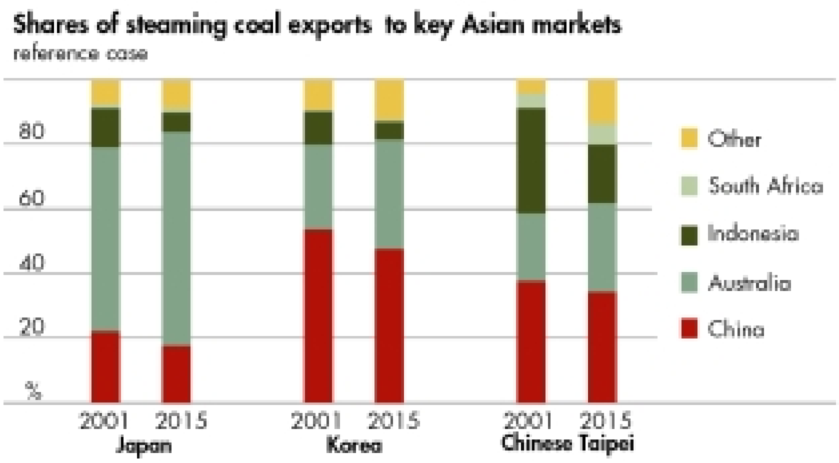
As the world's largest coal producer and second largest exporter, the Chinese coal industry has a significant impact on the global coal market, particularly since its admission to the World Trade Organisation (WTO), and with its increasingly open borders.

China is the world's largest consumer of coal, at an estimated 1205 Mt in 2001 (almost one-third of total global hard coal consumption). Of this, the electricity sector accounts for more than half.

While consumption has declined over recent years, there are now suggestions that coal consumption has started to rise again. A significant increase in production in the mid-1990s, combined with declining domestic consumption generated a serious imbalance in supply and demand, with few incentives to respond to the changing domestic market signals. This over-production led to a significant increase in the coal stockpile – estimated to be in excess of 200 Mt in 1998 – and low domestic coal prices, prompting producers to seek better prices elsewhere.

As a result, there was a dramatic increase in China's coal exports, from 32 Mt in 1998 to more than 90 Mt in 2001. The majority of this increase has been in the steam coal market, particularly to Korea. China's increasing competitiveness as an international supplier can be linked to a number of factors, including production assistance, export incentives, development of coal distribution infrastructure and the desire of Asian buyers to diversify their energy sources.

Graph 1-10:



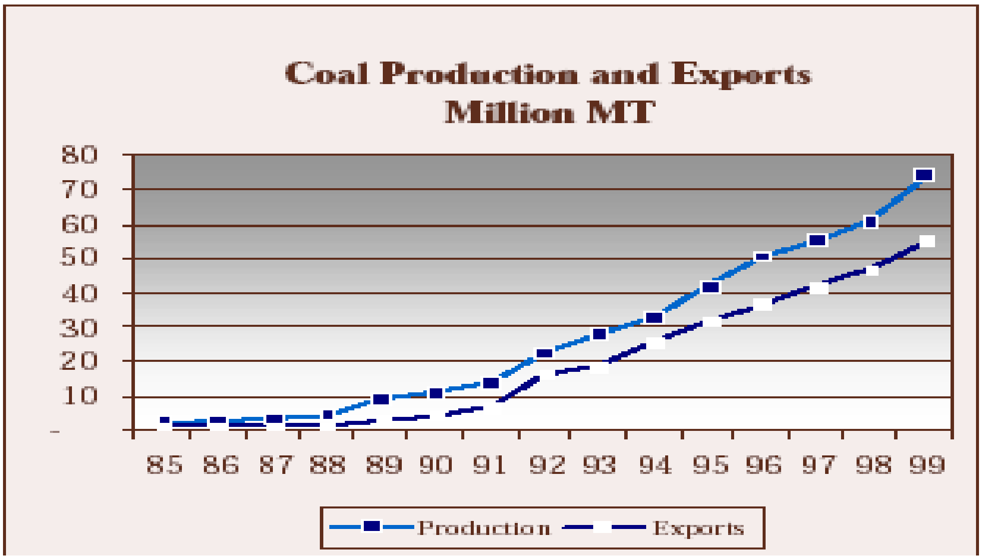
Source: ABARE

China is expected to remain the world's second largest supplier of coal to international markets, expanding by 1% per year to reach 105 Mt by 2015.

5.2 Indonesia – rapid export growth

Indonesia is the world's fourth largest exporter of coal, yet this growth has occurred only over the last twenty years. Almost all coal production, as shown in the chart below, is for the export market. In 1983, the country produced only 0.5 Mt, but by 1998 exports had reached almost 50 Mt, and by 2000 exports were around 60 Mt. Despite political instability in the country and the impacts of regionalisation, production levels continue to rise, and the increasing demand for the low-sulphur coals of the region from both European and Asian markets would appear to assure Indonesian producers of a steadily growing market for the foreseeable future.

Graph 1-11:



Source: US Embassy Jakarta, *Coal Report 2000*

Sources:

- IEA, *Coal Information*, 2001
- IEA, *World Energy Outlook*, 2002
- *World Market for Hard Coal*, Edition 2002, RWE Rheinbraun AG
- World Energy Council, *Survey of Energy Resources*, 2001
- "Trade in Coking Coal and Steam Coal", H-W Schiffer, 2001
- "Actual and projected Coal Prices – an inter-fuel comparison", L Gawlik, 2001
- "Consolidation & Globalisation in the Coal Industry", C Copley 2002
- WCI, *Sustainable Entrepreneurship – the way forward for the coal industry*, 2001
- "China's Changing Coal Industry: Implications & Outlook", ABARE, 2003

Chapter 2:
Coal Production, Productivity and Profitability: The Promise of Restructuring, Integration and Consolidation

Zygmunt Borkowski, Kompania Wcglowa S. A., Poland

Key messages:

- World coal production and demand will grow worldwide, as coal remains an attractive energy source: it is available, secure and affordable.
- Production will almost certainly continue to decline in Europe as industry restructuring continues. Also coal consumption may well decline (albeit at a slower rate) as environmental pressures tighten and public policy tends to encourage the use of gas and renewables. But any decline in consumption is likely to be relatively slow by recent standards and in comparison with production.
- In other regions, growth is more likely. In North America, IEA projects growth to 2020 to be steady, rather than spectacular (0.6% p.a.). Asia could see more rapid growth in coal demand: 2.2% pa for China and 3.4% p.a. for East Asia, for example.
- This reflects the fact that the underlying drivers which have boosted growth in coal production and demand over the past few decades remain firmly in place, including rapid growth in electricity demand and coal-fired generating capacity.
- World coal trade is projected to increase from 650 Mt in 2001 to 826 Mt in 2025, accounting for between 11 and 13 percent of total world coal consumption over the period. Steam coal (including coal for pulverized coal injection at blast furnaces) accounts for most of the projected increase in world trade.

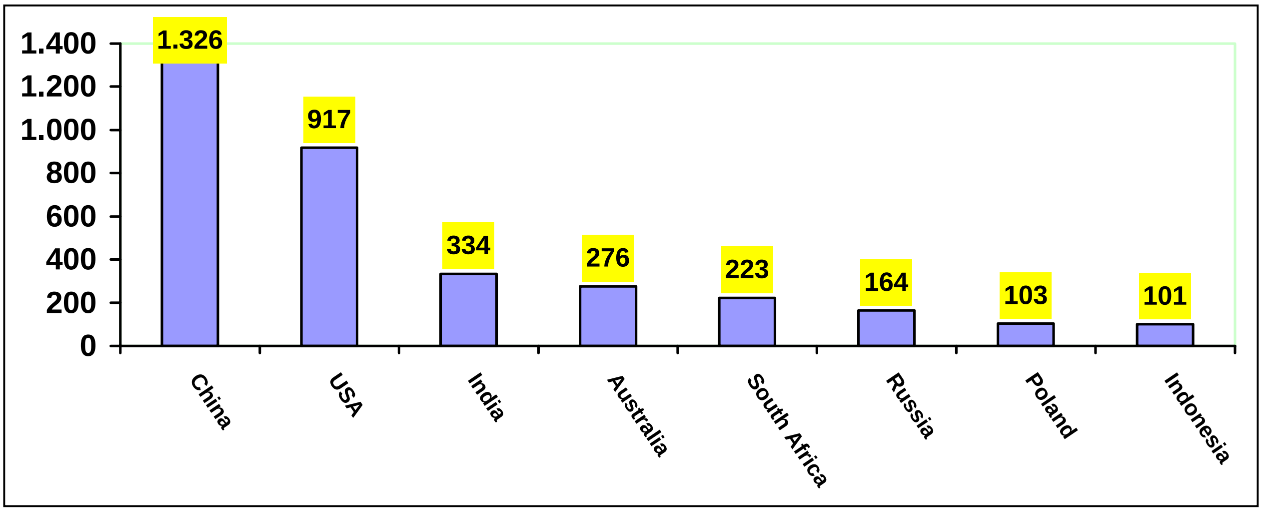
1. Production, Productivity and Restructuring of the Coal Sector as of 2001 and Prospects to 2025

Since the late 1980s, world coal consumption and production experienced a period of generally slow growth and this trend is projected to continue.

Growing production is the outcome of growing demand, especially from one main area that of Asia. Growth has been strongly driven by growth in electricity demand, which continues to be fuelled substantially by coal – as in other regions. Consumption in other sectors (industry, the residential sector and, in some countries, transport) is stable or declining.

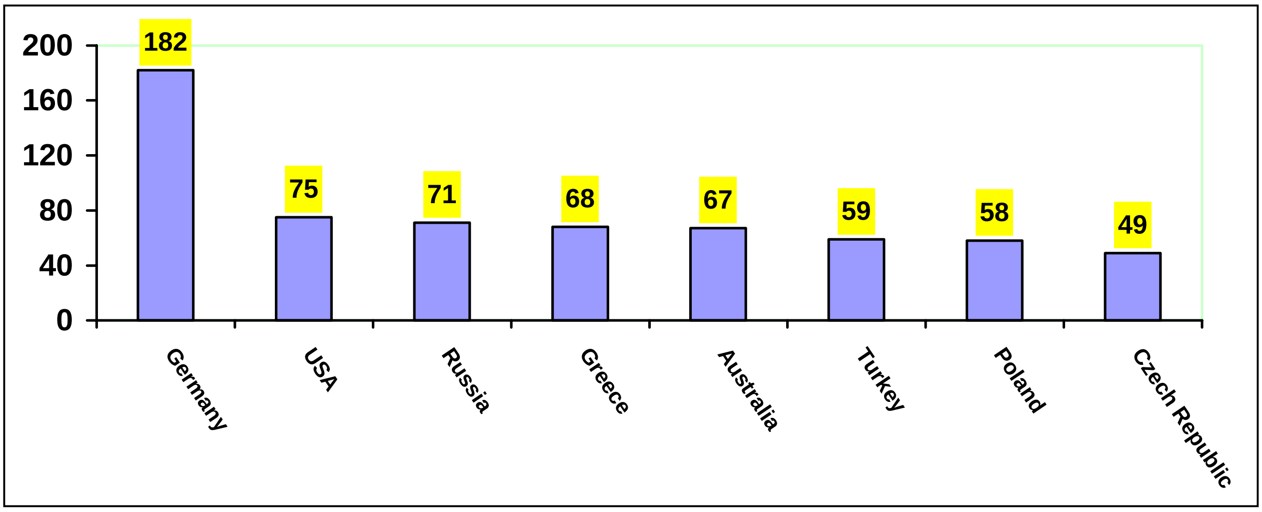
In 2002, total global hard coal production was 3.837 Mt compared to 2.563 Mt in 1977. This is a 50% growth over the past 25 years.

Graph 2-1: Major producers of hard coal in 2002 (Mt)



Total global brown coal/lignite production in 2002 was 877 Mt, slightly over 20% of this amount was produced in Germany - the world's largest brown coal/lignite producer.

Graph 2-2: Major producers of brown coal/lignite in 2002 (Mt)



Known coal reserves are spread over almost 100 countries. At current production levels, proven coal reserves are estimated to last over 200 years.

Due to the high cost of deep mined production, the gradual withdrawal of coal subsidies and the pressures of competition in electricity markets, coal production in Europe has declined. However, in Australia, coal production rose by over 50% during the 1990s and in Indonesia by 750%. Indonesia's production of hard coal was only 5% of that of the European Union in 1990. Recently with 100 Mt (2002), it was greater than that of the entire EU. These growth rates were produced by competitive private sector activity, driven by rapid cost reductions and the use of modern techniques, mainly in opencast rather than deep mines.

1.1 Europe

Coal as an energy source (both hard coal and lignite) was one of the leading factors that shaped Europe's economic and political development. Today, coal accounts for some 25% of the EU's electricity supplies. It is indispensable for steel production and other energy-intensive industries. Coal's importance in Europe is expected to grow with the EU enlargement. In many of the accession countries, hard coal and lignite play a key role in the energy supply sector.

The European Commission has established a new state aid scheme for coal to allow for the continuation of subsidies for hard coal production in member states until 31 December 2010. In essence, the Commission established measures that promote the development of renewable energy sources, in addition to maintaining a minimum capacity of subsidised coal production in the European Union for the purpose of establishing an "indigenous primary energy base." Under this new scheme, the guiding principle for coal will be that subsidised production will be limited to that, which is, strictly necessary for enhancing the security of energy supply (i.e., to maintain access to coal reserves, keep equipment in an operational state, preserve the professional qualifications of a nucleus of coal miners and safeguard technological expertise).

The recent trend in the consumption of hard coal in Western Europe is closely correlated with the trend in the production of hard coal, primarily because coal imports have increased to a lesser extent than production has declined. Following the closure of the last remaining coal mines in Belgium, in 1992 and Portugal in 1994, only four member states of the former European Union (the United Kingdom, Germany, Spain, and France) continue to produce hard coal, and all have seen their output decline since 1990.

In 2002, Europe and Turkey accounted for over 60 % of the world lignite output, which is contrary to the situation in oil or natural gas, since the focus of this energy source is on Europe. The enlargement of the European Union in 2004 added two important producers of hard coal and lignite: Poland and the Czech Republic.

United Kingdom (UK) Hard coal production in the UK decreased from 104 Mt in 1990 to 30 Mt in 2002, a decline of 74 Mt. Of total indigenous production, deep mines accounted for 16.4 Mt, with 13.1 Mt from surface mines and 0.5 Mt from other sources.

The UK's coal mines are located mainly in central and northern England, south Wales and central and southern Scotland, where there is the largest concentration of surface mines. At the end of 2002, there were 15 large deep mines in operation. Twelve of these were owned by UK Coal plc. The other large deep mine producers were Coalpower Ltd, Tower Goitre Anthracite Ltd. and Betws Anthracite Ltd. In addition, there were 10 smaller deep mines in production. There are about 50 surface mines in operation and about 20 surface mine operating companies. The largest of these are UK Coal and Scottish Coal, each producing over 4 Mt a year out of the total 2002 output of 13.1 Mt.

Currently, the UK's remaining coal mines are by far the most productive hard coal operations in Western Europe. Substantial improvements in the country's mining operations in recent years have led to an increase in average labour productivity from 1,190 tonnes per miner-year in 1990 to 3,200 tonnes per miner-year in 1999. Despite this achievement, the price of coal from domestic mines is essentially at parity with the price of coal imports, and it is likely that production from domestic mines will continue to be sensitive to changes in international coal prices. In fact, following several years of sharp declines in international coal prices in 1998 and 2000, the UK government reinstated coal production subsidies for 2000 to 2002 in an effort to protect the country's remaining coal operations.

Germany's[76] hard coal production declined from 86 Mt in 1990 to 32 Mt in 2001. The revised restructuring agreement calls for an additional reduction in Germany's coal production to 26 Mt by 2005, to be achieved by further mergers. The net result of all planned mergers: a capacity reduction of 8.2 Mt and the loss of over 10,000 jobs. The closure of three coal mines in 2000 (with a combined production capacity of approximately 6.7 Mt) leaves Germany with only 10 remaining hard coal mines in operation.

Sales of hard coal and coke from the German underground mining sector in 2002, amounted to some 28.6 Mtce. From this, the power generating industry consumed 20.8 Mtce while 7.2 Mtce was supplied to Germany's steel industry. On the heat market, sales totaled 0.6 Mtce.

[76] Case Studies by Eckart C. Günther. and Hans-Wilhelm Schiffer, in Part III

Deutsche Steinkohle AG (DSK) performs mining activities at the three locations: Ruhr, Saar and Ibbenbüren, under the umbrella of RAG AG, Essen. In 2002, DSK mined 26.1 Mt of saleable hard coal (corresponding to 26.8 Mtce).

In 2002, a steady decline in employment can be recorded. The workforce in the hard coal mining sector decreased from 52,576 employees on 31 December 2001 by 7.4% to 48,673 as of 31 December 2002; 24,635 employees worked in underground operations, which accounted for 51% of the workforce (31 December 2002). Mining production efficiency, in terms of output of saleable production per employee and shift in underground operations, increased by 4.7% from 6,244 kg in 2001 to 6,539 kg in 2002.

In 2003, the reduction of the workforce continued at about the same rate as in the previous year. By the end of 2003, the number of employees amounted to some 45,000, due to the optimisation of operations, thus the year 2003 is expected to record another increase in efficiency.

As early as mid-2002, the most important steps towards setting the scene for the longer-term perspective of the German hard coal mining industry were taken at a European level. On 23 July 2002, the Treaty on the European Coal and Steel Community expired. The day after the new regulation on public aids – now based on the EC Treaty - entered into force. Until 2010, this regulation permits the granting of aids to ensure that a minimum production of domestic hard coal is maintained with the object of retaining access to the deposits. Until late 2007, public aids can be granted for a cutback in mining operations. In addition, it is permissible to grant aids for covering extraordinary financial charges, such as, for the satisfaction of environmental liabilities incurred by former mining operations. Hence, the new European administration of public aids not only safeguards coal policies agreed between 1997 until 2005, but - above all - provides a perspective for an efficient and viable hard coal mining industry up to and beyond the year 2010.

DSK hopes to keep domestic coal output from the operating ten mines on a stable level, until 2005 when the existing German coal aid system is to be replaced. Beyond that, coal capacity must fall by 3-4 Mt before the end of 2007, in accordance to a requirement imposed by the European Commission, when it authorised German coal aid for 2000 and 2001; two mines will be closed in 2006 and 2007. This will reduce output to about 22 Mt by the end of 2007. Over the following five years, the latest political decisions will cause production to be further reduced by another 6 Mt to reach an annual 16 Mt.

For its energy supply, Germany is highly dependent on imports. Lignite is the only domestic energy source that is available in sufficient quantities and free of subsidies. In 2002, 182 Mt of lignite was mined. This quantity corresponds to a calorific value of 56.4 Mtce.

Power plants are the main consumers of lignite. In 2002, 169 Mt of domestic output was used for power and district heat generation. This is equivalent to 93% of total production. Nearly all of Germany's lignite is mined in opencast operations. In 2002, 933.7 Mcbm of overburden had to be removed for lignite extraction. In relation to output of 182 Mt, this yields an average overburden-to-lignite ratio of 5.1 cbm to 1t of lignite.

Lignite mining is concentrated in four regions. These are the Rhineland (55% of total output), Lusatia (33%), Central Germany (10%) and Helmstedt (2%). In the Rhenish area, RWE Power AG (formerly RWE Rheinbraun AG) extracted 99.4 Mt lignite in 2002. This output is distributed between the various opencast mines, Garzweiler, Hambach and Inden. In 2002, the Lusatian mines produced some 59.3 Mt of lignite. The only coal producer in this area is Vattenfall Europe Mining AG. The central German mining area located in the surroundings of Leipzig yielded a total lignite output of 20 Mt in 2002. The most important company in this area is Mitteldeutsche Braunkohlegesellschaft (MIBRAG).

In **Spain,** hard coal production declined from 22 Mt in 1990 to 16 Mt in 2001. Spain has adopted a restructuring plan for 1998 through to 2005, which provides for a gradual decline in production to 12 Mt.

In 2002, the country's hard coal output totalled some 13.8 Mt. Most of the output went to the local power plants. A significant amount of 24.5 Mt of hard coal had to be imported, mostly for power generation.

Hard coal is produced in several mining areas, especially in Asturias, León and Palencia where 98% of the Spanish coal mining occurs. Most deep mines can be found in the Asturias coal mining area near Oviedo. In the other areas, there are lots of underground and opencast mines. The state-owned Hunosa company runs the majority of the mines. Due to high production costs, many of the mines no longer exist.

In Santa Lucia, there is a big opencast mine and a new colliery ("Nueva Mina") which was built in the 1990s. The mines have three shafts: Aurelio del Valle (new shaft), Eloy Rojo and Emilio del Valle (new shaft).

Apart from the main mining areas, there are opencast and underground mines in Tineo (west of Oviedo), Vega de Rengos and Monasterio de Hermo (south of Cangas de Narcea), and at several places, south of the Cordillera Cantabrica between Santa Lucia in the west and Barruelo in the east.

In southern Spain, mining takes place in the Ciudad Real and Córdoba provinces. In Ciudad Real there are only opencast mines, in Córdoba there are also underground mines.

Spanish hard coal is too expensive to be competitive on a free energy market, therefore the Spanish government subsidises hard coal production. According to the new EU regulations, the financial aids will have to be reduced over the next few years and Spain will have to lower its coal production. But Spain is one of the three EU countries, which will be permitted to continue its hard coal production for reasons of security of energy supply, and hence will continue to receive subsidies in the long-term.

Spain's major lignite fields are located in the autonomous region of Galicia, in the northwest of the Iberian Peninsula. In addition, the deposit Ginzo de Limia is situated in the province of Orense in southern Galicia and two minor deposits, Arenas del Rey and Padul, near Granada in the province of Granada. Estimated reserves in Andalusia are 40 Mt each, but - as those of Ginzo de Limia – they have not been exploited for economic efficiency reasons as yet. In 2002, 8.6 Mt of lignite was mined in Spain.

The chief deposit is the As Pontes mine, some 60 km northeast of La Coruña. The opencast mine developed in 1976 is operated by the largest of the four private utilities, Empresa Nacional de Electricidad S.A. (ENDESA) and still has economic reserves of 40 Mt. In 2002, production in As Pontes totalled some 6 Mt. Extraction is based on german equipment and transport is secured by 25 km of conveyor belts. The overburden-to-lignite ratio is 2.8 cbm for 1t.

The second, more smaller, mine that has been in operation since 1980 is the Meirama opencast mine. It is located 30 km south of La Coruña and is owned by today's third largest utility company of Spain, Unión Fenosa S.A. The mine covers an area of 1.5 sq km (1.8 x 0.8 km). The remaining mineable reserves of 9 -10 Mt are deposited in two pockets. The current depth amounts to 200 m and is planned to reach 250m. Lignite production at Meirama totalled some 2.6 Mt in the year 2002. Lignite extraction is also mainly based on german equipment and transport by conveyor systems. In 2002, the overburden-to-lignite ratio was 1:1 (cbm:t).

All the lignite mined is used for power and district heat generation. The lignite-fired power plants are situated near the mines and have a total capacity of 1.950 MW. The power plants at As Pontes with 1.400 MW (4 units of 350 MW each, have been in operation since 1976 - 1979) and at Meirama with 550 MW (1 unit, in operation since 1980) are owned by the mine operators.

France: With the closure of the last French hard coal mines in 2004, the state-owned hard coal company, Charbonnages des France (CdF) will be closed in 2007. After three centuries, this will mark the end of the hard coal era, which in its heyday once ensured the livelihood of over 33,000 miners. The phase-out was negotiated between the state-owned monopolist, the trade unions and the government in 1994, but is hitting the coal regions hard. A new industrial orientation is being planned for the mining areas.

Poland[77] is the largest producer and consumer of coal; in fact, it is the second largest coal producer and consumer in Europe, outranked only by Germany when including lignite production. Poland’s hard coal industry produced 102.6 Mt in 2002. Brown coal producers contributed an additional 58.2 Mt.

Poland is not only one of Europe’s traditional hard coal producers; it was once one of the crucial suppliers to the world hard coal market. The country assumed the leading role among European mining countries in 1972 with a production of 150.7 Mt and, until 1979, was the second largest coal exporter after the US, selling 41.4 Mt that year. Although its role as an exporting country was already fading in the 1980s, output was maintained at a significant level (1988: 193 Mt) compared with other European countries. It was not until the political turnaround in eastern bloc countries associated with a growing market-economy orientation, that Poland, too, experienced in the early 1990s the process of contraction in hard coal mining that had begun in Western Europe two decades before. In 2001, for example, production was only 102.8 Mt, though this is likely to be just one stopover in the adjustment process. The decline in the competitiveness of domestic hard coal compared with other energies obtainable on the world market was having its effect, accompanied by a rapid fall in demand in home markets owing to economic restructuring. Nevertheless, coal still plays an important role, contributing 60% of the country’s supply of primary energy and 95% of electric energy production.

[77] Case Study by M.Turek in Part III

The country's commercially minable coal reserves, according to the WEC (2004), amount to 14.0 Gt, including 12.8 Gt hard coal. They are distributed between the Upper and Lower Silesian and the Lublin basins, with the Upper Silesian coalfield accounting for 93% of the total. As a result of restructuring coal production in Lower Silesian Basin was ceased at the beginning of 1990s.

In 1998, the government adopted an adjustment programme for the domestic hard coal mining sector, the fundamental aim of which was to place the sector on a profitable basis. These aspirations are to be seen not least against the background of EU access planned for 2004 and the resulting pressure to reduce subsidies. In view of the difficult geological conditions, a further fall in mining capacity and in total workforce is inevitable. As early as 1994, the state-owned hard coal mining sector was reorganised with the aim of later privatisation (now foreseen for 2004).

Mining in underground operations is at an average working depth of some 600m. Extraction is fully mechanised with over 90% of the coal being mined using longwall mining (163 longwalls). In 2002, out of 103 Mt of total production, some 16 Mt was accounted for by coking and 87 Mt by steam coal. The run-of-mine coal from underground operations is diluted by surrounding strata and requires preparation. The extension of existing, and the commissioning of new preparation plants in recent years has led to a qualitative approximation to world market requirements.

Poland's hard coal industry operated at a slight loss in 2001. Over the past several years, a number of coal industry restructuring plans have been proposed for the purpose of transforming Poland's hard coal industry into a position of positive earnings, eliminating the need for government subsidies. The most recent plan for Poland's final phase of coal industry reorganisation was announced in November 2002. Under the four-year plan, employment would be reduced to 100,000 workers by 2006, and seven coal mines would be scheduled for closure. That would leave Poland with 31 mines capable of producing 87 Mt of coal per year, eliminating the traditional surplus (3 Mt in 2002) along with a large portion of the heavily state-subsidised coal export business. However, the thirteen trade unions involved in Poland's coal industry are opposed to the proposed final phase, and the Polish government has now agreed to defer its decision on pit closures and to maintain the coal miners' traditional social benefits.

The Polish government estimates that sales of hard coal from domestic mines will decline from 116 Mt in 1998 to 77 Mt by 2025. In August 2001, the World Bank had approved a total of US$400 million in hard coal sector adjustment loans in support of the Polish government's restructuring programme. The most recent loan of US$100 million (referred to as the Second Hard Coal Sector Adjustment Loan, or SECAL 2) was designed to support the implementation of the Polish government's 'Revised Hard Coal Sector Reform Programme'. It will support capacity and financial restructuring, environmental improvements, privatisation, and social monitoring.

Polish hard coal being uncompetitive internationally, the prospects look gloomy, and the industry will take the same road that Western Europe has undergone for many years now. Further rises in productivity and any resulting cost savings appear insufficient, given the anticipated increase in wages to EU standards. Thus, recent (2000) expertises (NOBE) are assuming a fall in output to 83 Mt in 2010 and ultimately, to 68 Mt.

Seven mining companies were set up, which now operate 4–9 mines and have mining capacities of up to 20 Mt per annum. Four mines with an output of 9.2 Mt in 2001 have already been partially privatised.

On 1 February 2003, the Polish government created Kompania Wcglowa (KW), Europe's largest coal company. This meant the consolidation of mines from five failing coal firms (Bytomska, Rudzka, Gliwicka, Nadwislanska and Rybnicka). Due to the latest structural changes at the beginning of 2003, there are three companies operating in coal sector: Consolidated Coal Company (Kompania Wcglowa S.A.) with 23 mines, Katowice Coal Holding and Jastrzębie Coal Company (producing coking coal). There are also two independent mines: Bogdanka and Budryk undergoing privatisation. After protests from coal unions in December 2002, the government toned down initial restructuring plans. The government changed the total employment reduction to 27,200, gave workers job placement guarantees in surviving mines, if their own unit was closed, and required the company, KW to be responsible for the twenty-three mines held by the country's five worst mining firms. KW would be relieved of its five worst mines, provided that an expert group demonstrates that they are no longer economically viable.

The **Czech Republic**[78] continues its efforts to step up energy efficiency, which is reflected in the Energy Management Act, which came into effect in 2001. These developments have been furthered by the EU, which has attached vital importance to the increase in energy efficiency when discussing the energy issues in the course of the accession negotiations.

About 50% of the Czech primary energy requirements are met by coal, with hard coal contributing some 9 Mtce. In 2002, hard coal output of 19.6 Mt reached approximately the level of 2001. The largest hard coal deposits are found in the Upper Silesian basin (Ostrava-Karvina) and are extracted by underground mining.

Some 6 Mt of hard coal and 1 Mt of coke were exported. The latter benefited from the closure of several EU coking plants. Major marketing areas were Germany, Austria, Hungary and Poland. Hard coal (steam and coking coals) of 1.2 Mt was imported from Poland.

The Czech Republic has 410 Mtce of economic lignite reserves; 95% of these reserves are mineable in opencast operations. Besides three deposits in Northern Bohemia, the region of Sokolov and Southern Moravia, there are further lignite fields in the south of the country though these have not been mined for quite some time. Lignite plays an important role in the energy supply of the Czech Republic; its production totalled 49.4 Mt in 2002.

The chief deposit and the biggest mining area, measuring 1,400 km², is the Northern Bohemian basin. It extends along the towns of Kadaň, Chomutov, Most, Teplice and Ústii nad Labem. In this region, seams occur at depths of 400m and with a thickness of 15-30m depending on the depth.

The coal company Mostescka Uhelna Spolecnost (MUS a.s.) mines lignite in the central section of the Northern Bohemian basin. Set up in 1993, it has twenty lignite fields

[78] Case Study by Jiri Kalkus, Czech Republic, in Part III

covering a total 153.9 km^2. Altogether, MUS a.s. extracted 16.3 Mt of lignite in its operations. Most of the mined lignite is processed at the Komořany preparation plant with an annual capacity of 14 Mt. The sorted lignite types with calorific values of 17,000 to 18,000 kJ/kg and an ash content of 12 to 14% are bought by households and industry. Pulverized lignite with a calorific value of 17,000 kJ/kg and an ash content of 15 to 18% is delivered to industry. In 2002, the opencast and underground mines of MUS a.s. had a total workforce of 5,108 employees.

In the north-western section of the Northern Bohemian lignite basin and in the east of the central section of the town of Most, Severočeské uhelné doly, a. s., Chomutov (SD a. s.) extracts lignite in two mining areas: Doly Nástup Tušimice and Doly Bílina. Total output was 21.8 Mt in 2002. The Doly Nástup Tušimice lignite area with the two opencast mines of Libouš-East and Severní Iom is located between the towns of Chomutov and Kadaň. An annual 13 Mt of lignite is produced on average. Following treatment at the Tušimice crushing plant, most of the lignite is supplied to the power plants belonging to České energetické závody (ČEZ). Two further opencast mines (Libouš II-North and Libouš II-South) are scheduled to start in 2004 and 2007 respectively. The Doly Bílina lignite area with the Ledvice opencast mine is located between the towns of Bílina and Duchcov. Around 9 Mt of lignite is produced per year. The lignite is supplied to the Ledvice plant and treated there for making commercial products. The total workforce of SD a. s. was 4,101 in 2002.

Located in Western Bohemia is the third important lignite mining area in the Czech Republic, the basin around Sokolov, which has minable reserves of 400 Mt in three main seams. In the region, the Sokolovská uhelná, a.s. coal company, (SU a.s.) mined some 10.4 Mt of lignite in 2002. Lignite from the Sokolov area is used mainly in power and heat generation. The power plants of SU a. s. have a capacity of 620 MW. In 2002, 3.3 TWh of power (gross) was generated. The produced heat energy predominantly serves to cover the company's own consumption, with part of it being supplied to Karlovy Vary, Nejdek, Chodov, Nova Role etc. In 2002, the operations of SU a. s. had a total workforce of some 5,530 employees.

In the last ten years, lignite output in the Czech Republic dropped by 35% to less than 50 Mt; a further decrease cannot be ruled out. The major reasons were the commissioning of two units of the contested nuclear power plant of Temelin, discontinuation of lignite deliveries to Germany and higher power imports. However, the decrease was not so serious as originally expected. This was, to a large extent, due to the power exports to eastern and southern Europe by the Coal Energy Company which exported 3 TWh of power in 2002 and whose exports were expected to rise by another 70% in 2003. The lignite mining companies, ČEZ as well as Carbounion Bohemia set up Coal Energy. Coal Energy exports power in particular to Hungary, Romania, Croatia, Bulgaria and Serbia. The Czech lignite industry has always played an important role in the national economy. Despite present restructuring and a drop in demand, lignite will, for the time being, remain the chief energy source.

1.2 Commonwealth of Independent States (CIS)

In the CIS countries, the process of economic reform continues, as the transition to a market-oriented economy replaces centrally planned economic systems.

The dislocations associated with institutional changes in the region have contributed substantially to declines in both coal production and consumption. The three main coal-producing countries of the FSU— Russia, Ukraine, and Kazakhstan—are facing similar problems. The three countries have developed national programmes for restructuring and privatising their coal industries, but they have been struggling with related technical and social problems. Between 1990 and 2001, coal production declined by 72 Mt (19%) in Russia, by 79 Mt (47%) in Ukraine, and by 42 Mt (32%) in Kazakhstan.

Coal sector restructuring takes a number of different forms. They depend largely on the state of reform in a particular country and on the country's commitment to broader policy, regulatory and institutional changes, which are important for a competitive financially, socially and environmentally responsible industry to survive and grow.

In the majority of cases, the supply potential by far exceeds demand. Thus, considerations of restructuring the industry, in both capacity and employment terms, are critical. The introduction of competition in the industry is seen as a precursor to an efficient industry. An internationally competitive regulatory/fiscal regime is also important to the future health of the industry, including well-developed environmental rules and regulations, and arrangements for effective environmental monitoring and control.

The **Russian Federation**[79], with financial and technical assistance from the World Bank, began a substantive restructuring of its coal sector in the mid-1990s. The World Bank's first Coal Sector Adjustment Loan, starting in 1996, provided US$500 million to assist restructuring efforts, along with a US$25 million technical assistance loan. The World Bank followed that programme with a second Coal Sector Adjustment Loan in 1997 for US$800 million.

The restructuring plan calls for the closure of all unprofitable mines, the complete liquidation of the national coal company, RosUgol, and the eventual elimination of state subsidies to the coal sector. In addition, the plan provides funding for strengthening the social safety net for the workers and communities adversely affected by restructuring, promoting privatisation of the viable part of the industry, and improving sector governance through separation of state management and commercial activities.

The coal industry restructuring programme has already been very successful. Over 140 heavily loss-making mines have been technically closed, and RosUgol has been dissolved. By 1999, subsidies to the coal sector had been reduced to just US$400 million, of which only US$130 million were for production support; the remaining US$270 million in subsidies covered physical and social costs of mine closures, downsizing, and safety. In addition, in 1999, Russia's coal production increased after a decade of decline, with companies that were privatised by mid-2000 accounting for 43% of coal production. In 2000, privatised coal companies accounted for more than 60% of Russia's overall coal production.

In December 2001, the World Bank decided to release the final US$100 million tranche of the US$800 million loan, citing the "sound progress" that Russia had made in privatising its coal industry. Through the end of 2001, about 77% of Russia's coal production came from private entities, and the Russian government had more than 90% of the industry's production come from private coal companies by the end of 2002. Among

[79] Case Study “The Russian Coal Sector: Fit for the Future? Excerpts from Energy Strategy for Russia” summarised by E. Nekhaev in Part III of the study

the industry's tasks in 2002, were the closure and liquidation of six mines, as well as the implementation of the Russian government's plan to increase the share of coal in Russia's energy production.

In 2004, the WEC put Russia's commercially minable reserves of hard coal at 147Gt, as things stand today. The resources are distributed across a total of seven hard coal regions, namely Pechora/North, Donetsk, Ural Mountains, Kuznetsk, Kansk Achinsk, the Far East and the Northeast. Their run-of-mine coals have average calorific values of 4,900–5,700 kcal/kg (net as received), an ash content of 17–25% and sulphur content of 0.9–1.1%.

In 2001, the chief mining regions were western Siberia (127.6 Mt), eastern Siberia (45.9 Mt) and the Far East (28.2 Mt). The structural measures have greatly affected, the Donetsk mining area (9.5 Mt), where extraction is at depth below 1,000m in certain places and also from thin seams, and the sub-arctic Pechora region (19.1 Mt).

Average extraction depth in underground mines is between 500-550m. The chief mining method there — back in 1980 — was longwall mining, accounting for 85%, with 65% mechanisation. The rest was by block caving and hydro-mechanical extraction. Opencast mining of lignite is mainly by bucket wheel excavator, and of hard coal by shovel and truck. Owing to the high degree of mechanisation, the run-of-mine hard coal is highly diluted and requires preparation, so that roughly two thirds of the run-of-mine output passes through preparation plants.

With a coal mining capacity of 280 Mt p.a. at the end of 2002, coal production amounted to 235 Mt, including approximately 164 Mt hard coal and 71 Mt lignite. The share of coking coal in hard coal production reached 53 Mt (32%). In 2001, coal production still received subsidies totalling US$69 million; however these were to be discontinued by 2003. More than half the coal producers were already working profitably in 2001. The present total of 200,000 employees (2000) and total coal output of 270 Mt translates into productivity of 1,350 t/man-year. Although this value has tripled since 1992 (420 t/man-year), it is far behind international standards.

There are continuing reports that Russian energy policy for the next five years favours an increase in coal use to offset rising demand for natural gas, which may be priced more highly in domestic Russian markets to make more volume available for export and encouraging higher export earnings.

In **Kazakhstan,** by the end of 2002, many high-cost underground coal mines have been closed, and its more competitive surface mines have been purchased, and are now operated by, international energy companies. Total hard coal production amounted to 70.6 Mt in 2002. Kazakhstan is both a significant coal producer and exporter. Hard coal exports amounted to 13.7 Mt in 2002. Both coking and thermal hard coal are produced, but thermal coal is the primary export.

In **Ukraine,** a coal restructuring programme initiated by the government in 1996, with advice and financial support from the World Bank, has been generally unsuccessful in rejuvenating the industry. Key problems that continue to plague the Ukrainian coal industry are:

- Most of the country's mines continue to be highly subsidised, government-run enterprises;
- Dangerous working conditions prevail (several catastrophic mine disasters have occurred in the past several years);
- Wage arrears continue to be a serious problem, with miners currently being due wages of approximately US$3.5 billion;
- Productivity is very low due to outdated mining equipment and the extreme depths at which coal is extracted (only three of Ukraine's active coal mines are surface operations); and
- Non payment for coal by customers is rampant.

The World Bank has focused its efforts in Ukraine, in trying to convince the government that it needs to close additional unprofitable mines. In 2001, a spokesperson for the World Bank expressed his belief that an additional 50 to 60 of the country's remaining coal mines need to be closed. Others indicate that problems with the Ukrainian coal industry will not be solved simply through the closure of the least economical mines. They point to delays in privatisation of coal mining operations, widespread corruption and abuse in the coal sector, worsening geological conditions, and misdirection of government subsidies (e.g., not enough of the government subsidies have been directed towards upgrading equipment at existing mines). Most recently, the Ukrainian government indicated that it would not formally present a plan to privatise the coal industry until after 2003. Although coal demand was rising by 1.2%, hard coal production remained virtually the same in 2002 at 82.9 Mt.

Recent data show a slight resurgence in coal production in the Former Soviet Union since 1998, particularly in Russia and Kazakhstan. Due to new energy strategies for Russia and Ukraine, there is an optimistic long-term outlook for both coal production and consumption.

1.3 North America

Coal use in North America is dominated by United States'consumption. In 2002, the US consumed 896 Mt of hard coal, accounting for 98% of the regional total. By 2025 US consumption is projected to rise to 1,444 Mt. The US has substantial coal reserves and has come to rely heavily on coal for electricity generation (nearly 50%), from both greater utilisation of US coal-fired generating capacity and from additional 65 gigawatts of new coal-fired power plants by 2025. The average utilisation rate of coal-fired generating capacity is projected to rise from 69% in 2001 to 83% by 2025. In Canada, coal consumption accounted for approximately 14% of total energy consumption in 2002 and is projected to decline slightly in the future. In western Canada, increased demand for electricity is expected to result in the need for some additional coal-fired generation.

In 2003, coal production (hard coal and lignite) in the **United States** was expected to total approximately 986 Mt, nearly the same as the actual production in 2002 and forecast production in 2004. This "flat" production pattern is due to the relatively slow growth in the US economy in 2002 and 2003, a slow growth in demand for electricity, utilities' desire to reduce stockpiles, and low demand for metallurgical coal and for coal to export. Over time, however, the outlook for the coal industry is very favourable and production will continue to increase in all major coal producing regions. The country is still the world's second-largest hard coal producer after China.

The US is forecast to produce 1,089 million short tons (mst) of coal in 2003, down from 1,094 mst in 2002. Also in 2003, the US is expected to consume 1,081 mst (up from 1,065 mst in 2002). Led by Wyoming, the west is the leading US coal-producing region (with about half of the US total), overwhelmingly from surface mines. Appalachia (led by West Virginia and Kentucky) accounts for about 36% of total US coal production, mainly from underground mines.

The deposits are located in the Appalachian coalfield in the east, which has hard coal (and anthracite), followed by the Illinois basin east of the Mississippi, which has sub-bituminous coal high in sulphur. In the west, there are the low-sulphur, sub-bituminous coals of the Powder River, Green River, Uinta and San Juan basins. Extensive lignite reserves can be found in the southern Gulf region and in the northern lignite basin on the Canadian border.
Coal output in 2002 totalled 991.2 Mt of which 916.7 Mt was hard coal (including sub-bituminous coal) and 74.5 Mt lignite. Currently, approximately 38% to 40% of the coal mined in the US is from the eastern Appalachian coal-fields, 48% is mined in the west (led by Wyoming) and the remaining 12-14% is mined in the inner central region. For some years now there has been a noticeable trend towards a continued rise in output west of the Mississippi relative to the eastern mining areas.

US coal mining is entirely a private-sector activity. In 2001, some 1,400 mines were operational, divided equally between opencast pits and underground mines. The number of units has halved within a decade. Coal output, by contrast, rose by 13% in the same period. In the wake of this consolidation process, ten producers in 2001 accounted for 74% of total US coal output, so that the largeest coal mining companies today are Peabody Energy Corp., Arch Coal, Inc., Kennecott Energy Co., and Consol Energy, Inc. Coal mining is highly mechanised, and some 65% takes place in opencast pits with depths of approx. 60m.

In 2001, the US coal mining industry employed a workforce of 71,500. With an output of 1,017 Mt, this translates into an average productivity of 14,224 t/man-year, which even surpasses the Australian figure. In the US, high productivity ratios of 23,470 t/man-year are reported in opencast pits, above all in the large operations of the Powder River basin, while underground mines, located mainly in the Appalachian mining area, only reach 9,060 t/ man-year.

The prospects for US coal mining remain good. Although US coal has lost much of its competitiveness on world markets, it is still the lowest-cost primary energy source for the domestic power plant sector, which consumes 90% of coal output.

Canada
The WEC puts Canada’s measured and mineable coal reserves at 6.57 Gt (2004), including approximately one half (3.47 Gt) hard coal, 0.87 Gt sub-bituminous coal and 2.2 Gt lignite. Over 90% of all deposits are concentrated in the western provinces of Saskatchewan, Alberta and British Colombia. While the lignite basins are confined to Saskatchewan, the sub-bituminous coals are located in a belt starting in the United States, extending to Alberta and reaching into the northwest via the foothills of the Rocky Mountains. Parallel to this, a further hard coal belt in the west starts in the foothills of the Rocky Mountains and extends to British Colombia. Canada’s coal production totalled

66.5 Mt in 2002, including 29.7 Mt of hard coals and 36.8 Mt sub-bituminous coal or lignite.

While the entire output of lignite and sub-bituminous coal was used as steam coal in the country, nearly 90% of hard coal output or 26.8 Mt was exported in 2002. By contrast, in the same year Canada imported 19 Mt, mainly from the US, but also from South America. Coal mining in the western provinces is confined to opencast pits. As in the Powder River basin, waste is stripped by dragline from the sub-bituminous coal and lignite seams and the coal extracted by truck and shovel. Once crushed, the coal goes directly via conveyor belt to the nearby power plant without further preparation. Hard coal mining, by contrast, involves numerous 1–10m thick seams, usually with a 20–40° dip, requiring selective mining using bulldozer/front-end loader/shovel and truck. At present, twenty companies are mining coal in Canada, including eleven extracting hard coal and nine sub-bituminous coal or lignite. Only one was situated on the east coast and supplies local power plants, while the remainder is distributed across the provinces of Saskatchewan, Alberta and British Colombia, including three hard coal mines in Alberta and seven in British Colombia almost exclusively serving the export market.

In recent years, the Canadian coal industry has also undergone a profound consolidation process, accompanied by rationalisation measures, in the course of which seven mines, including five hard coal operations, were shut down; three further mines are scheduled for closure. However, this development was confined to Canadian and US companies, to the exclusion of international coal producers. Of the major companies operating at present (2002), Fording Inc. emerged from the former Canadian Pacific subsidiary Fording Coal Ltd., while Teck Cominco Corp. was the result of the merger with the former Cominco and Teck Corp. Luscar was taken over in 2000 by the Luscar Energy Partnership, an amalgamation of Sherritt Int. Corp. and Ontario Teacher's Pension Fund Board. In 2001, Consol Energy (US) extended its Canadian commitment with a 50% participation in the Line Creek mine.

With total coal output of 69.2 Mt and a total workforce of 5,900 in 2000, the productivity ratio for Canada's coal sector is approximately 11,730 t/man-year. Production and exports only pay off at present because most of the mines have been in operation for more than twenty years and have largely been written off. However, this is not true of the mines in the Peace River coalfield, which started full production in the mid-1980s and now face final closure. At present, the Canadian coal industry has export capacities totalling 33.7 Mt p.a. Although present coking coal projects have a capacity totalling 26.0 Mt p.a., these are generally small or medium-sized operations with a low waste/coal ratio. These projects can fall back on an already existing infrastructure, or they are follow-up operations designed to replace depleted mines with an already available infrastructure.

1.5 Central and South America

Coal has not been a major source of energy in Central and South America. In 2002, coal accounted for about 4% of the region's total energy consumption, and in previous years, its share has never exceeded 5%. In the electricity sector, hydroelectric power has met much of the region's electricity demand, and new power plants are now being built to use natural gas produced in the region.

Brazil [80], with the ninth largest steel industry worldwide in 2001, accounted for more than 65% of the region's coal demand followed by Colombia, Chile, Argentina, and to a lesser extent Peru.

Colombia's hard coal reserves are the largest south of the US, but the country is still one of the younger exporters serving the world coal market. Although its coal deposits have been known for decades and are located near the coast, they remained undeveloped for a long time because of the sub-optimal infrastructure. Development finally started in the wake of the second oil crisis of 1979/1980, which caused a shortage of steam coals on world markets.

2002 coal output totalled 40.4 Mt, and it was extracted by ten producers from some fifteen mines. This total ignores the output of numerous small companies, which only mine to meet local requirements.

At the start of 2002, the coal industry experienced a wave of consolidation. The owner consortium of Carbones del Cerrejón (BHP-Billiton, Anglo Coal, Glencore each holding a third) has now been renamed Cerrejón Coal Co.; it also owns 100% of the Cerrejón Zona Norte mine. The consortium is aiming at an early amalgamation of its mines to bring their activities into one company, which would then, as things stand today, account for some 53% of extraction and 55% of the country's coal exports. Of the above total output 6.0 Mt remained inside the country, leaving 34.4 Mt for exports. Some 24 Mt was mainly sold in Europe, ahead of the US's 9 Mt, and 5 Mt going to the rest of north and south America. With a mining capacity of 52.4 Mt in the exporting mines, utilisation was 66%. Almost all of the output destined for export came from opencast pits. Coal seams are usually at level (0–15°) and reach thicknesses of up to 150m; they comprise up to 27 workable seams with thickness of 1–15 m. Extraction is normally by truck and shovel with occasional support from draglines to remove the overlying strata. Only one export mine, that is known, is engaged in underground mining; its operations are only partly mechanised using the room-and-pillar method with drilling and blasting. Productivity of the Colombian coal industry is in the range of 4,900 - 5,400 t/man-year.

Venezuela. One potentially major contributor to the world hard coal market is Venezuela. This country initially made a big impression in 1991 with exports of 1.9 Mt. It now (2002) serves the world market with a volume of some 8 Mt, equivalent to a share of 1.5 %.

Most of the coal is mined in opencast pits using truck and shovel, in view of the large number of seams. Since the seams are not seriously diluted, even the run-of-mine coal is of very high quality and needs no further costly preparation apart from crushing and screening. Only one mid-sized mining operation (Mina Norte: 1.5 Mt p.a.) extracts from an underground mine using the room-and-pillar method. The remaining underground mines are confined to small companies with low degrees of mechanisation. Coal mining is currently concentrated in the Guasare region, which accounts for some 90% of total output, while mining by the small operators in the east of the country (Fila Maestra/Falcon) has been dormant for many years.

[80] Case Study by Fernando Luiz Zancan, SIECESC, and João Alberto Soraes, in Part III

The biggest producers are Carbones del Guasare and Carbones del Guajira (2001). In 2002, production was 9.1 Mt, as in 2000 and was almost entirely exported. Venezuela's export capacity is at 8.4 Mt per year. The production capacity of export mines was utilised to nearly 98% in 2002. Productivity is already high in fully mechanised opencast operations (Paso Diablo pit), although it is unlikely to reach international levels as yet.

1.6 Developing Asia

The countries of developing Asia accounted for 40% of the world's coal consumption, primarily as a result of substantial growth in coal consumption in China and India.

Coal remains the primary source of energy in China's industrial sector, primarily because China has limited reserves of oil and natural gas. The issue as to whether China will become a major coal exporter (because of its relatively inexpensive mining costs) or a major coal importer (because of anticipated growth in its coal use over time) has yet to be determined. In either case, however, the completion of two major non-coal infrastructure projects near the end of the decade should reduce domestic coal demand and allow more production for export. The first infrastructure improvement, a new west-to-east transmission line that will allow hydropower from the Three Gorges Dam complex, to be wheeled to load centres in eastern and southern China will, in all probability, result in the displacement of coal-fired generation at small older plants. The second infrastructure improvement, a new pipeline that will bring natural gas from northwest China to eastern and southern provinces, will likely displace coal used in industrial boilers and some utility generation.

In India, projected growth in coal demand occurs primarily in the electricity sector, which currently accounts for almost three-quarters of India's total coal consumption. Coal use for electricity generation in India is projected to rise.

In the remaining areas of developing Asia, a considerably smaller rise in coal consumption is projected based on expectations for growth in coal-fired electricity generation in South Korea, Taiwan, and the member countries of the Association of Southeast Asian Nations (primarily Indonesia, Malaysia, the Philippines, Thailand, and Vietnam) and power supply in South Korea (4,600MW), Taiwan (4,215 MW) and Indonesia (2,450 MW).

China's coal resources are practically immeasurable and vary considerable in type and quality. The WEC estimated, definitely measured and mineable reserves of 96 Gt of hard coal. Most of this (60%) dates from the Jurassic or Carboniferous (25%) periods, i.e. they sedimented 140–250 and 290–360 million years ago and have been subject to several phases of mountain formation since then. This being so, deposits being close to the surface are marked by strong seam dips, so that the reserves mineable in opencast pits are relatively low, and most of the mining is pursued in underground mines. Geographically, the coal resources are concentrated in north China, with 48% being located in the provinces of Hebei, Shanxi and Inner Mongolia.

In 2002, China's coal production amounted to over 1000 Mt, whereof 40 Mt are estimated to be lignite. This makes China the world's biggest producer of hard coal, ahead of the US with its 917 Mt. Only 30% of run-of-mine coal output is currently treated. The remaining 70% is delivered directly to consumers.

Coal mining is a public-sector industry under the control of the State Economic and Trade Commission (SETC). The authority in charge is the State Administration of the Coal Industry (SACI). The central government is increasingly focusing on the areas of welfare and mine safety, while most of the day-to-day business, including production, is left to the local administrations or provincial governments. Following successful restructuring of the coal mining sector, associated with the closure of some 60,000 small and very small operations since 1997, approximately 22,300 mining companies were still engaged in extraction in 2000. Hence, the entire coal mining industry is state-owned, and the ten largest coal producers are given guidance by the authorities of the central government. Productivity is on average about 287 t/man-year.

The volume and composition of China's coal production changed considerably during the 1990s, reflecting fundamental shifts within the coal industry and in government policy. Coal production has fallen over the past few years at a similar rate to coal consumption. The reduction in output has been a response to weak domestic coal consumption, and has been driven to a considerable extent by government policies aimed at rationalising the industry.

Raw coal production in China expanded from 1051 Mt in 1990 to a peak of 1402 Mt in 1996. It then contracted steadily by an average of 3.2% a year to 1231 Mt in 2000. Chinese coal production grew in 2001, for the first time since 1996. Coal mines in China can be defined by type of ownership into three broad categories:

- Key state mines (previously administered by the central government but now under the administration of provincial governments);
- Local state mines (administered by the provincial, prefecture and county governments); and
- Township and village enterprise mines (run by private individuals or local governments in townships and villages).

There are less than 100 key state coal mines and 33 of these mines are listed as key state enterprises in China. These mines tend to use advanced coal extraction techniques and most of their output goes to other state owned enterprises, including electricity generators, steel producers and other manufacturers.

There are around 2,000 local state mines. These tend to be much smaller in scale than the key state mines and are only partially mechanised. There are between 21,000 and 23,000 township and village enterprise (TVE) mines, although estimates vary and there may be some further mines operating without authority. These mines are characterised by low production levels and manual coal extraction techniques.

Prior to 1982, domestic coal supply was mainly provided by the key state coal mines. From 1983 to 1997, the Chinese government encouraged the development of TVE coal mines, to promote rural development and to help solve a shortage in coal supply in some areas. The percentage of total raw coal output from TVE mines increased from an estimated 18% in 1980 to around 45% of total coal output in 1996. Over the same period, the share of key state mines fell from 56% to 39%. However, since 1996 production from TVE mines has fallen.

Coal produced from TVE mines fell to 197 Mt in 2001, compared with 615 Mt in 1996. The fall in TVE production is mainly a result of government policy aimed at closing down such mines and is discussed in detail in the next section. Production by key state mines remained steady over much of this period and rose in 2001 and 2002.

China's coal industry has had a serious oversupply problem in recent years, particularly in the late 1990s, and the government has begun implementing major reforms aimed at reducing the oversupply, returning large state-owned mines to profitability as a prelude to possible future privatisation.

China has also emerged as a major exporter of coal to the Asian markets, as a way of dealing with its surplus production. The total production of export coal producers amounted to 188.8 Mt in 2002, of which 93.2 Mt was available for export. This yields a capacity load rate of 92%.

Japan and South Korea are the primary markets, and China is beginning to emerge as a serious competitor to Australia for Japanese coal imports. India has also been importing modest quantities of Chinese coal.

In contrast to the past, China is becoming more open to foreign investment in the coal sector, particularly in modernisation of existing large-scale mines and the development of new ones. The China National Coal Import and Export Corporation is the primary Chinese partner for foreign investors in the coal sector. Over the longer term, China plans to consolidate the large state coal mines into seven corporations by the end of 2005.

Indonesia[81]. The country’s coal resources were recently put by the Directorate-General for Mining at 38.8 Gt, including some 17 Gt in Sumatra and approximately 21.1 Gt in Kalimantan, although only one third consists of bituminous and sub-bituminous coals, the rest being lignite. According to the WEC (2004), the definitely measured and commercially mineable reserves currently total 4,968 Mt. In quality terms, Indonesian coals are generally low in ash and sulphur, but, on account of their low standard, they have a high content of volatile matter and moisture. All the same, the run-of-mine coal does not generally require preparation, and simple crushing and screening suffices to produce a marketable product. The coal has no or only minimal coking properties, so that - with few exceptions - it can only be used as steam coal.

In 2002, 101 Mt of sub-bituminous coal and hard coal was produced. Mining was conducted by 21 mostly “first-generation” producers operating in 35 mines. Production is concentrated on east and south Kalimantan. Coal mining has evolved on greenfield sites and under the control of the Ministry of Mining and Energy or its Directorate-General for Mining. The contractors are obligated to offer Indonesian investors at least 51% of the mining stock after a ten-year operating period.

Besides foreign and local investors, the state-owned P.T. Tambang Batubara Bukit Asam has developed production in Sumatra, mostly for domestic consumption. This company is to be privatised in a second attempt. In the development of Indonesian coal mining, two different concepts are pursued by the contractors. The one option — as in the case of Kaltim Prima — involves all investment being borne by the mining firm using conventional methods with production conducted under its own management. The other

[81] Case Study by Supriata Suhala in Part III

approach provides for investment only in the mine's infrastructure, e.g., road access, power supply, crushing and screening plant and loading equipment; whereas actual coal production, including waste removal and restoration of the terrain as well as coal transportation (by road or inland waterway) is outsourced to companies with their own personnel at a set price per tonne of coal or cubic metre of waste.

Coal is almost entirely extracted in opencast operations with mine sizes of 2–10 Mt p.a. However, there are also numerous smaller mines and co-operatives with an annual output of 0.5–1.0 Mt, which supply the big producers or exporters. Waste removal and coal extraction are mainly handled by truck and shovel.

The state-run company P.T. Tabang Batubara Bukit Asam mined 10.2 Mt in 2001 with 1,860 employees, posting productivity of merely 5,516 t/man-year. Lack of investment in the future may have an adverse impact on a favourable starting position for the Indonesian coal industry.

India[82]. Energy consumption in India is dominated by coal. Coal accounts for more than one-half of the energy consumed in the country, and it is expected to remain an important part of the future fuel mix. India has extensive coal reserves. Its 82 Gt of coal reserves account for about 8% of the world's total recoverable reserves. Most of the country's coal is sub-bituminous (non-coking) coal; only 2 to 3% is coking coal.

With large coal reserves and heavy use, it is not surprising that India is the third largest producer of coal worldwide. Both surface and underground mining techniques are employed in India. From 1980 to 1997, surface mining increased by a factor of 20, and surface mines currently account for 75% of India's total coal output. Underground mining, however, has not developed as rapidly, growing by only 0.7% per year from 1980 to 1997, compared with average growth of 7.6% per year for surface mining. For the most part, coal reserves are located in eastern India in the states of West Bengal, Madhya Pradesh, and Orissa. Coal can also be found in Maharashtra, Uttar Pradesh and Andhra Pradesh. India's proven reserves of lignite are located in Tamil Nadu and Ponicherry in the south, in Gujarat and Rajasthan in the west, and in Jammu and Kashmir in the north.

Hard coal production in 2002 totalled 333.7 Mt and some 22.4 Mt of lignite was produced from five opencast mines.

The coal industry in India is largely held by the public sector. Coal India Ltd (CIL) formed in 1975 to boost the coal production in the country in the public sector, is the largest corporate coal mining company and contributes towards 86% of the total Indian coal production. CIL has posted an incremental production of 179.2 Mt as against an overall increment of 209.3 Mt in the country during the last 25 years period up to 2001.

In recent years, funds have been mobilised to improve the coal quality by its preparation. There are currently fourteen coking coal washeries for catering to the demand of steel plants in operation over the last two decades. In addition, CIL has also set up and converted about seven coking coal washeries to cater to the thermal power sector.

[82] Case study by Shashi Kumar, Coal India Limited in Part III

In the near future, due to observance of environment stipulations, more power grade coal will be beneficiated and private sector participation is expected in this venture. Already four coal beneficiation plants (CBP) have been set up in the private sector to cater to the power sector and others. Thus, the combined operating capacity of coal beneficiation at present, which is 45 Mt, will essentially go up to 100 Mt in the next two planning periods:

Coking Coal: 23 Mt
Thermal grade coal: 22 Mt

Presently there are twenty coalfields in India, nineteen coalfields belong to CIL and one under Singareni Collieries Company Ltd. and the total production growth is shown in the table below.

Table 2-1: Coal production growth in India

Year	Production in Mt
1973-74	72.98
1978-79	102.02
1984-85	147.42
1986-90	200.87
1996-97	285.66
2001-02	328.86

The production from these coalfields is expected to increase to 386.1 Mt by 2006-07 and to a further 480.40 Mt by the year 2011-12.

The economy needs additional capacity on the power front and in the next twenty years coal production has to be increased by about 450 Mt per year, requiring a massive investment of about US$20 billion.

Since the present coal producing companies are unable to generate the finance for such huge investment, the government has taken the following steps to induce private capital for such purposes – both domestic and private foreign.

- Removal of restriction of captive use of coal by its producer through amendment of coal mines nationalisation act;
- Making available blocks for exploitation of coal;
- Allowing a private captive mine operator engaged in power generation or coal processing to have foreign equity up to 100%;
- Allowing a private captive mine operator engaged in production of iron and steel and cement to have foreign equity up to 74%; and
- Permitting joint venture participation.

Thus, a lot needs to be done on the coal front for its sustained growth over the next twenty years to keep the Indian economy in shape.

1.7 Australia and Industrialised Asia

Industrialised Asia consists of Australia, New Zealand, and Japan. Australia is the world's leading coal exporter and Japan is the leading coal importer in the world. In 2002, Australian coal producers shipped 198 Mt of coal to international consumers, and another

145 Mt of Australian coal (both hard coal and lignite) was consumed domestically, primarily for electricity generation. Japan, which is the third largest coal user in Asia and the seventh largest globally, imports nearly all the coal it consumes (159 Mt in 2002), much of it originating from Australia.

Australia. According to the WEC (2004), Australia's coal mining sector is underpinned by potential reserves of 78.5 Gt, including 54% hard coal. These reserves have a lifetime of 133 years, at present production. Australia's saleable hard coal production reached 266 Mt in 2001. The main producing states were New South Wales with 113 Mt and Queensland with 143 Mt. Minor levels of approximately 10 Mt output in Tasmania, south Australia and western Australia served the country's own needs. Some 153 Mt of total output was steam coal and 113 Mt was coking coal.

The chief mining areas in New South Wales, include the Hunter River and Newcastle areas with high volatile (> 30%) steam and soft coking coal. Also, the southern coalfield with low-volatile (22–25%) coking and the western and Gunnedah coalfield with high-volatile steaming coal. In Queensland, the Bowen Basin, with low to medium-volatile (18–28%) coking and steam coal, but also anthracite (12–18%) semi-soft coking coal, is of outstanding importance. In addition, the Moreton and Tarong basins with high volatile steam coal. Australian hard coal is mainly rich in ash and requires preparation. It is usually low in sulphur (< 1.0%).

In 2002, Australia produced some 66.6 Mt of lignite. There are large reserves in the Gippsland basin in the state of Victoria, three large mines in the Latrobe valley, as well as two smaller mines near Melbourne.

93 hard coal mines were operated, of which 52 were in New South Wales and 41 in Queensland; of these, 15 mines mainly extracted coal for domestic needs and 78 for exports. Some 146 Mt (57%) of hard coal was mined in opencast pits and 110 Mt (43%) in underground mines (Queensland and New South Wales). In opencast pits, with depths of 70m, both draglines (one to two seams) and truck and shovels (several seams) are used. In underground mines, which can reach depths of 200m, longwall mining has arrived and ousted the former room-and-pillar method.

In 2001, the New South Wales and Queensland-based coal industry, which mostly exports, had a headcount of 18,862; with total output of 256 Mt for the two states, productivity is 13,572 t/man-year. Here, the performance achieved in underground mines of approximately 10,300 t/man-year lagged behind that of opencast pits with 14,200 t/man-year.

Australia is a high-cost producer. The ongoing process of concentration and consolidation in world coal mining continued in Australia, and in 2001, reached new heights. The chief Australian producers and exporters are:

- BHP-Billiton Ltd.;
- Rio Tinto Ltd.;
- Xstrata Plc.; and
- Anglo Coal.

In 2001, the above companies, in line with their capital stakes in the mines, produced not only 43% of Australia's hard coal, but also 41% of its exports. Other major hard coal producers are MIM Holdings Ltd. (Mount Isa Mines) with a total of four mines and total output of 21.3 Mt, of which 19.9 Mt is exported; and POWERCOAL Pty. Ltd., nearly all of whose output of some 8.5 Mt p.a. from seven mines goes to the domestic steam coal market.

In 2002, Australia's export-geared hard coal mining sector had a mining capacity of 238 Mt p.a.; with exports totalling 198 Mt; utilisation was 84%. In view of the increases in demand expected on the world hard coal market, Australian producers in particular, are making preparations for marked extensions of their mining capacities. The additional total potential of 118 Mt p.a. mining capacity that can be tapped enables Australia to defend its top position as the world's leading coal exporter. Of this quantity, over 20 Mt p.a. is already being developed or is in a concrete planning stage and could be available within five years, i.e. in 2006. Since future growth in demand affecting world coal trade will occur on the Pacific market, the country is facing a special challenge.

1.8 Africa

Africa's coal production and consumption are concentrated heavily in South Africa. In 2002, South Africa produced 233 Mt of coal, representing 97% of Africa's total coal production for the year. Approximately three-quarters of South Africa's coal production went to domestic markets and the remainder to exports. For Africa as a whole, coal consumption is projected to increase by 103 Mt between 2001 and 2025, primarily to meet increased demand for electricity, which is projected to increase at a rate of 3.0% per year. Some of the increase in coal consumption is expected outside South Africa, particularly as other countries in the region seek to develop and use domestic resources and more varied, less expensive sources of energy.

The Ministry of Energy in Kenya has begun prospecting for coal in promising basins in the hope of diversifying the fuels available to the country's power sector. In Nigeria, several initiatives to increase the use of coal for electricity generation have been proposed. Also, Tanzania may move ahead on plans to construct a large coal-fired power plant. The new plant would help to improve the reliability of the country's power supply, which at present relies heavily on hydroelectric generation and would promote increased use of the country's indigenous coal supply.

Republic of South Africa.[83] Official estimates of South Africa's coal resources indicate an *in situ* quantity of 121.2 Gt, of which 55.3 Gt (45.6%) are classified as economically recoverable. The resources lie in nineteen coalfields across the country and it is estimated that at the end of 1997, some 3.5 Gt had been extracted, leaving some 51.8 Gt in the reserve base. Significant parts of the total resource lie in coalfields such as the Waterberg, which are situated deeply inland and thus are presently economically unviable for export purposes. The majority of the coal is of the bituminous type although limited areas of anthracite remain, particularly in the Kwazulu Natal province.
The South African coal industry produced a total of 223 Mt in 2002, 154.6 Mt (69.2%) was sold internally and the balance of 68.7 Mt (30.9%) was exported.

A total of 24 coal producers were active in the coal industry in 2000, engaged in both opencast and underground mining and employing combinations of room/pillar and

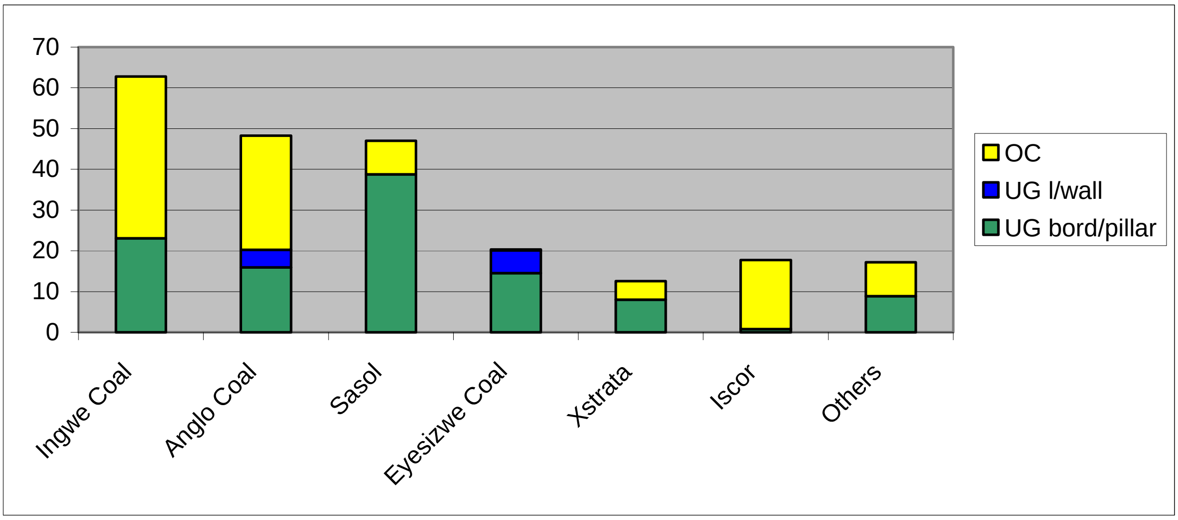
[83] Case Study by Alan Shout, South Africa in Part III

longwall mining in underground mining. Collieries generally fall into three different categories:

- Pit-head collieries supplying largely unwashed coal product to an adjacent power station for use in electricity generation;
- Multi-product collieries, producing coal largely for export markets but with a domestic component which can consist of middling products for power generation or a high quality sized coal for domestic industrial uses; and
- Export collieries, which upgrade coal to export quality specifications and discard the remainder of the run-of-mine product.

Of the total saleable tonnage produced, opencast mining contributed 47% and, of the balance of 53% sourced from underground mining, some 92% was mined by room-and-pillar methods. A breakdown of major producers, production methods and saleable tonnages is shown in the graph 2-3.

Graph 2-3: Coal Production in South Africa in 2000 (Mt)



Conventional drill and blast sections have largely been phased out in the underground mines in the interests of increased safety and productivity and, whilst continuous miner/mechanised road headers predominate, drill and blast mining is still employed when seam and geological conditions necessitate. Further technological advances have been made through the introduction of on-board roof bolting and battery haulers in place of conventional shuttle cars and, whilst continuous haulages have been deployed in certain operations, the success of such units has yet to be properly established under South African conditions. In the opencast mines some 67% of production is derived from strip mining using draglines and the remaining 33% from truck and shovel operations.

Whilst SASOL is the nation’s third largest coal producer, it is not a participant in the open coal market, since it consumes the majority of the coal it produces in its own petrochemical plants. ISCOR is also a producer/consumer of significance in the industry.

Coal mined for use in domestic power generation is generally un-beneficiated and thus falls within the calorific value range of 16-24 MJ/kg on an air-dried basis. The South African industry is predominantly a steam coal exporter, although certain grades are used in the metallurgical coal market. Coal for export is washed through DMS modules in single stage or double stage processes with yields of between 60 and 85%, to produce either export thermal coal or low ash coal at calorific values of 27.5 and 30.5 MJ/kg (adb) respectively. Coal intended for metallurgical applications consist of bituminous coals at ash contents of 7% and 10% (used for PCI and blend coking coal) and anthracite fines (used for briquetting, sintering and as a reductant). Overall production yield in 2000 was reported as 77.15% and significant quantities of poorer quality coal are discarded/stockpiled each year.

South African coal mines generally enjoy very competitive costs of production. Although specific information is not available in the public domain, many of the collieries are believed to fall into the lowest cost quartile for export coalmines on a global basis. An average of 42,530 people were recorded as being in service in the coal industry in 2000, and the productivity of these employees amounted to 13,542 t/man-year.

2. Consolidation in the Coal Industry[84]

Increased competition between coal producers resulted in a significant consolidation of the coal sector around the globe, in developed, transitional and emerging markets. Mergers and acquisitions grew to maturity; restructuring of inefficient state-owned coal sectors is taking place throughout the economies in transition; and the on-going removal of subsidies in European markets have all had a deep and lasting impact on the coal sector over the last twenty years.

Electric power industry restructuring may also result in renewed pressure for cost-cutting and consolidation in the coal industry, and risk management will become an important tool for coal producers – through hedging, or through potential vertical integration, alliances with power producers, transport companies etc.

Deregulation of the electric power industry has promoted competition and cost-cutting measures by the utilities – such as the reduction of coal stocks. Low coal prices and tight profit margins have restricted the flexibility of all but the largest operators – causing the rapid consolidation of the sector. Drivers of consolidation include, among others, rising demand for low-cost fuel for electric power generation that supported increasing demand for coal throughout the 1990s, with production levels rising steadily despite falling prices.

By enlarging assets, companies can take advantage of economies of scale, and can reduce their overhead costs. Larger operations bring greater revenues, unproductive activities can be closed, and the greater wealth of the company allows investment in modern mining technologies, increasing productivity and reducing labour costs. Consolidation is also a result of price decreases. As prices fall, fewer mines are considered economic as sole entities, and are sold off. Mergers and acquisitions increase, resulting in well-run, efficient companies taking the market. Horizontal integration may also come into play - mining companies today are usually conglomerates in the extractive industries, with coal being only one of their products.

[84] Case Study by Christine Copley in Part III

The market share of the large multinational coal companies may also be looked at to determine the real extent of consolidation within the sector. In 2002 the ten largest commercial coal companies produced around 970 Mt – around 30% of global hard coal production.

Table 2-2: Market Shares of International Companies

Company	2002 Production (Mt)
Peabody Group	180.0
Rio Tinto	173.4
BHP Billiton	149.4
RAG	97.0
Arch Coal	96.8
Anglo Coal	80.2
Consol Energy	60.0
Sasol	49.5
AEI Resources	44.4
Massey	39.8
Total	**970.5**

Coal India Limited, a state owned enterprise, produced 280 Mt in 2002, making it the largest coal producer in the world and Chinese key state-owned mines produced more than 500 Mt in the same year.

Consolidation is a dynamic process. Currently only four companies – Rio Tinto, BHP Billiton, Anglo American and Xstrata - control 40% of the export market, geographically concentrated in Australia, South Africa and Colombia.

However, the emergence of new exporters – China and Indonesia in particular – demonstrates that there are no major barriers to market entry. In 2000, the two countries respectively supplied 25% and 21% of thermal coal to the Asian market, creating significant competition. Almost all Indonesian production is for the export market.

One of the common conclusions to draw from a period of consolidation within an industry should be a resultant stabilisation of prices. The recent consolidation of supply in the major coal-producing countries - South Africa, Colombia, and Australia - together with the withdrawal of the US from the export sector, was expected to stabilise coal prices and allow effective planning for the future.

This has not been borne out by price statistics, which in 2002 saw a steady decline in coal prices, and their upward revival in the second quarter of 2003. This may be attributed to competition for business between the large South African producers, possibly due to the emergence of Chinese and Russian exporters as serious competitors on the market. The alternative view is simply that the effect of consolidation on the price cycle takes time – market bottom prices will gradually increase, leading to a slow stabilisation of prices.

3. Prospects

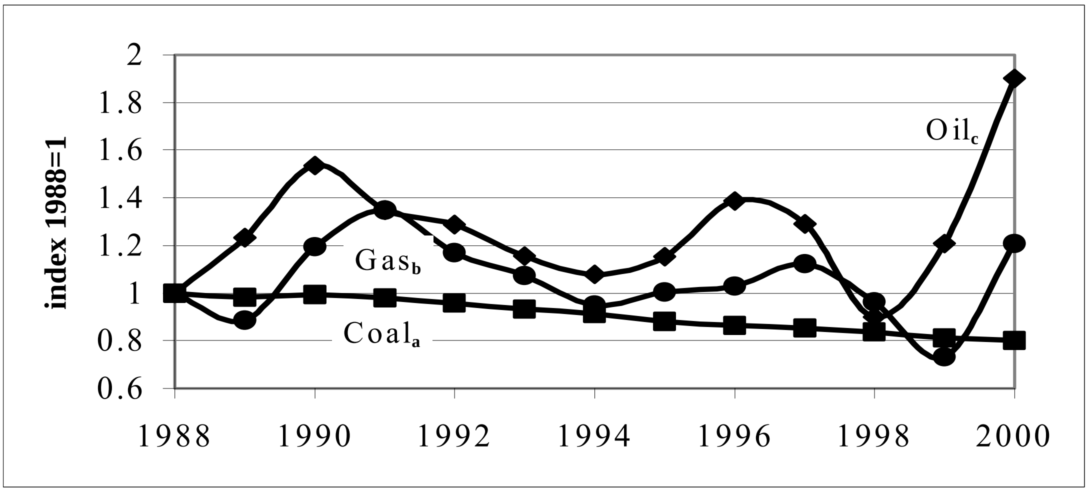
Coal production will almost certainly continue to decline in Europe as the phasing out of subsidies and industry restructuring continues; coal consumption may well also decline as environmental pressures tighten and public policy tends to encourage the use of gas and renewables. But any decline in consumption is likely to be relatively slow by recent standards. For instance, in its latest World Energy Outlook, the International Energy Agency projects that coal consumption in Europe will remain generally steady over the next thirty years (a decline of only –0.4% pa over the period). As in the recent past, indigenous production may well decline more rapidly, leading to an increase in coal trade.

In other regions, growth is more likely. In North America, growth is projected by the IEA to be steady, rather than spectacular (0.6% pa over the period), but Asia could see more rapid growth in coal demand – 2.2% for China and 3.4% pa for East Asia, for example.

This reflects the fact that the underlying drivers which have boosted growth in coal demand over the past few decades remain firmly in place, including:

- Rapid growth in electricity demand: in China, for instance, electricity demand is expected to nearly triple in the period up to 2030. Coal use in developing Asia alone is projected to increase by 1.9 Gt. China and India together are projected to account for 28% of the total increase in energy consumption worldwide between 2001 and 2025 and 75% of the world's total projected increase in coal use, on a Btu basis;
- Coal-fired generating capacity in China is projected to increase by 60%, from 232 gigawatts in 2001 to 371 gigawatts in 2025. In India, coal-fired generating capacity is projected to increase by 45%, from 66 gigawatts in 2001 to 96 gigawatts in 2025;
- World coal trade is projected to increase from 650 Mt in 2001 to 826 Mt in 2025, accounting for between 11 and 13% of total world coal consumption over the period. Steam coal (including coal for pulverized coal injection at blast furnaces) accounts for most of the projected increase in world trade;
- Coal as an energy source is attractive: coal is available, secure and affordable; and
- Prices of coal are pretty stabilised for a long term, as seen in the following graph:

Graph 2-4: Coal price development

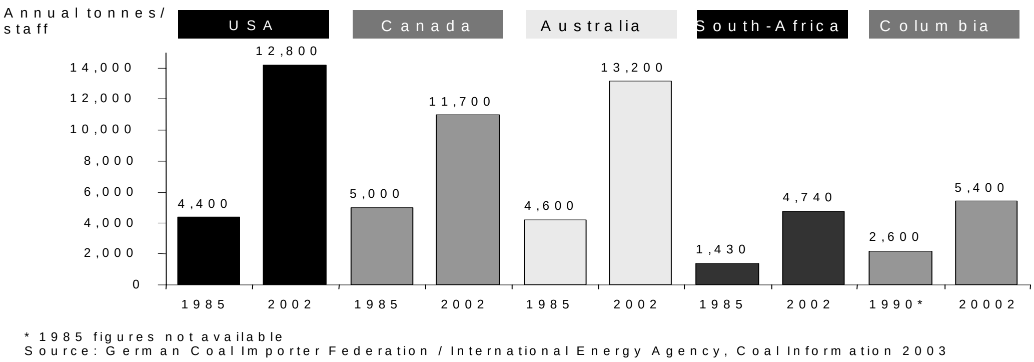


Growth in electricity demand is likely to mean growth in coal use. But in addition to the imperative of cutting discretionary costs, the industry's poor profit performance forced participants to confront the need for major change. Implementing that change has not been easy - neither for investors nor for the industry's workforce or the communities in which our employees live. Most mines have restructured their operations radically; they have achieved important economies of scale; and costs upstream and downstream of the mines have been reduced. Overall, mines have lifted productivity and lowered average costs. Consolidation of ownership and the extension of joint venturing with customer interests have been important elements in this transformation.

The process of industry change is a never-ending one.

Competition on the world coal market and competition between primary energy sources results in meaningful productivity gains in the industry as a whole. The most remarkable advances in productivity can be exemplified by the following graph:

Graph 2-5: Development of Productivity in the Hard Coal Mining Industry From 1985 to 2002



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Chapter 3:
Coal Mining Technologies – The Road to Efficiency and Acceptability

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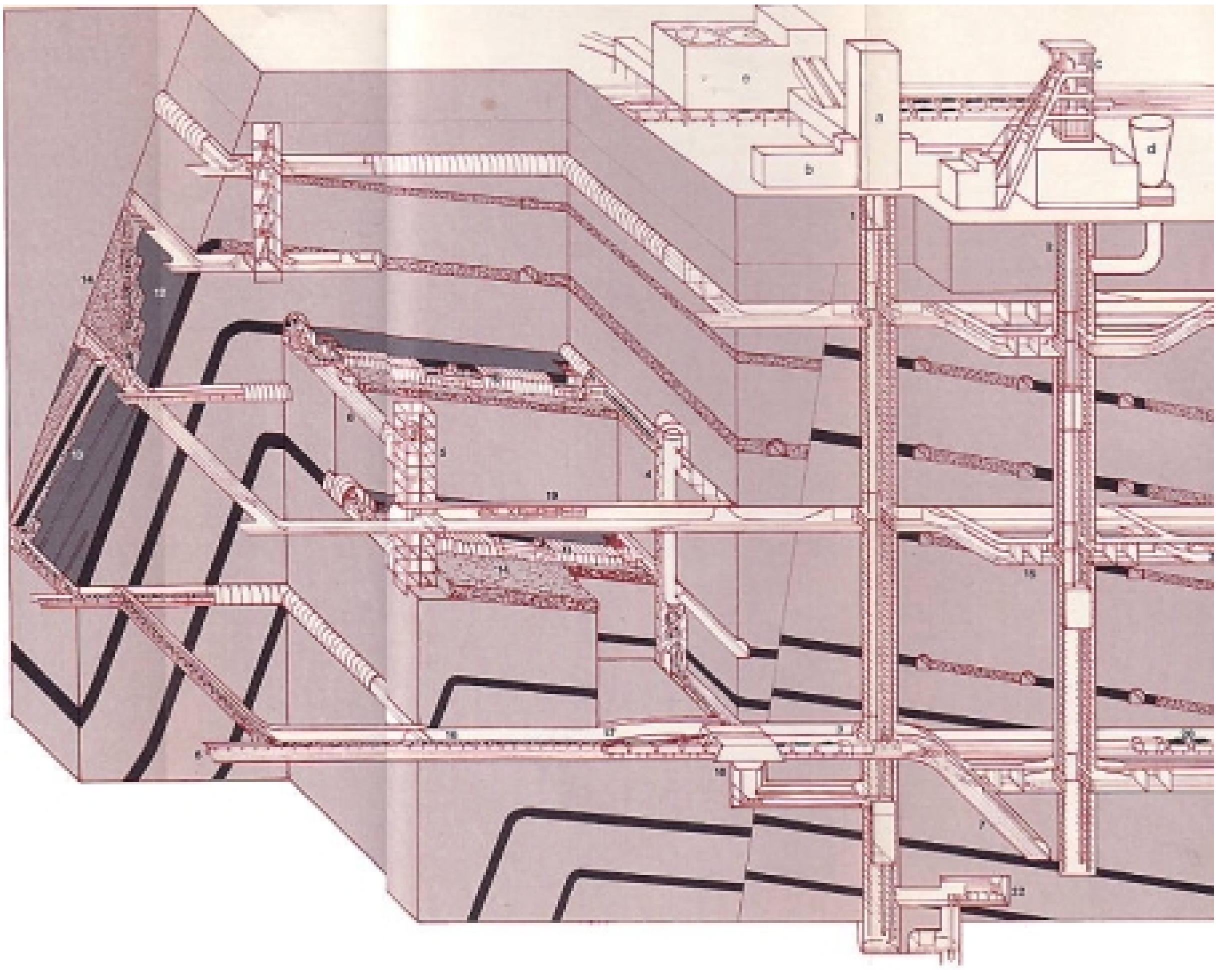
Key messages:

- During recent years, all advanced coal-mining nations have seen major improvements in coal mining technology.
- These have been driven by growing international competition in the coal-mining sector and by an increase in environmental awareness.
- An ever-greater share of mined coal is upgraded. Thus, coal preparation ensures an environmentally friendly use of coal in power generation.
- The capture of methane from coalmines not only reduces greenhouse gas emissions; methane can also be put to beneficial use, e.g., in power generation.
- The progress achieved in land reclamation enables the sustainable use and ecological stability of the recultivated areas.

1. Introduction

Due to the differences in international coal deposits, mine development (surface and underground mines) and the mining methods employed vary greatly, in response to specific circumstances. Generally, surface mining is chosen wherever overburden removal is an economic proposition. When overburden thickness rises, opencast mining may become uneconomic, and an underground mine has to be developed by sinking shafts or driving inclines. Often, one seam mining is employed. This is a common practice in many countries like the UK, the US, South Africa and Australia. If the coal deposit lies even deeper, which usually entails higher levels of investment in mine development, the trend is towards multiple seam mining. This technique is traditionally used in countries such as Germany, Poland and the former Soviet republics. The definite advantage here is that the existing mine infrastructure can be used to mine several seams simultaneously in order to increase output and efficiency. The obvious disadvantage is that the mine layout becomes more complicated as regards mine ventilation, haulage and transport tasks. The following figure shows the typical layout of a deep mine with the chief features.

Fig. 3-1: Typical layout of a deep mine along with chief features



Legend: 1 Hoisting shaft, 2 Ventilation shaft, 3 Loading point, 4 Blind shaft, 5 Blind shaft, 6 Cross cut, 7 Main road, 8 Gate road with development, 9 Gate road, 10 Plow face, 11 Shearer face, 12, 13, 14 Abandoned workings, 15 Vent door, 16 Belt conveyor, 17 Rail haulage system, 18 Raw coal bunker, 19 Monorail, 20 Rail haulage, 21 N.A., 22 Water drainage: a Hoisting shaft, b Hoisting system, c Ventilation shaft, d Ventilation fan, e Preparation plant

Typically, the mine has two central shafts for hauling coal and material (1) and for ventilation (2). In a modern deep mine, multiple seam mining (10, 11) is predominant, with a substantial portion of development work accounted for by overburden and rock. The coal preparation plant (e) and the rail loading facilities are concentrated around the central shafts, with hoisting system (a, b), ventilation shaft (c) and ventilation fan (d). If mining is to be extended within the present mining field, it becomes necessary to provide for additional shafts as much as 20 km away from the main shafts. These are generally used for man-riding, material transport and ventilation. To protect the environment, it is common practice to integrate these new shafts into the landscape.

1.1 Mining Methods Underground

The most common mining methods are longwall and room-and-pillar mining. Traditionally longwall mining has been found in Europe, and subsequently transferred to the US, Australia, South Africa, India and China with variable degrees of success. By contrast, geological conditions and the structure of the industry in the US have favoured the development of room-and-pillar mining, which also found widespread acceptance in Australia, South Africa and elsewhere. However, the room-and-pillar method is viewed by some mine operators as uncompetitive and is becoming obsolete in the face of newer techniques, such as longwalls. Nevertheless, both methods are widespread and will be discussed below.

1.1.1 Room-and-Pillar

Typically, a five-entry production panel has a continuous miner, two shuttle cars and a roof-bolting rig. The recovery rate using this design is about 60%. In principle, the recovery rate can be increased by subsequently extracting the pillars. The shuttle car transports the coal from the miner to the central tip into a feeder-breaker, which is moved forward regularly to minimise the transport distance from the faces. From the feeder-breaker, the raw coal is transported to the surface via belt or rail haulage. Mining and roof bolting are sequential operations, the miner completing the maximum allowable depth of cut in one heading before moving to the next. Parallel operation of mining and bolting is also possible, this depending on the specific machine design. Some continuous miners have additional equipment for drilling and setting roof bolts manufactured, (e.g. by Joy or Voest Alpine).

The principle scheme of a room-and-pillar operation is shown in figure 3-2.

The heart of any continuous miner is the cutting system with cutter drums for medium to high seam applications. The loading rate is between 20 to 35 tonnes/min. The cutting depth depends on the cutter head diameter, which can be chosen individually according to the underground mining conditions. The continuous miner is operated by remote control, which gives the operator greater flexibility in observing and, if necessary, adjusting the cutting process, while remaining safe under the supported roof.

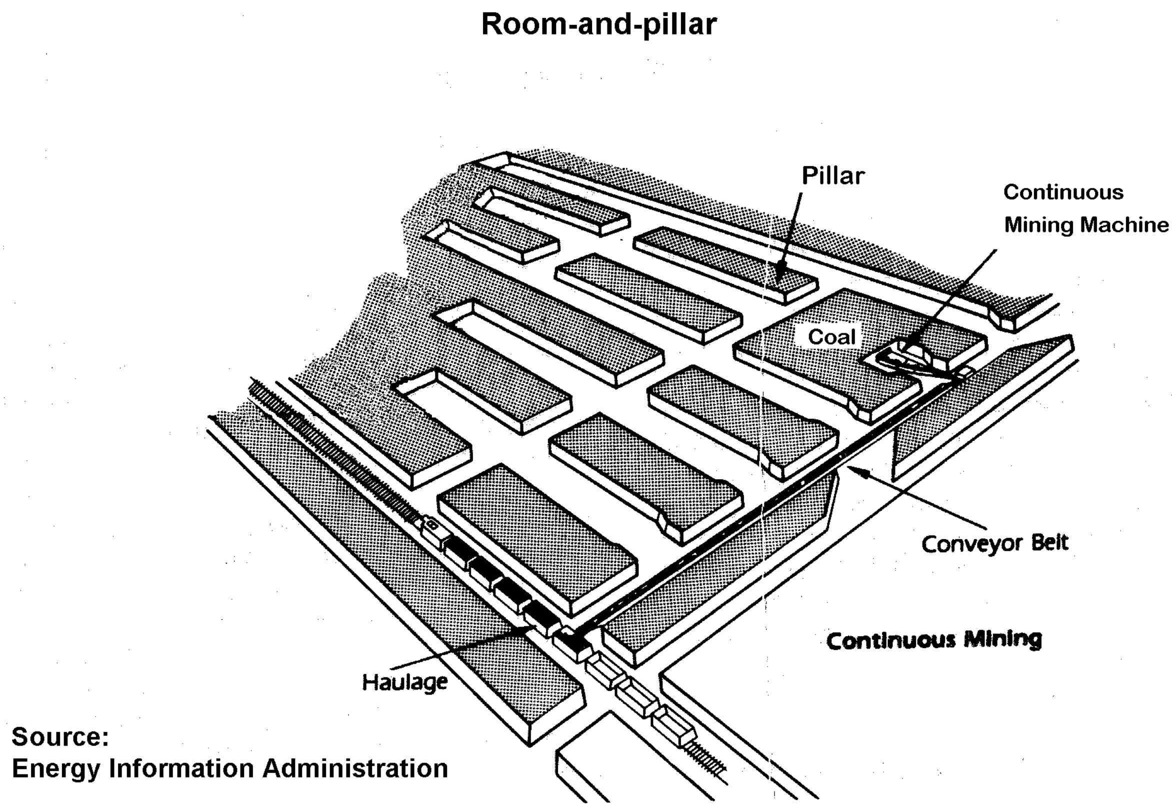
The basic principles of room-and-pillar mining:

- ***Cutting the road as wide as possible.*** The standard width, and that usually permitted by the authorities, is around 6m;
- ***Extending the cutting operation as long as possible without bolting.*** This is the limiting point, where the shuttle car operator moves under an unsupported roof. With advanced continuous miner technology, including remote control, a length of cut of around 7m is normal and permitted within the roof control plans (US standard). By an

exceptional ruling of the local mining authorities, the cut may be extended up to a length of over 10m;

- ***Driving square pillars*** requires the provision of crosscuts, which keeps haulage distances to a minimum and also minimises the moving time for the continuous miner;
- ***Maximizing the utilisation of belt conveyor systems.*** Operational experience has shown that a system of ten roadways driven by two continuous miners is optimal for utilisation of one belt conveyor system; and
- ***A separate bolting operation*** using the place change method is most productive, keeping the continuous miner and the shuttle car running simultaneously.

Fig. 3-2: Principle scheme of a room-and-pillar operation



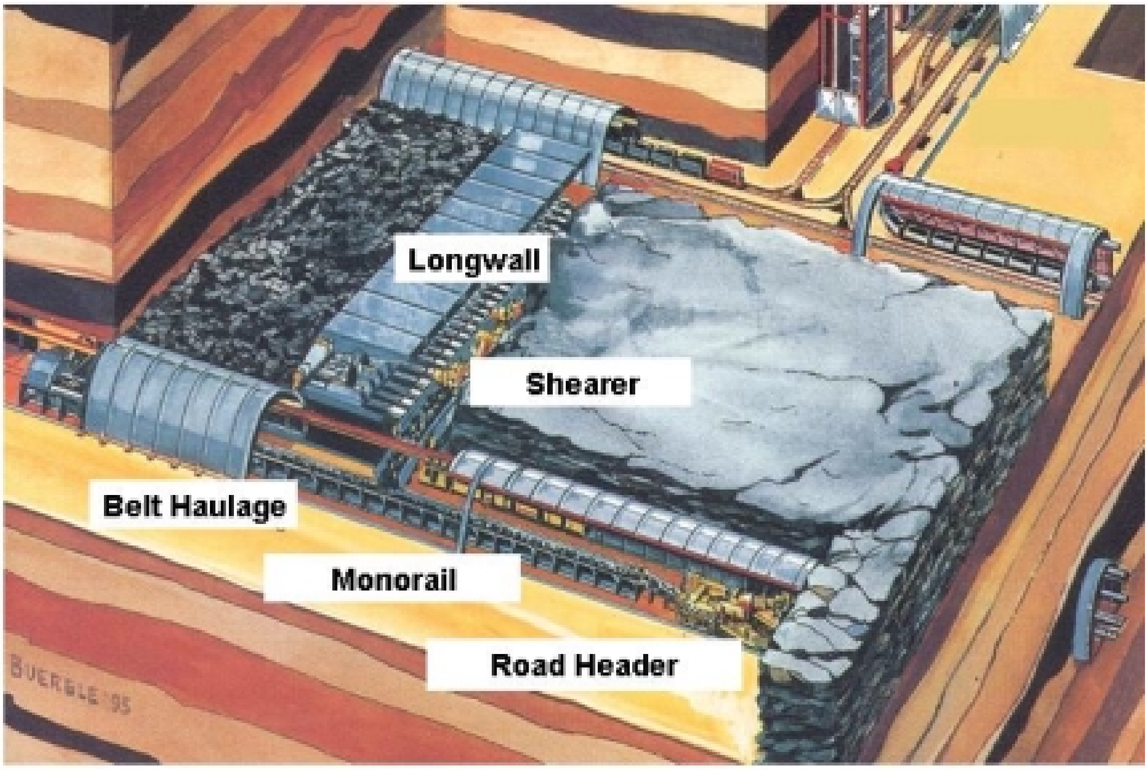
The advantages of the room-and-pillar method:

- ***Flexibility.*** Especially in the eastern US, unpredictable sandstone erosions occur and make quick changes in mine design essential;
- ***Low capital requirements.*** Most of the drainage reserves in the hills of the Appalachian coalfields are too small to justify high investment;
- ***Low subsidence.*** From an environmental standpoint, and with a view to avoiding surface damage, mining with stable pillars is an advantage;
- The typical performance of continuous miner operations using the place change method is about 60m to 120m per shift. Depending on the amount of coal cut per m and the working schedule (e.g. 18 production hours per day), production peaks of 2,400 tonnes/day per continuous miner can be achieved.

1.1.2 Longwall

The typical layout of a longwall operation is illustrated by the next figure 3-3.

Fig. 3-3: Layout of a longwall operation



The longwall face retreats towards the main haulages. The gate-roads at each end of the face are no longer required behind the face. The area behind is called goaf, where all the roof material collapses. Material services via monorail or other transportation methods and conveyors for coal haulage shorten as the face retreats. Longwall block dimensions, which describe face and panel lengths, vary and certainly depend on geology and individual circumstances. Today's high-production longwall operations have face lengths exceeding 400m and panel lengths are over 2000m. The best longwall operations are within seam thickness between 0.6m and 4m. There are two different coal cutting machine systems available: the automated plow system for thin and medium-thick seams (0.5m -1.5m) and the shearer system for seam thicknesses greater than 1.2m. The plow and the longwall shearer are operated between the gate roads, plowing and cutting the coal and loading it directly onto a chain conveyor. Hydraulic roof supports are used to protect the whole face operation from falling roof after the coal is cut.

Generally it can be said that economic longwall operations depend on

- Good geology to achieve world class performance;
- Selection of advanced mining machinery components;
- An effective mine infrastructure, comprising coal haulage, transportation of men and material, and ventilation; and
- A skilled workforce.

The geology is usually predictable only to a limited extent; this depends greatly on the thoroughness of previous exploration work. The objective is to achieve as much certainty as possible, as regards all determining factors (e.g. surrounding rock strata, inclination, and water). This is the basis for finding an optimised panel layout.

The mine infrastructure services are very much dependent on the basic mine layout, which is, in its turn, determined by the geology of the deposit. There is a wide range of different technical means available for optimising the haulage and transport functions. Many of these require special installations within the mine workings, and these have to be considered at the planning stage. Finally, the selection of the optimal equipment is based on cost/benefit analysis.

High-performance longwall units rely on achieving high raw coal output with minimal personnel, so that a skilled workforce is a precondition of successful longwall operations.

1.2 Surface Mining Methods

There are two basic methods of surface mining; the open pit method and the opencast method. Opencast is more commonly known as strip mining.

Opencast normally refers to a method involving the casting aside of the overburden a short distance away, with a relatively small portion of the coal being uncovered at one time. This coal is removed, and the process repeated. In opencast mining, one machine often performs both functions, digging and transporting, e.g. a large dragline strips waste/overburden. This can occur when the cover is sufficiently shallow to permit it to be stored in an area close to the excavator.

Open pit mining normally refers to a method in which the overburden is removed from the coal across a relatively wide area, so that the material has to be loaded and transported over considerable distances. The main items of mining equipment deployed in large-scale open pits, consisting of extraction units, haulage and handling units are:

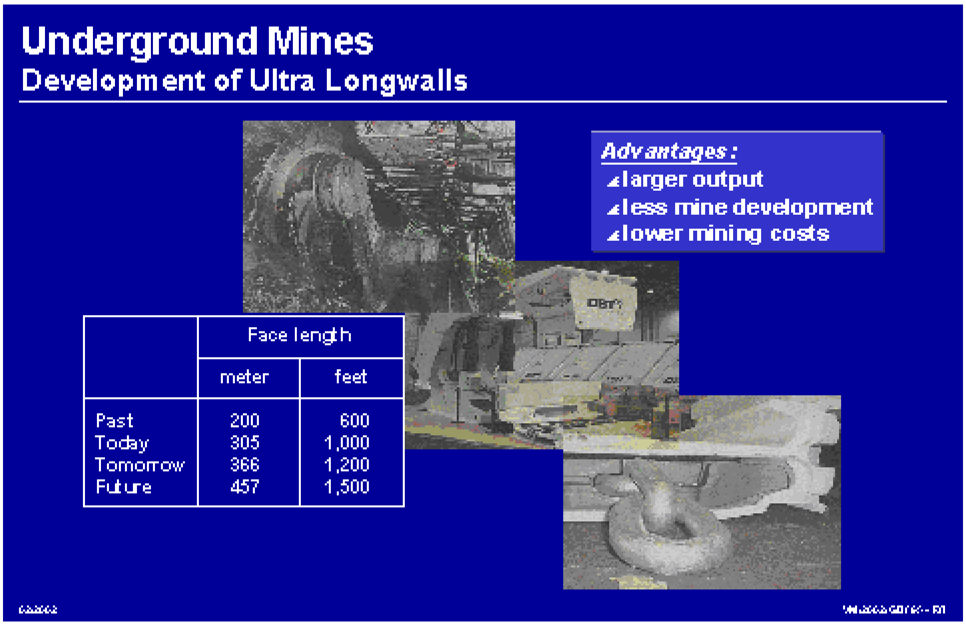
- Rope shovel, hydraulic shovel or backhoe, wheel loader together with trucks;
- Bucket wheel excavator together with belt conveyor line and spreader.

2. Mining Technology

2.1 Underground Mining

It is the difficult geological conditions, in particular, that determine the efficiency of the European mining industry, and these conditions have forced the sector to rationalise mining operations and use new technology wherever possible. Accordingly, the hard coal industry in US, Australia and Europe is now operating very modern deep mines often employing "high-tech" systems. Developments in mining technology are mainly focused on the operating panels, where substantial improvements have taken place. The processes of coal winning, face conveying and face support are increasingly being integrated into a combined, high-capacity system. The mechanization of winning and face support now permits face lengths of over 400m. Primarily more efficient face conveyors with stronger chains and drive systems have facilitated this development.

Fig. 3-4: Developments in ultra longwalls



Not only in Germany, but also in the US and other advanced coal mining nations, several important factors have been affecting the development of longwall equipment. A case in point is the US market, which is extremely competitive. The only underground longwall mines remaining are those that are able to produce coal at the same or a lower cost than surface mines or in room-and-pillar operations. The general trend has been toward the production of more and more coal from even fewer longwalls in operation. Similar developments are reported from Australia. The international coal mining community is certainly monitoring new developments, especially in countries known for their high technical standards and regarded as trendsetters in coal mining technology.

There are a variety of options available for improving longwall equipment and the various components. Given that, it is the whole set of equipment that has to operate under what may be very tough mining conditions and has to yield good operational and productivity figures. Technical developments in the various components of a longwall involve:

- Transport technology with armoured face conveyor (AFC);
- Drive technology;
- Roof support technology with electro-hydraulic shield supports;
- Shearer technology; and
- System of automation and electro-hydraulic controls.

2.1.1 Armoured Face Conveyor and Drive Technology Systems

The basic principle of the Armoured Face Conveyor (AFC) has remained virtually unchanged since its inception. The AFC not only conveys coal, but also acts as a track for the mining machine – the shearer or the plow – and serves as a reference rail for the shield supports. Modern AFCs are up to 1,342 mm wide, with an installed carrying capacity of more than 5,000 metric tonnes per hour. The operating voltages are up to 3,300 volts (50 Hertz) or 4,160 volts (60 Hz).

In recent decades, the pan width, together with the deck-plate thickness, has increased significantly, particularly during the past ten years. This is also the case with the thickness of the profiles and the breaking strength of the pan connectors. Contrary to conventional wisdom in the early 1990s, the hardest material has not been the best for wear resistance, and a high-strength manganese-based steel has shown minimum wear, especially as the production rate rose over time. This material's surface has hardened as more and more coal was conveyed. As examples of maximum pan life - assuming good conditions - some AFCs have conveyed more than 20 Mt and are still in operation with the original 40mm deck-plate.

New AFC developments have been initiated by coal operators mining under difficult conditions and conveying more rock, which is the case especially in Germany, but also internationally in those cases where the longwall is operated close to fault zones and/or faces with larger stone beds in the coal seam. One new development is the DBT PF 5 pan model. Compared with the older PF 4 pan model, the profiles are larger, and the typical deck-plate thickness has increased to 50mm. The dog-bones each have a breaking strength of more than 4,500 kN, compared with 4,000 kN for the PF 4.

Face conveyor systems in operation have horsepower installations of up to 3,200 kW (each drive frame is capable of 2 x 800 kW) with high AFC chain speeds of up to 1.8 m/s. The AFC system is designed for maximum carrying capacity and/or maximum face length.

One important component that helps maximise the performance of high horsepower AFCs is an intelligent drive system for soft start, load sharing, and overload protection. The Controlled Start Transmission (CST) drive system, developed especially for use with a chain conveyor, is a user-friendly drive control unit.

2.1.2 Roof Support Technology

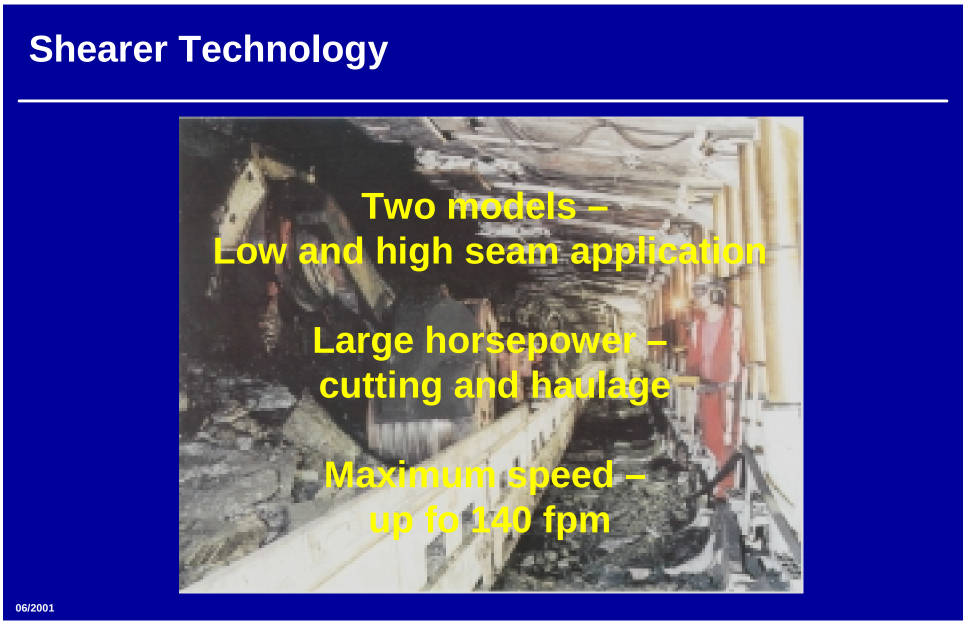
Shield support is available for seam heights from 0.6-6m with setting and yield loads tailored to the operator's requirements and the geological conditions. Most of these shields are in a two-leg design today. Support capacity can now exceed 1,000 t, if required. The original 1.5m shield width has grown to 1.75m. The advantages are obvious. Fewer shields are required for the same face length, which reduces the total number of shield units and, hence, the costs. Furthermore, longwall move times can be shortened using fewer shields.

Recent developments suggest that shield width may grow to 2m; use of this new shield support type will certainly depend on specific conditions. A 2m wide prototype shield is now in operation at Cumberland, US. Leg diameters have now grown to 400mm and are typically double-telescopic cylinders, maximising the support density at a given open-to-closed height ratio. The large diameters improve the hydraulic flow characteristics with the leg, and yield quick minimum shield lowering and setting times. Maximum operating pressure is allowed to be over 350 bar.

2.1.3 Shearer Technology

Shearer technology is very important for any longwall operations. Usually, various manufacturers offer two shearer types - for low and mid-to-high seam applications. Total installed power is up to 1.5 MW for the larger machine types.

Fig. 3- 5: Shearer technology



Haulage speed ranges between 10 and 20m/min where the full web cutting method is used. Cases using half web cutting have yielded haulage speeds of up to 40m/min. In thinner seams of 0.6m-1.5m, however, the latest plow system technology is now outperforming shearers. Plow technology is used in China, the US and Germany. Plow systems are very simple: a plow guide via an endless chain pulls a steel plow body with teeth alongside the face conveyor, peeling strips of coal from the face.

Compared with a shearer, the plow operates very quickly (up to 3m/s) with up to 250mm cutting depth per plow pass. This allows a fast mining speed and maximum productivity. The latest generation of plow systems uses more than 2 x 400 kW and even more for cutting. The main advantages are:

- Proven complete longwall system for thinner seams;
- Accessibility of lower coal reserves;
- Ease of automated longwall operation;
- Maximum safety (no operators required on the face);
- Minimum maintenance;
- Easy working through areas of hard coal or faults by simply adjusting the cutting depth (smooth control).

2.1.4 Automation and Electro-Hydraulic Controls

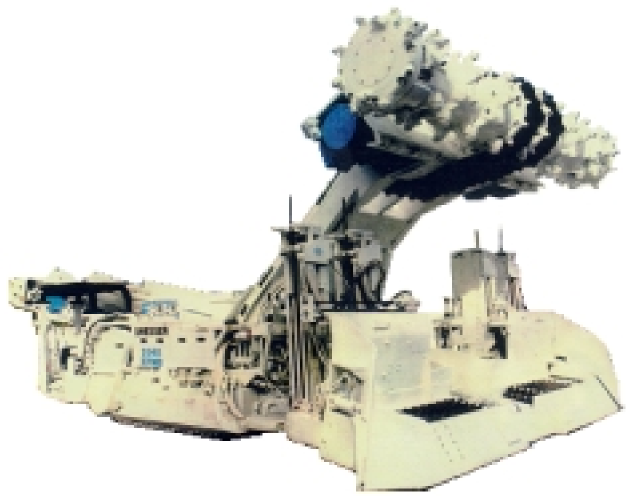
The PM 4 electro-hydraulic control system brings the operator one step closer to full automation of the longwall systems. The basic concept is “in-shield intelligence”. By having individual power groups, there is little or no limitation to flexibility in running the mining sequence to efficiency. A central computer can be located at either the head-gate or surface (or both) for maintenance data acquisition and face monitoring.

All shield features activated by the PM 4 electro-hydraulic shield control system are programmable. This creates a safe environment for longwall personnel working at some distance from the moving shields in all longwall mining methods. In view of increasing levels of automation and the need to make installations more user-friendly, a PC-based system with a standard Windows platform and Pentium processor is available for use both underground and on the surface.

2.1.5 Continuous Miners (CM)

For roadway development in longwall mines and coal production in room-and-pillar operations, continuous miners (CM) are in use. In the main coal mining countries - the US, Australia and South Africa - use of a CM as sole development machine is fairly widespread. Typically, rectangular cross-sections of 10-15 m² dimensions are driven. The smaller the number of CM development sections required by a mine, the better the cost performance. Hence, the rate of advance of a CM section is beginning to be the most important factor in speeding up mine development. There has already been a considerable productivity increase during the past decade. Today, CM advance rates vary widely, but a 100m per day linear gate-road advance on a 3-shift/d basis is standard throughout the industry, whereas main-road and other development forms achieve only 20 to 25m per unit shift.

Fig. 3-6: Continuous miner



Operators and machine manufacturers are working together to enhance CM performance, with a focus on improvements to machinery and organisational setups. While the standard CM section requires a CM, a bolter and shuttle cars rotating according to the change-place principle, more recent concepts favour the use of in-place machines, which should allow for simultaneous cutting and bolting.

2.2 Surface Mining

Surface mining involves a number of different activities that can be grouped into different cost centres. The more important cost centres are:

- Site clearance and reclamation;
- Overburden removal and dumping;
- Coal extraction and haulage;
- Ground water and surface water control.

The key economic factor in surface mining is the stripping ratio, i.e. how many m^3 of waste has to be removed in order to expose one tonne of coal for extraction. In fact, this means that overburden removal is the most important cost centre, and it has to be monitored closely in operations. In mines with relatively high stripping ratios (10 m^3/t - 20 m^3/t), a cost saving of even a few cents/m^3 of waste may amount to a substantial total saving of several €/t on coal, and this can be added directly to the profit of the mine.

2.2.1 Surface Mining Machinery

The major types of digging and loading machinery used in the surface mining industry can be divided into four categories based on their mode of operation.

Dig and load motion	Machine type
Continuous	Bucket wheel excavator
Pivotal	Draglines
Discontinuous	Shovels/Backhoes
Load and propel	Loaders/Scrapers

The question of the most suitable surface mining equipment for overburden removal and coal extraction is one that arises in the most varied of surface mining projects. The complete development of a new opencast mine certainly involves the most complex of demands, but increases in the mining capacity of an existing opencast mine, or the replacement of existing continuous or discontinuous equipment also requires careful scrutiny of all criteria. Only detailed project-geared investigations can form a basis for the choice of equipment.

The actual type of machinery selected depends on factors such as:

- Digging conditions;
- Output required;
- Mobility;
- Physical working dimensions;
- Selective coal mining, particularly in multi-seam deposits;
- Climate and/or environment;
- Capital cost vs. operating cost (long term vs. short term project);
- Reliability.

To ensure economic extraction of run-of-mine lignite, for example, bucket wheel excavators (in equipment combinations consisting of excavators, belt conveyors and spreaders) have been deployed in opencast mines for almost seventy years now. Besides the high capacity units with service weights of 14,000 t and daily mining capacities of 240,000 m^3 operated in Germany's Rhenish lignite mining area and the C frame units (7,500 m^3/h with a service weight of 3,500 t), large numbers are now used worldwide. There is the strong category of compact bucket-wheel excavators with service weights ranging between 55 t and 1,000 t and with hourly production capacities of 500 m^3 to 5,000 m^3.

Belt conveyor systems now have capacities of up to 37,000 t/h and are among the most powerful worldwide. They have created the preconditions for efficient and, hence, low-cost mass removal. In opencast lignite mines, the spreader is used to dump overburden into the mined-out section. This high-capacity machine covers the mine dump with fertile soil layers and shapes the terrain's relief, thus paving the way for the post-mine landscape.

The various elements in this technology work together as follows: Bucket-wheel excavators remove the loess, gravel, sand and clay located above the lignite or extract the coal. They operate on several benches. The largest bucket-wheel excavators are 220m long and 90m high. The bucket wheel has 18 single buckets and a diameter of up to 22 m and is manned by four operatives.

Fig. 3-7: Bucket wheel excavator

From the bucket wheel, coal or overburden is transported to the conveyor belt of the bench concerned by conveyors installed on the machine and by a loading unit. All belt conveyors on the extraction side (the side of the opencast mine where the excavators are located) intersect at the material distribution centre. Here, each incoming conveyor can be linked to any outgoing conveyor, thus allowing the different overburden types and the coal to be selectively directed to various destinations. The coal is directed to the "bunker" for storage or intermediate stockpiling of the mined quantities. Belt conveyors or the company's own railway system/trains bring the coal from the bunker to the power plants or refining facilities. The overburden is transported by the belt conveyors on the dumping side (the mined-out side of the opencast mine, where the spreaders are located) to the spreaders, which dump it onto the various mine levels, the "benches". Belt conveyors and spreaders are connected by tripper cars, which take the overburden from the belt and supply it to the spreader via a boom. The option of arbitrarily varying the linkage between the overburden excavators and the spreaders via the material distribution centre allows the dumping side to be firmly constructed for future use and the fertile loess to be spread as top layer for subsequent agricultural or forestry recultivation.

While the bucket wheel excavator has a very economical dig and load motion, its drawbacks - such as high capital cost, low availability, high maintenance cost and its inability to dig anything but soft material - make it unsuitable for most open pit mining applications.

The wheel loader's disadvantages include the inability to handle tough digging, its relatively low availability, compared with a shovel, and the higher energy and time requirements for moving the bucket load and machine weight from the face to the truck, and then returning the machine to the face. Given this, the wheel loader is generally used for stockpile type work and because of its high mobility.

In overburden removal, the rope shovel is most often selected as primary loading equipment because of its:

- Ability to handle the complete spectrum of digging conditions;
- High productive capacity;
- Reasonable mobility;
- Suitability for work in banks up to 15 m and its ability to load all sizes of haulage units;
- Adaptability to all climates;
- Relatively high capital cost, but low operating cost, which is a significant factor in long-term projects; and
- Long life expectancy and high availability (i.e. 20- 30 years with 75 - 85% availability).

Particularly in multiple-seam operations, hydraulic excavators and/or backhoes are often selected as additional loading equipment for interburden removal and as primary loading equipment for coal extraction and quality control because of their:

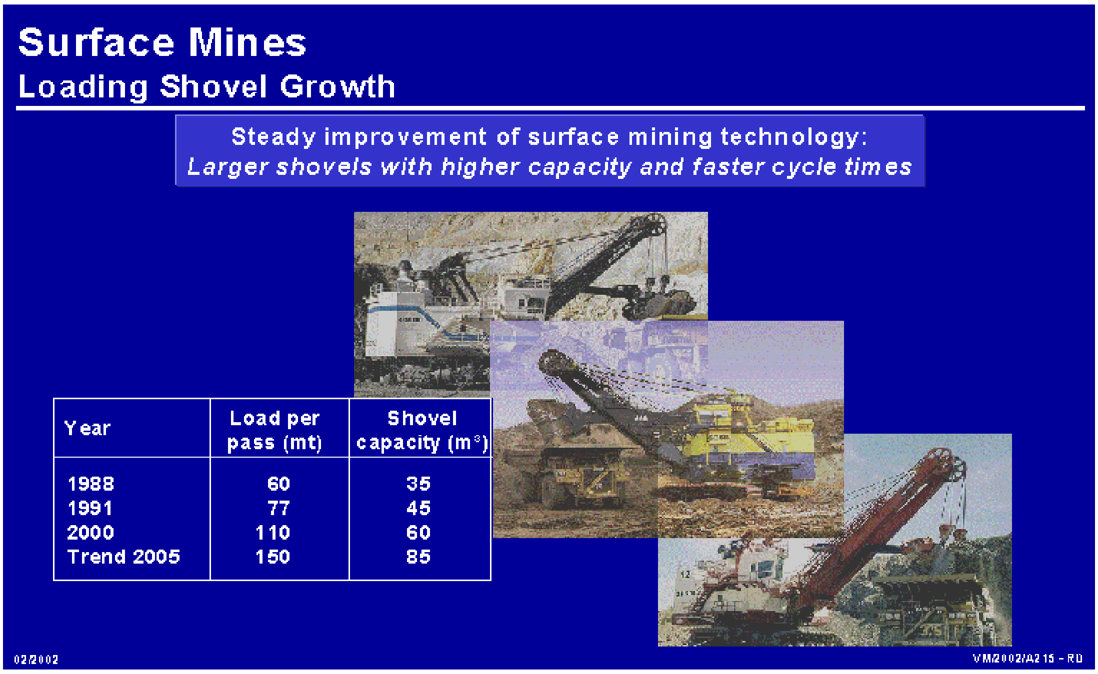
- High productive capacity;
- High availability (75 - 85%);
- High mobility;
- Abilities in selective coal mining.

2.2.2 Technical Development in Surface Mining

Shovel-truck operations are a more flexible system in surface mining with a high degree of horizontal and vertical selectivity and an ability to accommodate rapid changes in mine plan; which is required owing to production constraints. The mining method is also well proven and is employed worldwide.

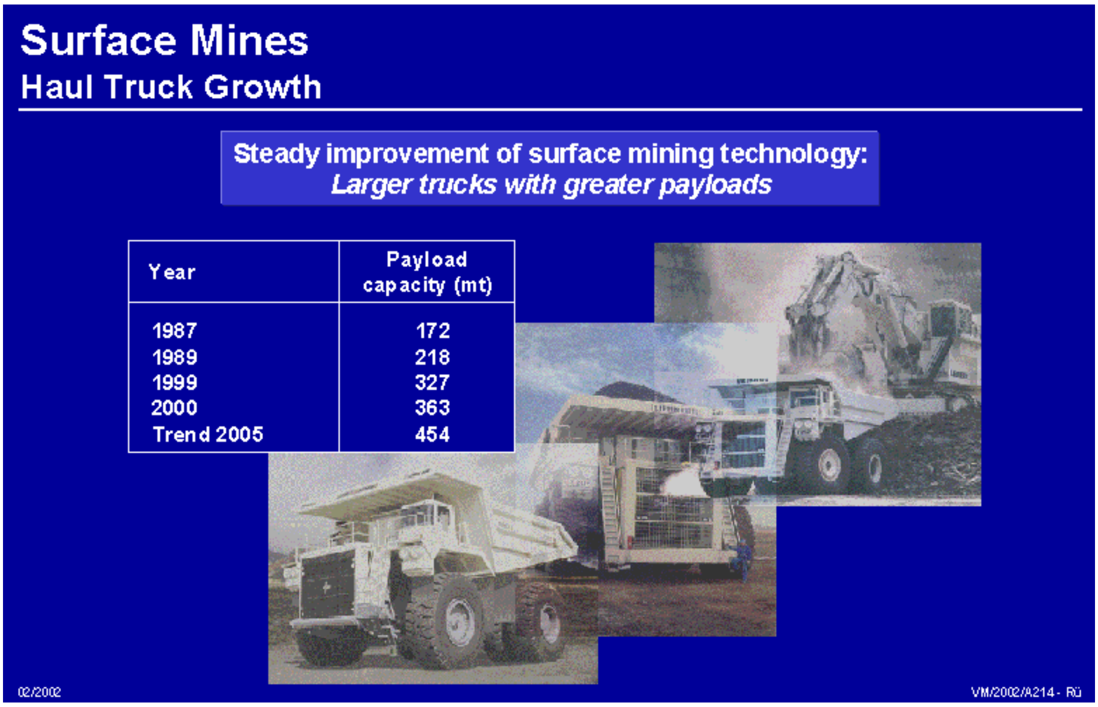
The choice of shovels and trucks for most mining applications requires a decision on the number of units as well as unit size. Contrary to the selection process for strip mining equipment, no constraints exist for machine dimensions as regards bench height, spoiling area, spoil pile shape, etc. Bench height is not a fixed dimension; it can be varied by the mine operator. Shovel dumping height and reach are a function of the truck dimensions and the method of operation, both of which can be selected. The initial shovel selection process, then, depends essentially on the output required. Hence, the number and size of the shovel units are first defined, against which the number and size of truck can be matched. Recent developments have brought increases in the size and capacity of shovel and trucks.

Fig. 3-8: Loading shovel growth



The figure shows advances in shovel dimensions. Since 1988, shovel capacity has been steadily increased from 35 m³ to 60 m³, while maximum load per pass is now over 110 t. The trend points to 150 t and a shovel capacity of 85 m³, so there has been a general rise in truck dimensions.

Fig. 3-9: Haul truck growth



Truck dimensions with payload capacities of up to nearly 400 t are 'state-of-the-art'. Various truck manufacturers already envisage further increases in truck capacity. The trend is towards payload capacities of up to 500 t.

Larger truck and shovel dimensions are necessary in order to cut operating costs. Material transportation by truck from the loading areas to the dumping areas constitutes between 30 and 50% of total mine operation costs, i.e. the greater the truck requirements, the higher the operating costs (of manpower, fuel needs, maintenance and repair, and spare parts). Every effort must be made in terms of proper mine planning, optimum haulage profiles, optimum haul road construction and maintenance to keep capital and operating costs to a minimum.

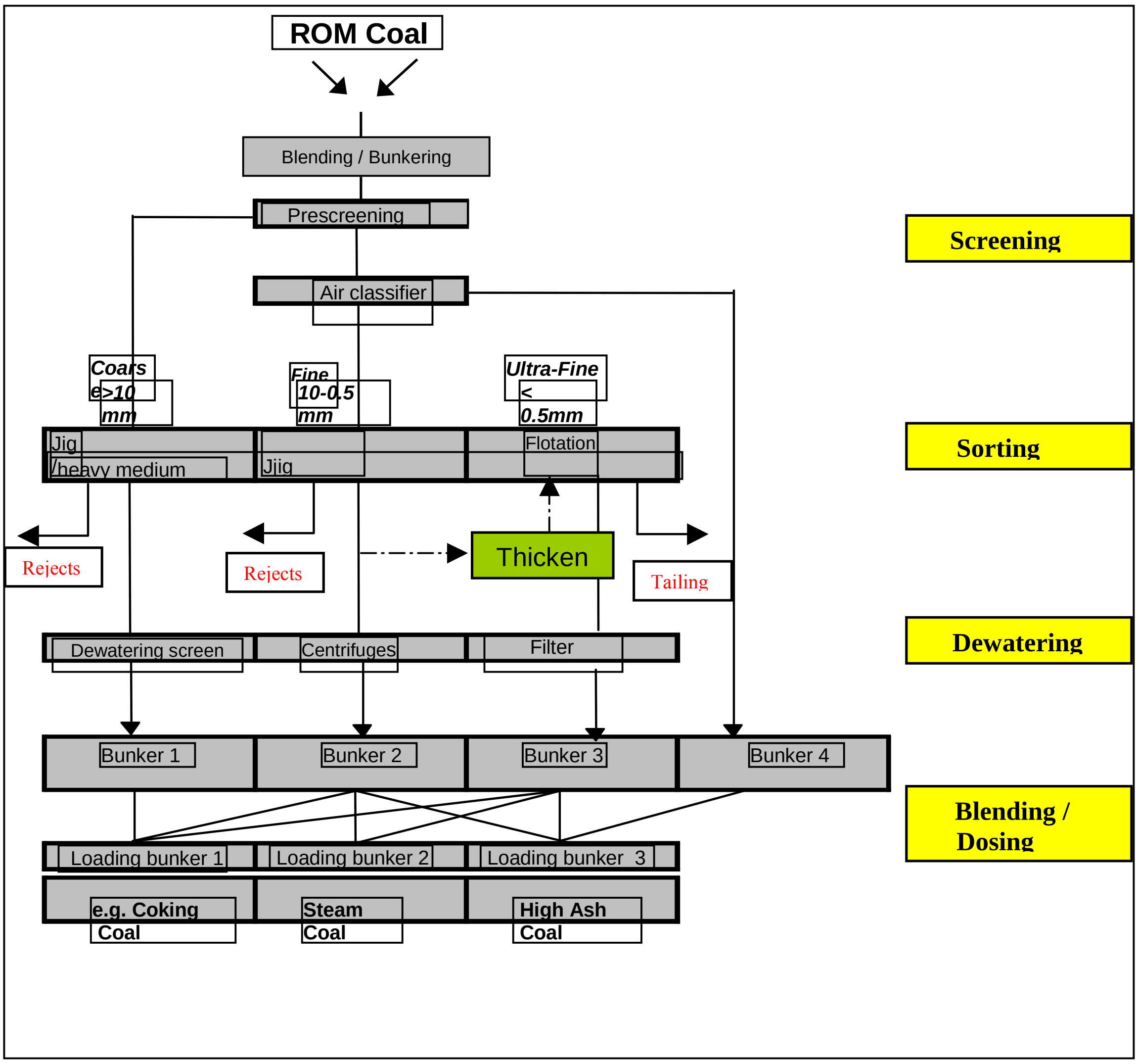
3. Coal Preparation

In most cases, run-of-mine (ROM) coal, whether from underground or from opencast mines, has to be processed to obtain certain grain sizes and/or to reduce impurities, e.g. ash or sulphur.

This is done in preparation or washing plants with capacities of up to 2,000 t/h, in which ROM coal is crushed, screened and treated physically or chemically to reduce ash and sulphur. The "washability" of ROM coal and customer requirements determines the process employed.

Figure 3-10 shows a flow sheet typically used in the German coal industry:

Fig. 3-10: Flow sheet (used in the German coal industry)



ROM coal from underground operations is stockpiled in homogenisation plants before being conveyed to the preparation plant where, in a first process step, coal is screened or treated in air classifiers to obtain well-defined grain sizes. The lumpy material is then separated into coarse coal and stone (= rejects) using "jigs" or heavy media; for separation of fines in the range of 10 - 0.5 mm, jigs are mainly used. In both processes - jig or heavy media - particles of mixed sizes, shapes and specific gravities are separated by gravity or by centrifugal forces.

Material < 0.5 mm is treated in the flotation process, in which surface chemical differences between coal and rejects are used to separate them. All the separation processes described work with water, so that the coal products obtained in the various process steps have to be de-watered using screens, centrifuges or filters. All process water is re-circulated, i.e. the water is collected in thickeners, clarified and reused.

After storing, the coal streams are blended and sold, e.g. as coking or metallurgical coal for coke making or as steam coal for power generation. Depending on ROM coal properties and customer requirements, the process layout may change. Fig. 11 shows an example of a flow sheet used in an Australian preparation plant to produce coking coal for export.

Fig. 3-11: Flow sheet (Australian preparation plant)

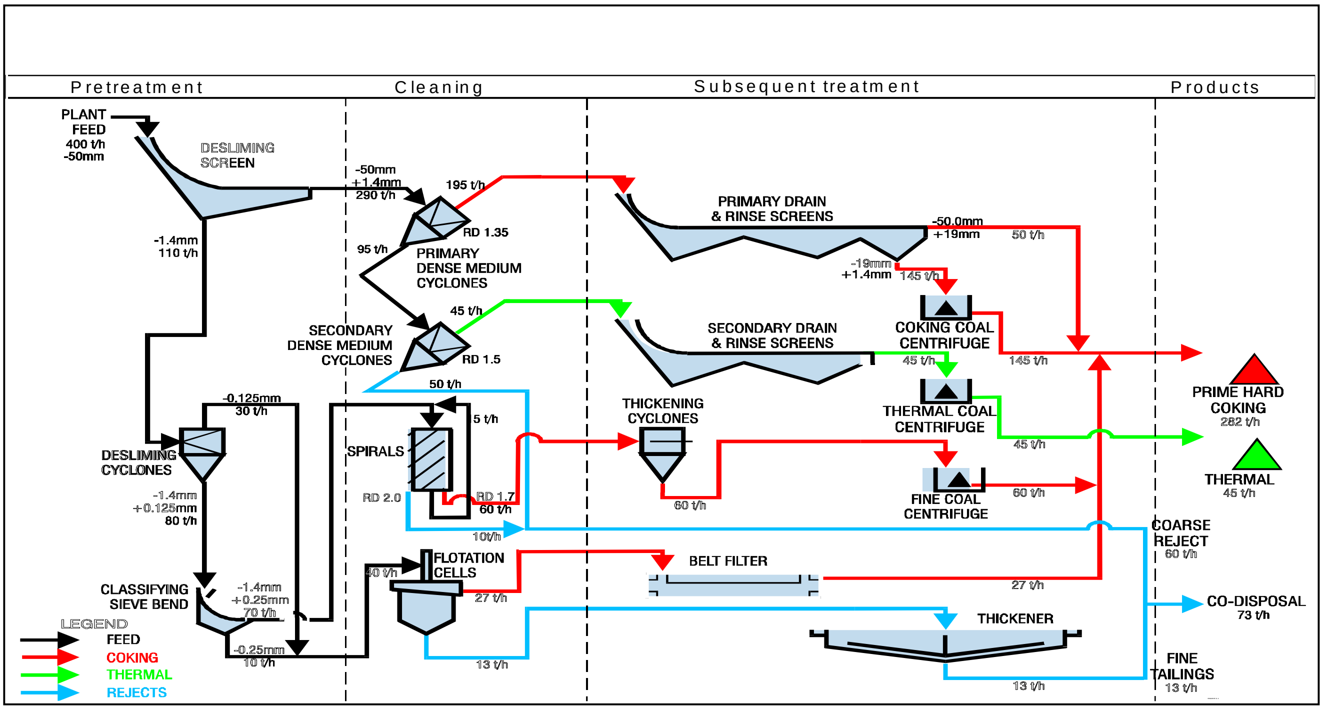
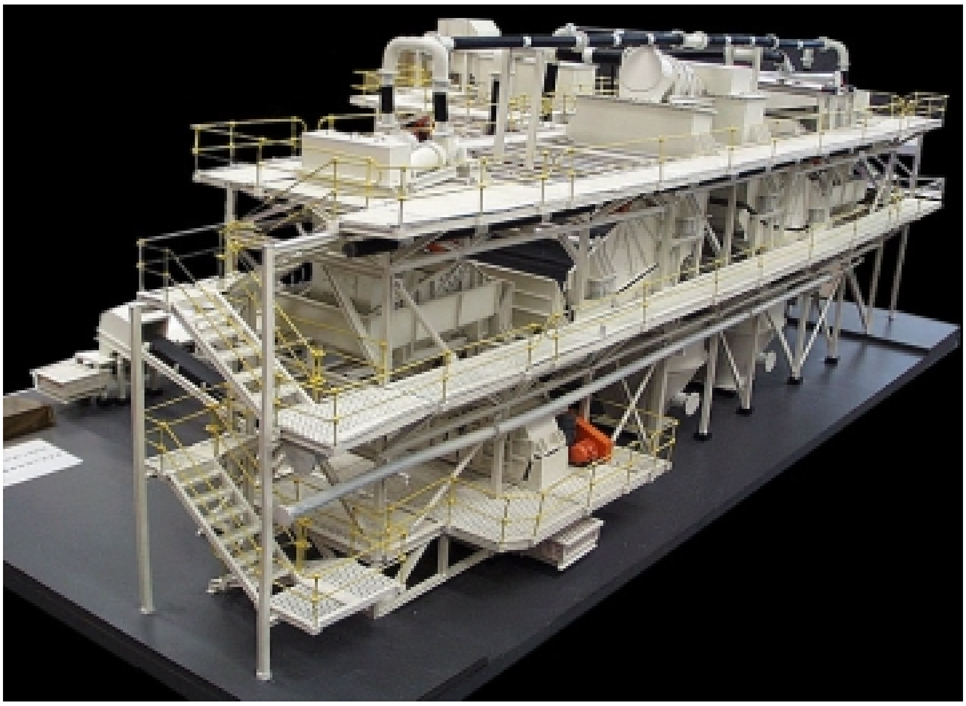


Fig. 3-12: Model of a modern preparation plant



Only in very few cases, can ROM coal be sent to customers directly without being treated in a preparation plant. In steam coal for power generation in particular, undesirable impurities have to be reduced as far as is technically and economically feasible.

Lower ash content (= less rock or stones) in the coal translates into lower energy needs to haul the coal from the mine to the power plants. At the power plant site, less ash means lower investment and operating costs for ash treatment and less space needed for ash disposal.

Reduced sulphur content in the steam coals means smaller flue gas desulphurisation (FGD) plants and lower SO_2 stack emissions. With constant quality parameters in coal, power plants could be operated more efficiently, which would result in greater boiler efficiency, lower coal consumption and hence, lower CO_2 emissions.

Coal preparation, therefore, is an essential element in the coal supply chain from mine to power plant, setting the stage for environmentally friendly use of coal in electricity generation.

4. Implications of Modern Coal Mining Technologies

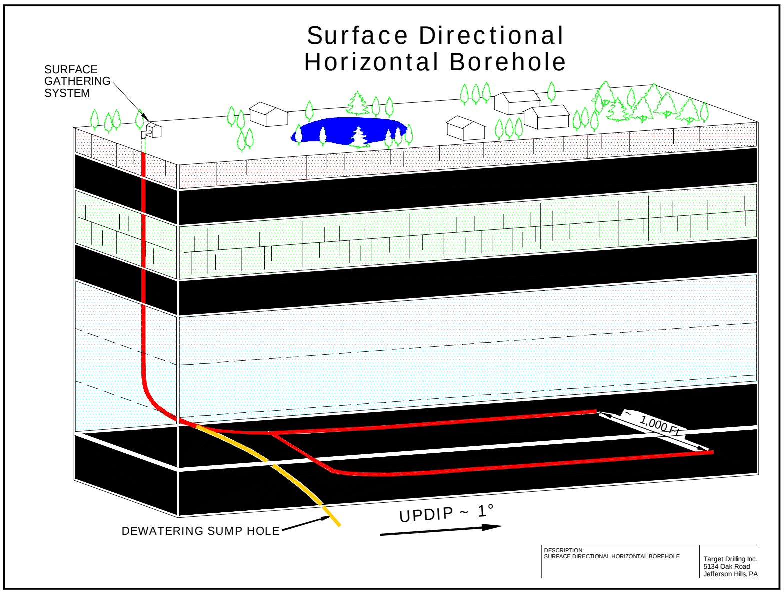
4.1 Production of Coal Bed Methane - A Contribution to Environmental Protection

In recent years, many countries have developed additional business activities derived from the original coal mining process. In an age of rising energy prices and growing environmental awareness, the use of methane gas from coal seams has been attracting more interest. Methane, a gas that occurs in all coal deposits, is released in varying concentrations from each underground mining operation and in the course of surface

mining. Since methane is explosive at certain concentrations, it has been regarded as a potential safety hazard in underground operations.
To obtain safe mining conditions in underground mines that are rich in methane, the gas is drained via shafts and drill-holes. This is common practice in the coal mining industry, and mining authorities often demand such gas drainage prior to the start of mining, in order to minimise the safety risks. Hence, many mines use a system of de-gasification to assist in reducing emissions of methane into their mine ventilation system. Typically in underground mines, horizontal drilling from existing main or gate roads is used to de-gasify the coal seam.

Recently, a new technique called directional drilling has been developed. This de-gasifies coal seams from the surface over several years in advance of mining without disrupting underground mining operations. This drilling technique uses sophisticated locational monitoring and detecting instrumentation located directly behind the down hole drill motor, to steer the drilling in the planned direction and hold the borehole within the coal seam.

Fig. 3-13: Production of coal bed methane scheme



In many cases, gas recovered from the mines is discharged directly into the atmosphere. This not only causes safety and environmental concerns, but is also regarded as the waste of a potential resource.

Given this, methane produced from coal beds, i.e. CBM (coal bed methane) - referred to as coal mine methane or CMM if produced along with coal mining - is now also valued as a fuel. The gas is mostly used for on-site power generation in gas power plants or sold as natural gas for a variety of off-site uses. After treating the gas to remove impurities like carbon dioxide, nitrogen and oxygen, the gas is fed into the grid. The energy content of 1 m^3 of methane gas is approx. 37 MJ. In a typical project for a mine in Pennsylvania, planning calls for production of 230 to 240 million m^3 of mine gas over a period of 5-6 years.

The use of mine gas in power generation, therefore, helps lower the amount of methane released to the atmosphere, where it contributes to the greenhouse effect. This is a further contribution towards sustainable use of coal deposits and resources. This natural gas from coalmines could replace some electricity in domestic water heating and displace oil, coal and other natural gas in heating applications.

Technical and economic circumstances, however, may mean that it is not always possible to exploit the gas recovered, in either power generation or even as vehicle fuel alternatives. In these cases, some coal companies have taken the interim step of installing flaring facilities at the mines to burn methane and convert it into carbon dioxide and water; by doing this, the carbon dioxide equivalent released into the atmosphere can be reduced by 85%.

4.1.1 Coal Bed Methane from Abandoned Mines

The coal and gas industry is also becoming more and more involved in the recovery and sale of methane from abandoned coalmines. Many abandoned coal mines are capable of producing significant quantities of medium to high heating value gas, and the ability to drain the gas from existing boreholes or ventilation shafts reduces or eliminates drilling costs.

A good example of CMM production from abandoned coalmines is German CMM production in the Ruhr Basin. The gas there is used in semi-mobile power plants for power generation.

Fig. 3-14: Power production from coalmine methane at an abandoned coal mine in the Ruhr Basin, Germany

4.1.2 Coal Bed Methane from Surface Mines

In simple terms, production of CBM from a new coalfield involves drilling a well in the coal and reducing the pressure, which allows methane to desorb from the coal and flow.

Fig. 3-15: Coal bed methane well in the Powder River Basin, Wyoming, US

The principal conduits for the transfer of gas from coal reserves are natural fractures in the coal. These cleats are commonly filled with water, so that pumps are required to de-water and de-pressurise the coal beds in order to allow methane to flow to the gas well. Also, to ensure commercially relevant rates of gas flow, stimulation methods like hydraulic fracturing are needed to enhance the natural gas flow by raising the permeability of coal. The technical data for a typical CBM well in the Powder River Basin, Wyoming/USA, are as follows:

- Depth 500 feet
- Capital cost US$60,000
- Output 200 mcf/day (~5,660 m³/d)
- Life 6-12 years

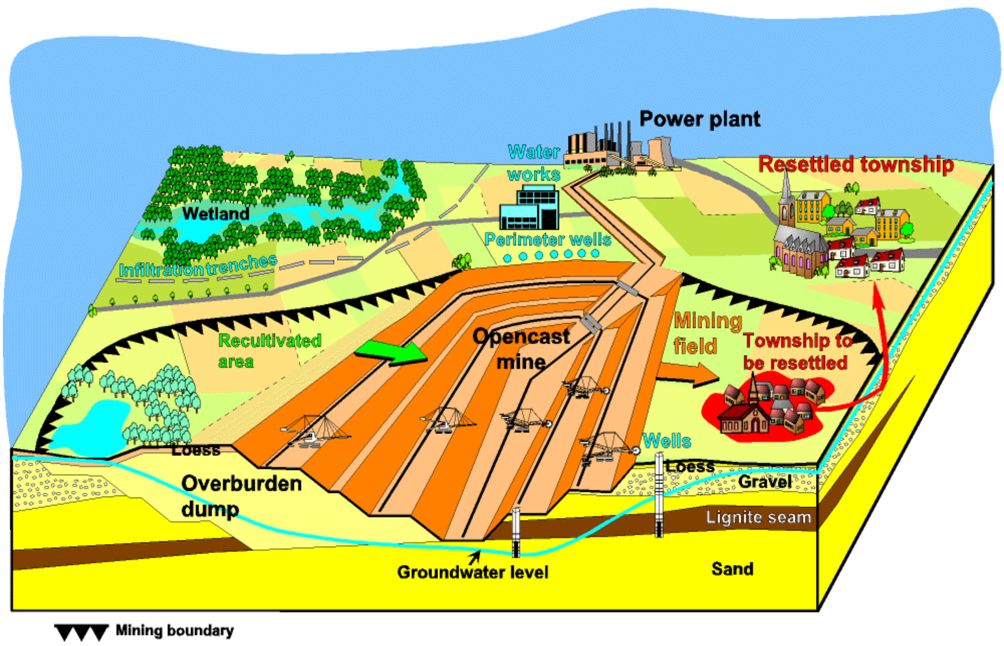
4.1.3 Coal Bed Methane Utilisation - A Contribution to the Sustainable Use of Energy Resources

Around the world, mining companies are stepping up their efforts to make use of the methane that occurs in any coal mining operation. Until recently, methane was regarded as a hazard to miners' health and safety, especially in underground mining. Today, methane has come to be a valuable fuel contributing to a responsible and sustainable use of coal deposits and energy resources. In cases where this is not feasible for technical and economic reasons, e.g., due to low concentrations of methane, the mine gas is often flared to avoid unnecessary emissions of carbon dioxide into the atmosphere.

4.2 Re-utilisation and Recultivation/Reclamation in Opencast Mining

Perhaps the most important interference of opencast mining with the eco-balance is land use; however there is no alternative. Hence, the mine operator’s most urgent task is to compensate for this interference as quickly as possible by reclaiming and rehabilitating the mined-out areas.

Fig. 3-16: Lignite opencast mining



Landscaping and reclamation must be directed toward creating new cultivated land. Planning has to achieve three objectives, creation of a landscape that ensures: 1) sustainable use, 2) ecological stability, whilst 3) maintaining its regional character. Almost 100 years of reclamation practice have shown that the various uses must be well balanced. Reclamation targets depend very much on pre-mine uses. The fertile Rhenish plain with its high-grade arable land or the Lusatian forest and pond landscape differ in soil, settlement and economic use. The requirements to be met by the post-mine landscape differ accordingly. Regional characteristics are to be maintained. Preservation and resettlement of the fauna and flora species typical of the landscape are given high priority.

The goal is to create favourable preconditions for regeneration, which allow a landscape to redevelop, which ensures sustainable use and ecological stability. Experience has shown that this goal can be achieved. In Germany's Rhineland, for example, some 240 hectares of recultivated land are recognised nature reserves.

From the start of mining operations until the end of 2002, a total of 164,571 hectares or some 1,646 km² were used for mining operations, with 28,392 hectares being accounted for by the Rhineland, 80,831 hectares by Lusatia, 47,458 hectares by central Germany and the rest by the remaining mining areas. Also by the end of 2002, a total 104,761 hectares of land had been rehabilitated. Two thirds of the area affected in the Rhineland has already been put to subsequent uses. In Lusatia, the figure is nearly 60% and in central Germany 70%. In the last two years, the amount of land reclaimed in each of the two eastern German mining areas was double the area newly used for mining purposes.

The lignite-mining plan drawn up for each opencast lignite mine describes the fundamental features of surface design and rehabilitation. The plans are based on comprehensive ecological investigations of the mining field and on detailed analyses carried out to establish which features and which types of land use should be given priority in the post-mine landscape. The essential elements in this planning phase are those of water management, pollution control, resource preservation or life-cycle management and, last but not least, settlement.

4.2.1 Water management

The most important prerequisite for the operation of mining equipment is the creation of a dry opencast mine with stable slopes and working levels capable of bearing loads. However, to start with, the soil layers are generally filled with groundwater to some meters below the surface, which requires drainage of aquifers overlying the coal and a sufficient lowering of the potentiometric surface below the deepest coal seam (de-watering). For this purpose, a large number of wells are built, and these are used to lower the groundwater. Much of the water obtained in this way is used to ensure the region's supply of drinking and process water. In addition, it is selectively re-discharged into the groundwater and surface water cycles.

Before opencast mine de-watering can begin, comprehensive water law permit procedures are necessary. In the course of these, the authorities make detailed investigations of the impact of de-watering and call for appropriate remedial measures from the company. During the de-watering process, all relevant measures are also subject to ongoing monitoring by the authorities. To this end, a wide range of documents on developments in groundwater levels, amounts withdrawn and groundwater quality must be submitted to the authorities.
Hydro-geological conditions do not usually allow groundwater lowering to be confined to the area close to the opencast mine. Agriculture and forestry are not generally impeded by groundwater lowering, since plants and trees are not directly dependent on groundwater but live from the water stored close to the surface in humus and loess; whereas the surrounding water balance and the landscape are inevitably affected.

The mine operator, who takes measures to provide substitute water at his own expense, compensates the effects on the water supply. These measures may involve water supplies, well-deepening activities or the assumption of additional costs. Feeding in water, where wetlands in need of protection are preserved by water percolation, conserves significant water bodies. In addition, water is discharged into trenches and creeks in the area of wetlands worth protecting. In specific cases, like the Lusatian mining area, slurry walls are an additional suitable way of limiting the effects of groundwater lowering.

The water withdrawn and discharged also has to meet quality requirements subject to continuing specification. For this purpose, the surface water withdrawn in the opencast mine is first cleaned mechanically in large settling ponds and, if necessary, processed chemically, so that it satisfies the needs it must meet for its subsequent use.

Hence, a wide range of measures are used to keep the effects of de-watering to a minimum, by taking necessary precautions, or providing substitute water or an offset. Altogether, this ensures safe control of the water management conditions prevailing in the area affected by lignite mining.

4.2.2 Pollution control

To guarantee that the people living near the opencast mines are protected against unreasonable levels of dust and noise, internal calculations and evaluations of the expected pollution situation to village sites are carried out as early as possible in the long-term opencast mine planning process. The results obtained are taken as a basis for drawing early inferences on the acceptability - in terms of dust and noise pollution - of the advancing mine or the need for, and the extent of, protective measures. In a further step, the correctness of the plans drawn up by the company itself and the protective measures envisaged are reviewed and assessed by independent experts, in order to ensure the application of ‘state-of-the-art’ technology.

In the field of noise insulation, priority is given to primary protective measures that effectively avoid noise emissions at source. In terms of mechanical engineering, these measures include the pinpointed deployment of noise-reduced drives such as those installed in bucket-wheel excavators and the provision of belt conveyors with noise-reduced idlers. In addition, drives located unfavourably for nearby residential areas, are fitted with soundproofing cases. Where mechanical engineering measures alone do not provide sufficient protection, they are effectively complemented by noise-protection dams or walls installed near villages. These facilities are supported and complemented by a comprehensive programme of protective planting and measures to preserve forest stands in areas near the opencast mine.

The main measures taken to ensure effective protection against dust blowing off exposed opencast mine surfaces are quick final recultivation or continuous interim greening of dozed dumps. For some opencast mine sections such as rim slopes, which perform mining-related functions over longer periods of time, the process of spray-sowing has proved to be an efficient way to reduce dust emissions.
The technical measures of dust emission control consist mainly of the spraying of stockpiles to reduce dust formation, the wetting of paths and tracks or the covering of mine roads with non-dusting material, from asphalting or the use of sprinkling systems at dust protection walls. Further measures involve the sprinkling of transfer and discharge points in conveying routes and fitting them with protective covers.

In townships located near opencast mines, pollution measurement networks have been installed. The results show the efficacy of the manifold pollution control measures taken; this also allows any deficits to be identified and eliminated.

4.2.3 Sparing of resources and life-cycle management

Sparing use of non-renewable natural resources makes a significant contribution towards environmental protection and is an essential element in shaping sustained developments. This includes, for example, use of the raw materials occurring in the overlying strata of opencast lignite mines, such as gravels, sands, clays, peat, glacial marl and boulders.

Selective preliminary extraction of reserves occurring close to the surface in areas to be mined; is itself one approach to putting these raw materials on the market in qualities and quantities that meet specific requirements. This allows raw materials obtained during the overburden removal process to be selectively mined, stockpiled and - following appropriate processing - set aside for marketing.
The strategy must aim at making the raw material potential within an opencast mine operator’s own field of responsibility, accessible to economical use. This would avoid additional land use for the separate extraction of such raw materials in the regional catchment area.

Due to the extensive mass removal of overburden and coal, opencast mining involves considerable energy expenditure. Given this, energy-saving measures are given a high priority. The employment of speed-controlled belt drives with appropriate control equipment, for example, allows the power consumption of belt conveyor systems to be reduced by up to 20%.

Within the scope of life-cycle management, the lignite ash produced during combustion in the power plants and the gypsum from flue gas de-sulphurisation are returned to the areas of the coal's origin and stored in landfills installed for that particular purpose. For gypsum, this means intermediate storage for subsequent industrial use. By installing these landfills in the depleted mine sections, the surfaces required have been given an additional land use - and at a sufficient distance from residential areas.

The landfill concept meets all requirements for the distance from the future groundwater level, for the creation of a barrier layer at the landfill base and for surface sealing. The clay needed for the top seal and the drainage material are taken from the opencast mine's overlying strata. The final contoured landfill surface is immediately sealed and then recultivated.

The ash landfills are integrated into the landscaping, and recultivation concepts drawn up for the post-mine landscape. Landfill planning and operation are subject to the same high environmental standards as those employed in actual mining operations.

4.2.4 Resettlement

Due to the extent of opencast mines, land use conflicts arise between the energy sector and other use functions such as settlement, forestry and agriculture, etc. While the reclamation measures performed immediately, following the land use for mining purposes involve time-lagged compensatory efforts, settlements are subject to continuing relocation.

The planning of lignite mining is a multi-stage process extending several decades into the future. As far as resettlement of a village is concerned, this means that - depending on its location within the mining field - the decision on the need to act is taken a long time before actual land use. The specific design for a particular resettlement is decided some 10 to 15 years before extraction takes place. The generation of residents to be affected in that future is now involved in the planning, with due account being taken of the social setting and local conditions - if necessary within the scope of separate sectional lignite mining plans. The concept of offering people the possibility of a joint move to a new location has proved invaluable. This "joint resettlement" option allows the village community and social links to be preserved.

The following procedure is generally applied: Proposals submitted by the citizens concerned are taken into account, the resettlement location preferred by the majority is defined at state planning level, organised by the competent municipality and further developed. During the entire procedure, citizens have extensive access to information and consultancy and rights of participation in all questions related to identifying, planning and developing the new location. The compensation practice employed by the mining company is aimed at maintaining the resettlers' material assets and, hence, their standard of living. This being so, each homeowner in the resettlement is generally given an opportunity to build a new building at the new location. For the resettlement of tenants, a specific concept for action to be taken is developed at each new village. Where appropriate, special options are also developed for other groups such as the elderly. The resettlement of industrial and agricultural operations is also implemented according to the principle that the security of all operations affected is to be maintained if so desired.

5. Conclusion

In recent years, all advanced coal mining nations have seen major developments in coal mining technology. These improvements have been caused by growing international competition in the coal-mining sector and by a rise in environmental awareness.

Dependent on geological conditions and on various technical, environmental and economic considerations, coal is mined in underground or surface operations. The most common mining methods for underground mines are the longwall and the room-and-pillar method. Surface mines employ both the open pit and the opencast mining methods.

Modern longwall mines achieve a yearly output of up to 7-8 Mt of coal out of one seam. The general trend in recent years has been towards producing more and more coal from fewer longwall mines. Developments in mining technology focus mainly on the operating panels, where substantial improvements have taken place. For roadway development in longwall mines and for coal production in room-and-pillar mines, continuous miners (CM) are used. Typically, rectangular cross-sections of 10-15 m^2 dimensions are driven. Today, CM advance rates vary widely, but a 100 m per day linear gate road advance is standard throughout the industry.

Surface mining is preferred, as this sector has been successful in developing very efficient mass excavation methods, rapid adaptation of the most modern technology and an ability to secure high levels of miner safety. Lignite and hard coal extraction worldwide is mostly by continuous opencast operations; the highest possible environmental standards are applied. Efficiency and environmental compatibility in the extraction of lignite have improved steadily in recent years. In particular, the successes scored in land reclamation in all mining regions during recent decades have demonstrated that the lignite mining industry can create new landscapes that leave no scars in the countryside.

Only in very few cases can the raw coal from the mines be sent to customers directly, without being processed to produce certain grain sizes and reduce impurities like ash or sulphur. This is done in preparation or washing plants with capacities of up to 2,000 t/h, where the coal is treated physically or chemically to reduce ash and sulphur. Specifically in the case of steam coal, reducing the sulphur content results in smaller flue gas desulphurisation plants and reduced SO_2 stack emissions.

Methane, a gas that occurs in all coal deposits, is released in different concentrations from each mining operation. Being explosive at certain concentrations, methane has been regarded as a potential safety hazard in underground mining, and the gas is drained via shaft and drill-holes. In many cases, gas recovered from the mines is discharged directly into the atmosphere, which not only causes safety and environmental concerns, but is also regarded as a waste of energy. Therefore, methane produced from coal beds (CBM - Coal Bed Methane) or from mining operations (CMM - Coal Mine Methane) is now often used for on-site power generation in gas power plants.

Chapter 4:
Coal-Based Power Plant Technology: A Competitive and Efficient Bridge to a Benign Future

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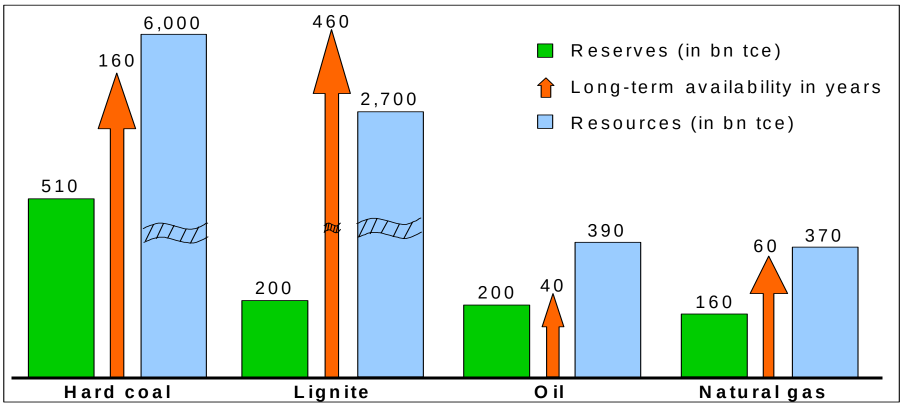
Key messages:

- The preferred use of coal is power generation, unlike the use of other high-value fossil fuels like oil and gas.
- Coal-based power generation moves forward on a technological pathway that has already brought major environmental improvements. The technology is modern, reliable, highly efficient, environmentally friendly and is available at a low price.
- The modern power plant process is based on pulverized fuel (PF)-firing, supercritical boilers and advanced flue gas treatment.
- The driving force behind all development efforts in power plant technology is the desire to achieve high thermal efficiencies together with low emission levels. This minimises CO_2 emissions, saves limited resources and is economically sound.
- On a long-term basis, new technologies, such as ultra low or even zero emission (carbon sequestration) processes, have the potential to make additional contributions to the emission control targets to which all countries are committed under the Kyoto Protocol. However, they will have an adverse impact on the efficiency of fossil fuel use.

1. Introduction

In view of the long-term availability of the reserves - compared with gas or oil - hard coal and lignite will remain a dominant fuel in future power generation (Figure 4-1).

Fig. 4-1: Reserves, resources and long-term availability of the various fossil fuels



1.1 Efficiency of Various Power Plant Processes

The efficiency of the power plant process is basically determined by the upper process temperature, which is limited, however, by the specific process chosen and the materials available (Figure 4-2). In the case of the Carnot process and the conventional power plant process, the highest possible upper process temperature and the lowest possible lower process temperature increase efficiency. In the conventional power plant process, the process temperature is governed by the main steam condition and the related materials. In the case of the gas turbine process, the upper limit temperature is determined by the possible gas turbine blade temperature. The lower limit temperature of power plant processes depends on the cooling water temperature and, hence, on local boundary conditions, so that it can be influenced to a limited extent only.

1.2 Clean Coal Technologies for Power Generation

Driven by the progress made in advanced clean coal technologies, the efficiency of conventional process equipment with pulverized fuel (PF)-fired boilers, which account for the majority of the world's coal-fired power plants, has gradually improved, while maintaining high availability as well as competitiveness, in terms of generating costs and low emission levels.[85]

Efficiency depends primarily on the characteristics of the thermodynamic steam cycle, which has undergone considerable changes. Steam pressure and temperature have steadily increased with improved characteristics in the available materials. Further progress is still achievable, by taking advantage of new materials to accommodate even higher steam conditions and to further improve cycle characteristics.

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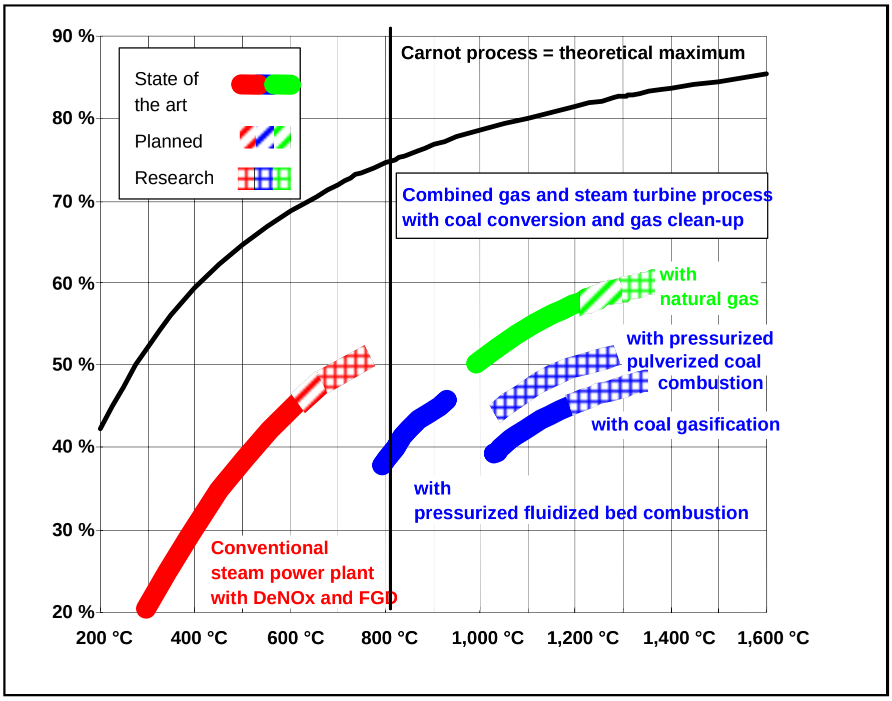
[85] For detailed information on small- and medium-sized boilers see: K. Brendow, 'Clean Coal Combustion in Small and Medium-Sized Boilers in Central and Eastern Europe'

Fig. 4-2: Efficiency of various power plant processes



A wide range of other clean coal power plant technologies is currently being discussed. These include coal gasification and liquefaction as components. The latter is of no major economic significance today, but remains an option in the event of any drastic rise in oil and gas prices and may be a limiting factor against excessive price increases for oil or transport fuels. The former will be discussed in detail later. Hydrogen production from coal is also discussed, but in view of the limited reserves, this could only be an option for the future.

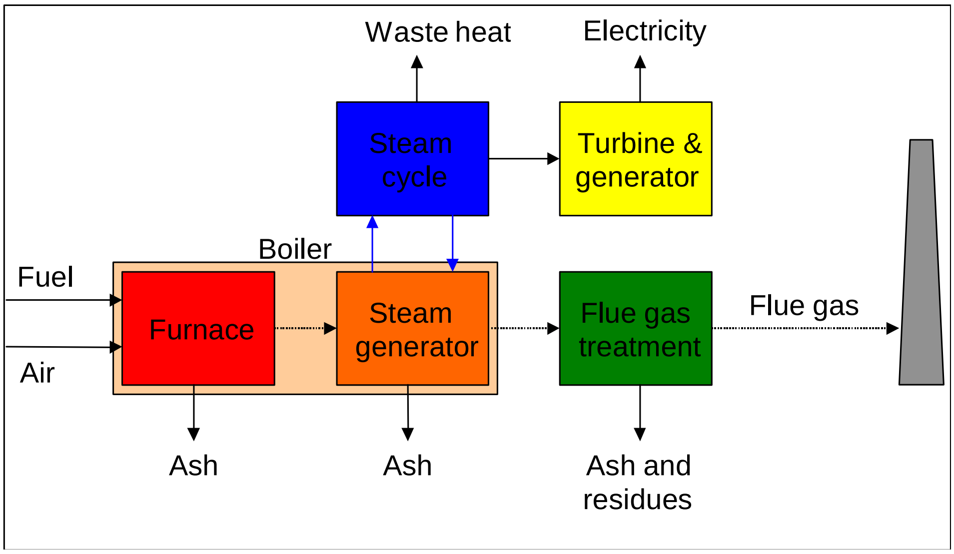
Improved conventional clean coal processes, employing supercritical PF-boilers on a hard coal basis can reach an efficiency level of around 45% to 47%, depending on plant location (e.g. sea water cooling). Similar developments are under way for lignite-fired power plants. The lignite unit with optimised plant technology ('BoA' = “Braunkohlenkraftwerk mit optimierter Anlagetechnik”) has an operating efficiency of over 43%. It went on stream in August 2002 after an approximately four-year construction period. The next development phase will integrate optional lignite pre-drying. A plant based on this concept is expected to reach an efficiency of around 47%.

Clean coal power plant technologies provide technical solutions for using coal efficiently and in an environmentally sound manner. In this way, coal can contribute towards protecting the environment while enhancing the security of the energy supply.

2. Status of Technology for the Conventional Steam Power Plant

All steam power plants are based on the same principle (see Figure 4-3).

Fig. 4-3: Principle of a conventional steam power plant



The fuel is burnt with air, and hot combustion gas, also called flue gas, is produced. The flue gas heats the water in the steam generator, thereby producing hot steam at high pressure. The furnace and the boiler are usually located together in the steam generator.

Downstream the steam generator, the flue gas is conducted to the flue gas treatment plant and, along with the vapour of the cooling tower, is discharged into the atmosphere via a stack. The energy of the steam is converted into rotational movement in the turbines to produce electricity in generators. Downstream the turbine, the low-energy steam condenses by heat release and is then fed back into the cycle by condensation and feed-water pumps. The highest energy losses during the conversion of coal's chemical energy into electric energy occur in the steam cycle upon condensation by heat loss. If a heat sink is available, similar to district heating or this is a need for processing steam, this heat can also be used. This combination of firing and subsequent steam generation is used for many fuels.

2.1 Technology of Existing Hard Coal-fired Power Plants

The hard coal-fired power plants built in the last few years are based on proven and fully developed engineering. The steam power process is the heart of the power plant. A process with simple reheating and six to eight-stage feed-water heating is standard. Apart from low power and low efficiency demands, the steam generator in modern plants is almost always designed as a once-through boiler on the water and steam side. For high power output, pulverized coal combustion predominates on the combustion side. The hard coal is first milled to a powder. This pulverized coal is then mixed with air and combusted like a liquid fuel, e.g. oil. During combustion, ash is left as a solid residue, which has a proportion of approx. 10-25% by weight depending on the coal used. The ash is extracted dry with the flue gases (dry bottom furnace). The design and operation of the combustion system are determined, inter alia, by the use of low NO_x burners.

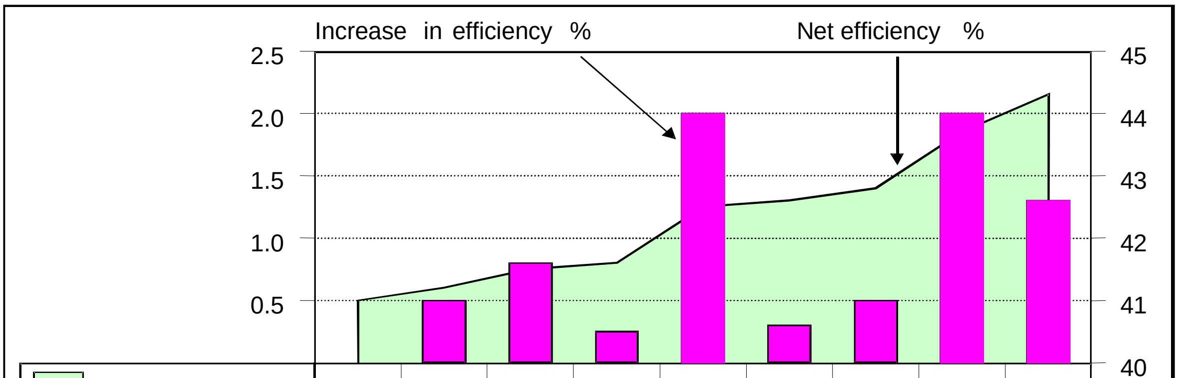
The slag tap-fired combustion system with liquid, molten ash removal, often built in the past for low-grade coals, automatically produces more NO_x than the combustion system with dry, unmolten ash removal, which dominates the scene today and can now also be used for ash-rich and low volatile coals. Given this, the slag tap furnace is only used today for special purposes.

2.1.1 Measures for Increasing the Efficiency of Conventional Hard Coal-fired Power Plants

At present, the hard coal-fired power plants being planned at the moment can be designed for net efficiencies of about 45% with cooling tower.

Figure 4-4 shows examples of the various stages involved in achieving these efficiency levels. One very effective measure for enhancing the efficiency of the process is raising the main steam temperature, the creep resistance and scale resistance of the heat-resistant steels limit it. Increasing the wall thickness to any extent is not a solution, because this causes deterioration in load change behaviour, the start-up and shutdown times and gives a considerable increase to the associated costs. The main steam parameters can be increased to approx. 300 bar and 600°C with currently available materials. The rise in the main steam pressure also improves efficiency. However, the positive effect decreases as pressure rises. Increasing the main steam pressure from 180 bar to 250 bar yields an efficiency improvement of approx. 1.5%, but a further increase to 300 bar only brings about an improvement of approx. 0.3%. Main steam temperature and main steam pressure should not be increased independently of each other; an economical optimum has to be achieved.

Fig. 4-4: Increasing the efficiency of hard coal-fired power plants. Examples of individual measures



Efficiency	%	41.0	41.2	41.5	41.6	42.5	42.6	42.8	43.7	44.3
Improvement	%	0	0,5	0,8	0,25	2,0	0,3	0,5	2,0	1,3
Main steam pressure	bar	250	250	250	250	250	300	300	300	300
Feedwater temperature	°C	260	280	280	280	280	280	300	300	300
Main steam temperature	°C	530	530	540	540	540	540	540	580	580
Reheat steam temp .	°C	540	540	560	560	560	560	560	600	600
Condenser pressure	bar	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.04
Waste gas temperature	°C	130	130	130	125	125	125	125	125	125
Others	%	0	0	0	0	2	2	2	2	2

When determining the main steam condition, the expansion line of the steam turbine must also be taken into account, otherwise an unfavourable steam condition characterised by excessively wet steam, is reached in the final stages of the low-pressure turbine. The lower process temperature is reached in the low-pressure turbine condenser (cold end) and also has a considerable effect on the efficiency. The design of the cold end involves improving the turbine outlet geometry, condenser pressure and outlet losses peculiar to the site concerned in order to achieve minimum waste steam enthalpy. The outlet geometry is limited by the feasible turbine outlet cross-sections, and the temperature of the cooling medium limits condenser pressure. Their interaction determines the outlet losses. Cooling water re-cooled in a wet cooling tower is warmer on average throughout the year, compared to sea-water which is often used as cooling water for advanced power plants, e.g., in Denmark.

Improved flow programmes and higher computer capacities have enabled in-depth investigation of the flow conditions of the steam turbine blades. As a result, blade profiles have been developed that have helped considerably increase the inner turbine efficiency. The feed-water temperature also has a significant impact on efficiency.

The reduction in exhaust gas loss also has a positive effect on efficiency. The exhaust gas temperature, for example, has already been reduced to the acid dew point limit in the exhaust gas, which is 120 °C to 125 °C, in all new hard coal-fired power plants. In addition, the excess air at the stack has to be minimised. The lower limit results from the demand for complete combustion, from avoiding carbon monoxide (CO) formation in the combustion system and also from unavoidable leaks at the flue gas air pre-heater.

Minimising the auxiliary power of the ancillary installations necessary to operate the power plant also opens up a considerable efficiency potential. Speed-controlled drives, for example, can reduce the auxiliary power requirements of the power plant at many points in the power plant process. A further reduction in auxiliary power needs can be achieved through further developments in flue gas clean-up installations and their improved integration into the process. Overall, it can be seen that many individual stages, with a minor effect in some cases, have to be implemented in order to achieve the desired efficiency of around 45%. When certain boundary conditions exist, e.g. fresh water cooling and other special measures, such as double reheating, efficiencies of up to 47% can be obtained. Experience at these plants still needs to be gathered. As far as further developments are concerned, it must be remembered that for plant operations, it is the operating data with normal fouling and wear that are important, not the design data, and that deviations of the operating point from the design point affect efficiency.

2.1.2 Materials

As mentioned, the important step towards further increasing efficiency can be made through developments in materials. It is necessary to classify materials for higher temperatures according to a number of requirements. This concerns materials for:

- Membrane walls;
- End super-heater surfaces (in contact with the flue gas);
- Main steam manifolds;
- Steam turbine blades and housings; but also
- Corrosion-resistant materials for an increase in the use of exhaust gas heat.

Using super-heater materials as an example, figure 4-5 shows the contribution, which further developments in high temperature-resistant materials can make towards improving the efficiency of a steam power plant. Today, the above materials, allow main steam parameters of 270 bar/580°C and 600°C. Further developments towards tungsten-alloyed steels, like NF12, allow parameters of 300 bar and 625/640°C. As part of the research programme, the transition to even higher steam parameters (720°C and more than 300 bar) will be investigated. To do this, the “steel barrier” has to be overcome, this means the manufacture, processing and testing of nickel-based super-alloys. Process material developments are insufficient in the medium-term to move the conventional power plant process towards and over the 50% mark; therefore process improvements are necessary.

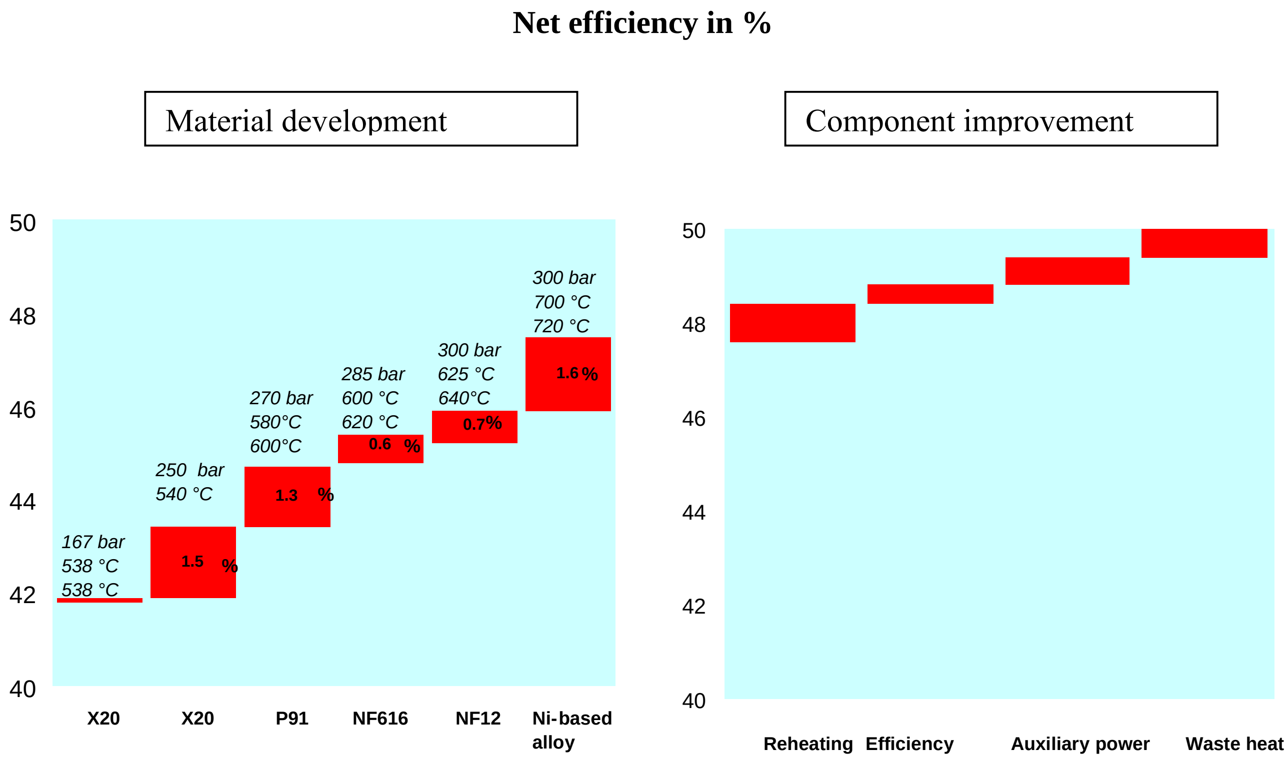
These include:

- Further use of waste gas heat;
- Double reheating; and a
- Further increase in steam turbine efficiency.

But many small measures are also continuing to help:

- Reduction in pressure losses; and
- Reduction in auxiliary power demand.

Fig. 4-5: Increasing the efficiency of coal-fired power plants - material developments and improvements in components



Source: Siemens

The aim must be to increase efficiency, but also to improve the economics of the plant and the operating characteristics because, ultimately, the latter has economic implications.

In principle, the same technologies employed for efficiency improvement in hard coal can also be used for lignite.

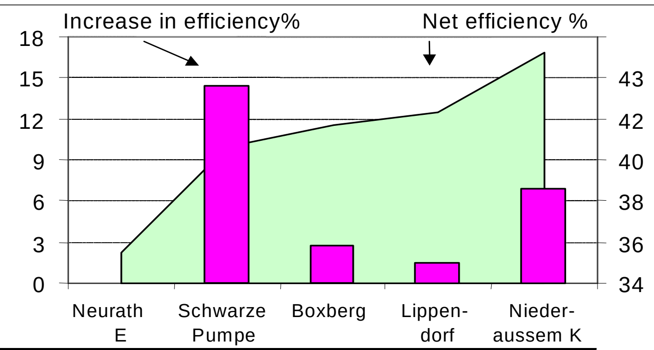
2.2 Technologies for Efficient Lignite Utilisation

Before discussing the various technical solutions for the efficient utilisation of lignite, some specific characteristics of lignite should be briefly examined.
Relative to conventional hard coal, lignite differs in some decisive properties. Lignite contains high amounts of moisture and/or ash. In some cases, the sum of moisture and ash could be close to 80%, which leads to a net calorific value (NCV) of less than 4 MJ/kg, while hard coal could have 28 MJ/kg. Besides moisture and ash, the hydrogen and oxygen contents of lignite, are also somewhat higher, resulting in a volatile matter content of about 50% on a moisture- and ash-free basis. Thus, once dried, lignite becomes a very reactive fuel. Owing to the relatively high moisture content and a correspondingly lower calorific value compared with hard coal, lignite is mostly used close to the mines. The focus of lignite use - nearly 90% worldwide - is on power generation.

In the 1990s, new power plant units were planned in Germany. Capacity was further stepped up to values of 800 to 1,000 MW, mainly because of the more favourable economic efficiency and power plant modernisation programme in eastern Germany. As a result of the CO_2 discussions, these new units were designed for high efficiencies. Advanced steam conditions and waste gas utilisation were implemented. Thus the efficiency gain obtained is quite remarkable compared with a 600 MW lignite unit designed in the early 1970s (Figure 4-6).

Fig.4-6: Increasing the efficiency of lignite-based power plants. Examples of individual measures

Measures for Increasing the Efficiency of Lignite-fired Power Plants



		Neurath E	Schwarze Pumpe	Boxberg	Lippendorf	Niederaussem K
Efficiency	%	35.5	40.6	41.7	42.3	>43
Improvement	%		14.4	2.7	1.4	>1.6
Main steam pressure	bar	165	262	266	267	269
Feedwater temperature	°C	235	274		270	295
Main steam temperature	°C	525	547	545	554	580
Reheater steam t.	°C	525	565	581	583	600
Condenser pressure	bar	0.066	0.035/0.046	0.041	0.038	0.028/0.034
Waste gas temperature			X	X	X	X
Exhaust steam cross section	m^2	4x5.9	4x10	6x10	6X10	6X12.5

The progress made in lignite-based power plant technology during the last decade, which has been implemented in the renewal of the power plant portfolios in eastern Germany and in the Rhenish lignite area, is an example of constant further developments in power plant technology, culminating in the most modern lignite-based power plant worldwide.

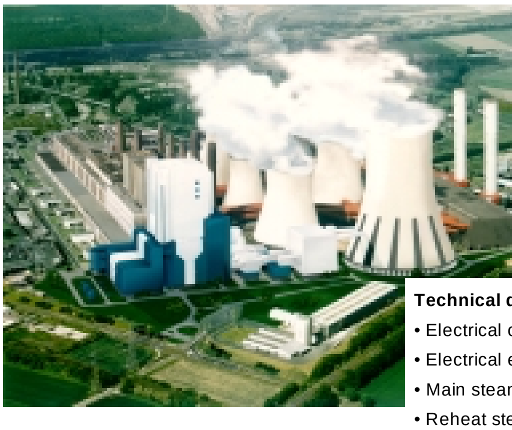
2.2.1 Lignite Units with Optimised Plant Technology, Niederaussem (Germany)

The claim that coal-based power generation can be justified even from an ecological viewpoint is demonstrated in exemplary fashion by the Rhenish lignite industry.

In the last 50 years, the deployment of new technologies has resulted in continuous efficiency increases in the power plant population. A provisional high point in these developments is the construction of the BoA[86] power plant; a lignite-fired power plant with optimised plant technology boasting over 43% efficiency. The rise in efficiency obtained here means higher power output and, hence, a reduction in specific CO_2 emissions. With the commissioning of the 1,000 MW BoA unit in August 2002, annual total CO_2 emissions fell by up to 3 Mt compared with the figure for the oldest power plants (Figure 4-7).

All in all, efficiency at the theoretical best point of the BoA unit can be stepped up by 9.7 percentage points compared with the 600 MW units recently erected in the Rhineland. Even taking an average after some operating years, the BoA unit will still have a net efficiency of more than 43%. Due to this high efficiency, the fuel consumption of the BoA unit falls by about 30% compared with the 150 MW units to be replaced by this new facility. The major advances made by the BoA concept will be dealt with in the following.

Fig. 4-7: Lignite-fired power plant at Niederaussem, Germany (Rhineland)



Lignite fired power plant, 1,000 MW type

Technical data Niederaussem:

• Electrical output, net	965 MW
• Electrical efficiency, net	> 43 %
• Main steam	580 °C/275 bar
• Reheat steam	600 °C/59 bar
• Start of construction	August 1998
• First electricity	August 2002

Compared with former plants, the auxiliary power requirements of the BoA unit have been substantially lowered. A vital factor here is that the reduction in fuel requirements translates into lower driving powers needed for transporting the air and flue gas amounts and for the coal mills. In addition, the individual components have been optimised to a

[86] German abbreviation: 'BoA' standing for 'Braunkohlenkraftwerk mit optimierter Anlagentechnik'

great extent. In particular, automatic speed control of the coal mills over the entire load range is planned.

Water-steam cycle:
Feed-water preheating takes place in ten steps, including HP bleeding. This results in a final feed-water temperature of 295°C. With the heat supplied from waste gas heat recovery, the amount of steam to be extracted from the turbine will fall, so that additional steam will be available for power generation. Structure and configuration of the steam generator allow minimisation of the pressure losses, viz. to only 30 bar in the high-pressure stage and to 2 bar in the reheater. Moreover, the injection devices for steam temperature control in the reheater, which have an adverse effect on efficiency, are replaced by a Triflux heating surface.

Supercritical steam parameters in the steam generator's high-pressure stage of 275 bar and 580°C, together with the high temperatures in the reheater's hot section of 600 °C call for the use of special materials. Due to the most recent developments in the field of materials technology, the materials required are now also available for plants in the 1,000 MW capacity categories.

The steam turbine is also a state-of-the-art component. The turbo-set, for example, is fitted with three-dimensionally designed turbine blades. Also, the comparatively large exhaust areas of 12.5 m² for each six-flow low-pressure turbine stage, in combination with the low pressures of the two-stage condenser (29 and 35 mbar), make a significant contribution toward efficiency enhancement.

The major innovation in the flue gas path is the intensive use made of the heat contained in the flue gas. This variant is implemented in two novel plant sections:

- First, an air pre-heater is located in parallel with a pre-heater bypass economiser.
- Second, a novel flue gas heat exchanger is employed upstream of the inlet of the flue gas de-sulphurisation system.

About one third of the 350°C hot flue gases pass through the pre-heater bypass economiser, thus contributing to feed-water preheating. Both the air pre-heater and the air pre-heater bypass economiser cool the flue gases to a temperature of 160 °C. An electrostatic precipitator follows these two equipment units. Between this electrostatic precipitator and the flue gas cleaning system, another flue gas heat exchanger is installed which cools the flue gas temperature to approx. 100 °C, with use being made of this heat to increase the fresh air temperature from 25 to 120 °C.

A flue gas inlet temperature of 100°C is necessary for the flue gas de-sulphurisation section to work in a waste water-free operating mode. Altogether, this intensive use made of the flue gas waste heat calls for high plant-specific outlays. Measuring 150,000 m², the heat exchanger areas required are larger than the steam generator's total high-pressure and reheater heating surfaces.

Cooling water cycles:
With its pressure stages of 36 and 29 mbar, the condenser is of a two-stage configuration. The vacuums concerned call for a corresponding dimensioning of the main cooling water system and the cooling tower. At the design point, a cold-water temperature of 14.7°C is required. The circulation amount of the main cooling water comes to 88,000 t/h. The total

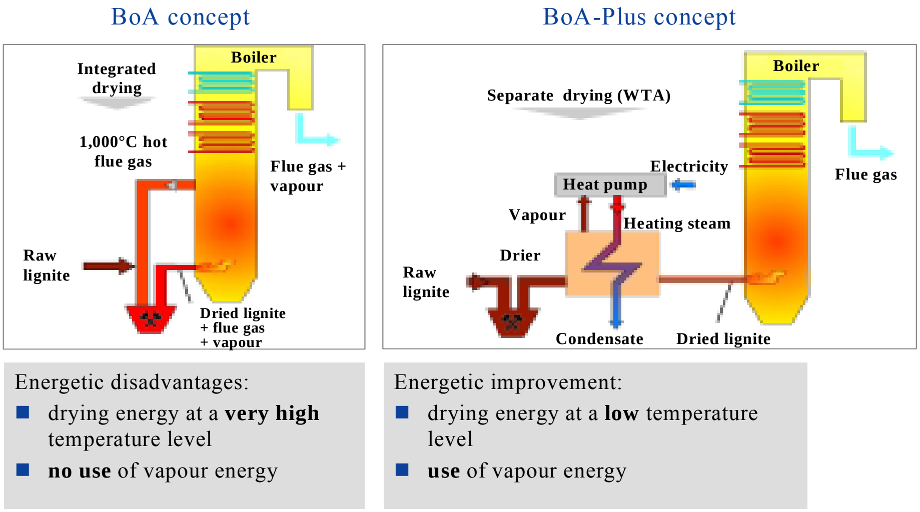
height of the cooling tower is 200m, which can be divided into 180m required for the throughput and a further 20m required for pressure compensation of the sound absorbers installed in the suction openings.

2.2.2 External Drying

Lignite extracted in the Rhenish mining area contains about 55% moisture, a criterion that makes it unsuitable for combustion. In state-of-the-art mill drying, the coal is dried by means of hot flue gases. Depending on the coal's moisture, up to 20% of the primary energy used serves to evaporate the coal-inherent moisture. That is why recovery of this drying energy and/or the reduction in energy requirements are expected to offer significant potential for efficiency increases in future new power plant units (Figure 4-8).

With the object of developing the existing plant concepts towards industrial-scale application maturity, RWE Power is operating test plants. A pilot drying plant featuring a section using fluidised-bed drying with internal waste heat utilisation ('WTA' is the German abbreviation for this process) started working on a trial basis in the Niederaussem power plant in mid-2001.

Fig. 4-8: Lignite drying - Key component in the further development of power plant technology



2.2.3 Fluidised-bed drying with internal waste heat utilisation (WTA)

In the WTA process, the energy required to evaporate the coal-inherent moisture is contained in the steam. This energy is recovered and used in power generation or coal drying processes instead of being discharged, together with the flue gas as waste into the atmosphere – a concept implemented in the mill-drying process employed hitherto.

During the lignite drying process, the moisture evaporated from the coal yields a condensate amount of 80 m³/h in the WTA plant section. This water is treated to enable it to be used in the power plant process, e.g. as cooling tower water. The dried lignite produced in the WTA plant section is fired in a 600 MW unit located in the immediate vicinity. For this purpose, special types of combined dried lignite/oil burners have been retrofitted. Dried lignite co-combustion accounts for around one third of the unit's electric power output.

From 2004, a prototype plant is to be erected and tested together with the dry coal firing system. This so-called BoA-Plus[87] variant with complete commercial pre-drying may be suitable for use in the third new power plant unit in the Rhineland. It allows an additional efficiency increase of some four percentage points.

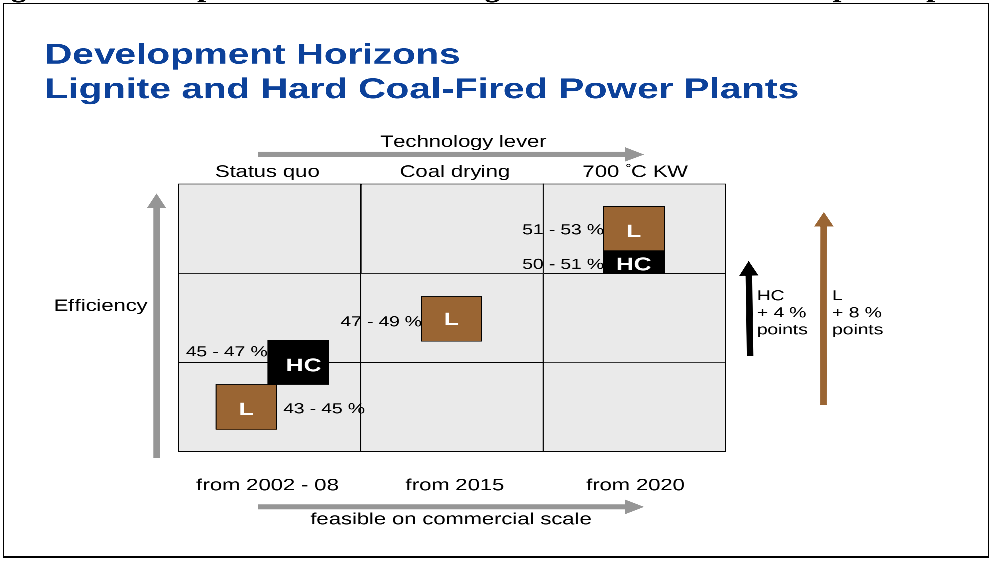
2.2.4 Further Development of the Coal-Based Steam Power Plant

In the foreseeable future, the steam power plant will be the basic technology for power generation from hard coal and lignite. The increase in the steam parameters and the pre-drying process described above are starting points for a further efficiency-related improvement in this technology.

For coal-fired power plants, the intended steam temperatures of 700/720°C at a steam pressure of 375 bar make feasible an efficiency leap of another four percentage points. The transition to these steam conditions calls for the use of high-temperature, corrosion-resistant nickel-base materials, which also have the required endurance strength. Before being used commercially, these materials have to be subjected to prior qualification tests, and the same applies to the build ability of major components in the 700°C power plant.

Such 700°C power plants will start commercial operations in about 2020. The crucial prerequisite in this context is that the very expensive development work be supported by public funds at both national and European level. The technical improvements obtained, allow the efficiency of future coal-fired power plants to be increased to over 50% (Figure 4-9).

Fig. 4-9: Development horizons for lignite and hard-coal fired power plants



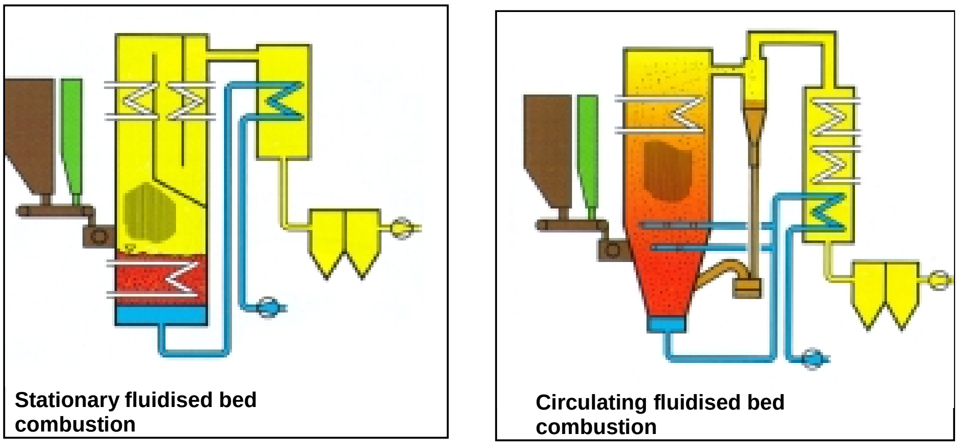
[87] German abbreviation: 'BoA-Plus' standing for 'Braunkohlenkraftwerk mit **o**ptimierter **A**nlagentechnik plus vorgeschalteter Kohletrocknung'

3. Fluidised Bed Combustion

As an alternative to pressurised fluidised (PF) combustion, the fluidised bed combustion technology could be used for hard coal as well as lignite. The "fluidised bed" process was first used for the gasification of coal and for industrial chemical process reactions between solid materials and gases. From 1970, the first plants burning solid fuels were used. Today there are two principles (Figure 4-10):

- Stationary or bubbling fluidised bed combustion (SFBC)
- Circulating fluidised bed combustion (CFBC)

Fig. 4-10: Fluidised bed technology



Especially for small (SFBC) and medium capacities (CFBC), fluidised bed combustion presents an alternative to PF firing with additional FGD equipment and allows the use of low-quality, ash-rich fuels. In a comparison between the two combustion technologies, the following issues have to be examined:

- Kind of Operation;
- Cost of by-product handling;
- Fuel quality;
- Plant Investment cost; and
- Availability.

The advantages of fluidised bed combustion are:

- Very high exchange rate of media;
- Very high exchange rate of heat. The heat exchange factor is between 200 to 800 W/m^2K. Comparable factors of coal-dust firing are 150 W/m^2K for the area of evaporation and 50 W/m^2K for the area of super-heater and economiser;
- Low combustion temperature, approx. 850°C;
- Long residence time in combustion zone;
- No need for FGD and $DeNO_x$ plants.

CFBC technology has taken a big step forward in unit capacity (e.g., Gardanne power plant with 250 MW_{el} initially and higher now). Both the technology developed and the new designs and components are now available, such as cooled cyclones, simplified cyclone design and special heat exchangers for re-circulated fly ash.

The CFBC-technology is a useful and environmental friendly combustion technique, especially for fuels with widely varying ash-content and if no high-value by-product is desired. Its market share is increasing for steam generators of a medium size (approx. 100t/h to 400 t/h steam capacity). Today's CFBC plant design is second-generation, relying on operational experience from the first plants. Availability has improved due to the use of newly developed and highly reliable components. Also, it has been possible to eliminate all unnecessary components - which were implemented due to uncertainties with the first plants - resulting in lower investment costs.

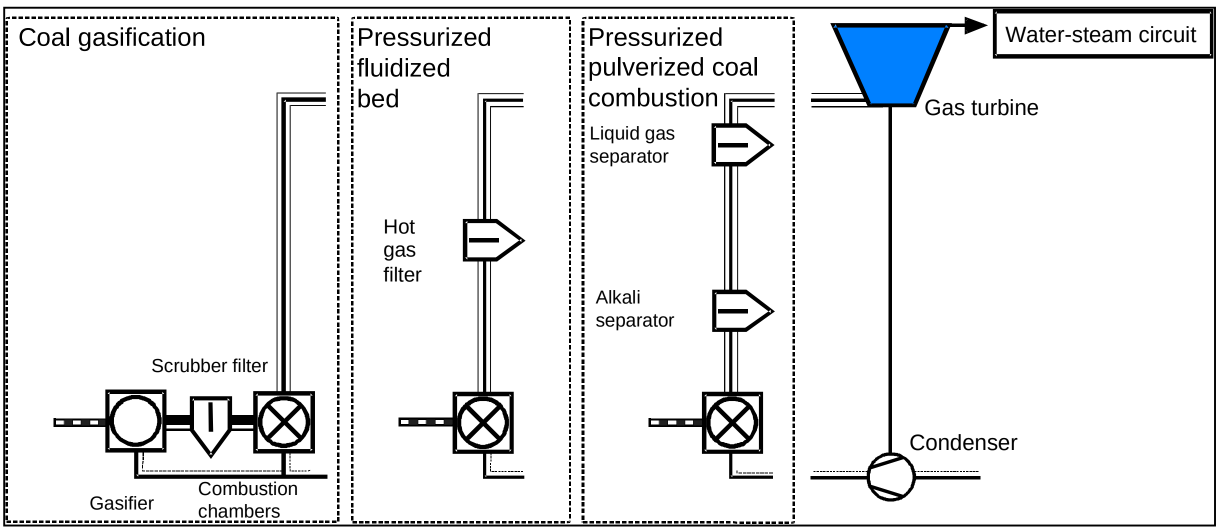
However, although experience has shown that the fluidised bed combustion technology is environmentally friendly, it needs skilled operators and must be designed carefully for the envisaged fuel range. This means that theory and practical experience have to join, and this combination will yield good results. Relative to other combustion technologies, furnace temperature is of great importance. Maintenance costs could differ from those of pulverized coal-fired power stations.

4. Other Coal-Fired Power Plant Processes

Today, particularly high levels of efficiency can normally be achieved with natural gas in the combined cycle process. Unfortunately, however, natural gas stocks are lower than coal stocks. In addition, natural gas is not available in all regions and, unlike coal, can generally only be transported by pipeline. This makes the coal-fired combined cycle power plant process particularly attractive. Gas turbines can only be operated with ash-free fuels. In order to make coal usable as a fuel for the combined gas and steam turbine process, various variants of the combined cycle process have been developed (Figure 4-11). These include:

- The combined unit with integrated coal gasification (IGCC);
- Te combined process with pressurised fluidised bed combustion (PFBC); and
- The pressurised pulverized coal combustion system (PPCC).

Fig.4-11: Integration of coal gasification, pressurised fluidised bed and pressurised pulverized coal combustion in the combined process



4.1 Integrated Gasification Combined Cycle (IGCC)

Beginning in 1972, STEAG gained experience with this technology at the Lünen power station, including the world's first prototype plant with an electric rating of 170 MW. Intensive work is currently being done on further development at other demonstration plants. Proof of successful operation still has to be furnished for raw power plant operation with high availability under changing conditions of use. Reliably controlled coal gasification, on the one hand, and the combined cycle process, on the other, has to be developed first to achieve a highly available unit.

Interesting efficiency prospects emerge, particularly if higher gas turbine inlet temperatures can be used with purified coal gas. In the case of the combined process with integrated coal gasification, efficiencies of around 45% are currently feasible. In Europe, demonstration plants are operating on an industrial scale in Buggenum/The Netherlands and at Puertollano/Spain. In the US, some demonstration plants are also being operated. The aim of more recent investigations has been to demonstrate the possibilities of improving IGCC, which will lead to higher efficiency levels, higher plant capacity and, hence, to reductions in costs compared with the plants built until now. Plant availability, has to also be improved.

4.2 Plant with Pressurised Fluidised Bed Combustion (PFBC)

Combined gas and steam turbine power plants with pressurised fluidised bed combustion are considered in the discussions on advanced fossil-fired power plants. They promise an alternative concept for efficient end low-emission generation of electricity from hard coal and lignite. The suggested concept of pressurised fluidised bed combustion offers the exciting possibility of using the primary fossil fuel coal directly in the gas turbine without the intermediate gasification step. It is fundamentally different from the oil and gas-fired combined cycle plants in the pressurised fluidised bed concepts. Heat is transferred to the water steam cycle in the fluidised bed to reduce the combustion temperature to some 850-900°C.

In order to take full advantage of fluidised bed technology, low NO_x emission and integrated de-sulphurisation, the entry temperature of the gas turbine in this process remains restricted to about 900°C. Hence, the advances made in gas turbine technology in increasing the permissible entry temperature cannot be fully exploited. Even in this variation the efficiency potential is fully exhausted at around 42 to 45%.

The first plants are now operational. In addition to the evaluation of the various processes, account must be taken of intended use and local conditions. Thus, the pressurised fluidised bed technology is especially relevant for plants with a capacity of < 200 MW, since higher efficiencies cannot be achieved by having higher steam parameters. This leads to unfavourable conditions (very small steam turbine blades with high losses).

4.3 Plant with Pressurised Pulverized Coal Combustion (PPCC)

Pressurised pulverized coal combustion can achieve power plant efficiencies of over 50% when designed as a combined cycle power plant process. For this, coal must be combusted at high temperatures under a pressure of about 16 bar. The present target is to achieve a gas turbine temperature of 1,250°C, which completely exhausts the efficiency of current turbines. This temperature should increase with further developments in gas turbines. The high combustion chamber temperature promotes the formation of molten ash particles. Like the alkalis (mainly sodium and calcium components), they also must

be removed before the flue gas enters the gas turbine. The problem of cleaning the flue gas has still not been completely solved. Although a good degree of success has been achieved with fixed bed separators, the level of purity demanded by gas turbine manufacturers has not yet been reached. However, good improvements have been achieved recently using electrostatic effects.
Besides pressurised coal-dust combustion with the separation of molten ash, other variations of the process are being tested. They allow the use of the conventional filter technology for dust separation. The aim is to bring the flue gas to a temperature of 800 to 900°C with a minimum loss of energy. The problem of slag formation needs to be solved when a high-temperature heat exchanger is used. Along with this, suitable materials need to be developed that are resistant to high temperatures and pressures and can also withstand the chemically aggressive ash.

5. Ultra-low Emission Technologies and CO_2 Sequestration

As a precautionary measure against climate change, the International Panel on Climate Change (IPCC) has recommended an 80% reduction in CO_2 emissions by 2050, even though it is still controversial today whether such a target - after weighing costs and benefits - is justified in view of the current status of climate research. Should the results obtained by climate researchers in the next few years substantiate the proposition that anthropogenic emissions have a long-term influence on the climate all over the world, the efforts to develop ultra low-CO_2 or even zero-CO_2 energy supplies would have to be stepped up on a long-term basis. But what has to be realised is that such an extreme decision would have a dramatic impact on fuel and money reserves.

The development of renewable energy carriers has shown that, despite all the development efforts, they can only make a limited contribution to world energy supplies, and then - apart from market niches - only at a much higher cost. For wind, biomass, small-sized hydroelectric and photovoltaic power plants, CO_2 avoidance costs considerably exceed € 50/t CO_2. Furthermore, they need conventional power plants as backup. A largely zero-CO_2 power generation is therefore only realistic on a long-term basis, if we succeed in using fossil fuels, such as coal, and without causing any CO_2 emissions into the atmosphere. First, this presupposes capture of CO_2 from the power plant process, and second, the use or safe permanent storage of CO_2.

For coal-fired power plants, various process variants seem conceivable. There is CO_2 capture from a current power plant type, although this is expected to be too expensive and less efficient. Two other processes are favoured in both technical and economic terms. One is the IGCC process, whose development has already made considerable strides. CO_2 can be captured from coal-derived gas by processes available in the chemical industry. The main differences in integrating such a process into a power plant are flexibility in operation and fuel load. This is highly desirable for the power plant, but not for the chemical plant which typically operates under base-load. An alternative that has only been tested on a laboratory scale is combustion with oxygen to form CO_2 and H_2O with subsequent condensation of steam. Compared with today's power plant, the efficiency of plants employing these techniques will dip some 6-8 percentage points, which will result in a more rapid consumption of resources.

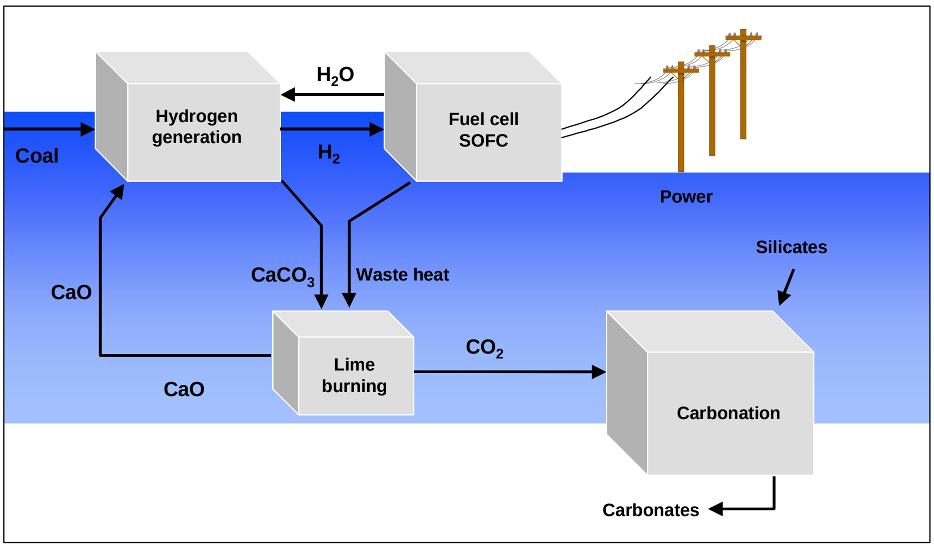
The basic prerequisite for implementation of this technology route is safe and permanent storage of CO_2 on an adequate scale. Hence, many more development efforts are still required for the exploration and testing of safe permanent CO_2 storage concepts than for CO_2 capture. At the present time, storage in depleted oil and gas deposits is favoured. The alternative, with the greatest potential by far, is storage in aquifers. Research activities have been launched in Europe, the US and Japan, with environmental concerns having to be considered. As a result, power plants may be erected in future not at an optimal location in terms of fuel and cooling water availability and electricity supply needs, but depending on CO_2 dumping options. This would of course have an impact on efficiency and economics.

The development of CO_2 capture and sequestration techniques could allow the vision of the zero-CO_2 power plant to be realised in the longer term. However, by 2015 at the earliest, research activities will have created the preconditions for commercial-scale test plants. By 2020, a first commercial-scale plant concept will be capable of implementation. From the present point of view, CO_2 avoidance costs for such a concept, including sequestration, are estimated at € 60-80/t CO_2. Furthermore it must be clearly pointed out that this would lead to a tremendous decline in coal resources. A reduction in such costs to below € 50/t CO_2 seems feasible, considering the advances in technological developments. Viewed against this background, this technology would be more favourable than most of the renewable energy processes, since electricity would be produced when needed.

5.1 The "ZECA" - Process

Regarding the CO_2 problem, a process called “Zero Emission Coal to Hydrogen Alliance”, (ZECA), is being developed based on research work being conducted at the Los Alamos National Laboratory. The concept is based on many known technical processes involving the generation of electricity from coal without the release of CO_2. Around 18 members from industry and science have come together, with a view to making the concept a reality.

Fig. 4-12: The ZECA process



In the process, a carbon-water emulsion is gasified hydro genetically, thereby releasing hydrogen and CO_2 (Figure 4-12). The CO_2 is converted to limestone ($CaCO_3$) together with calcium oxide. The hydrogen is fed to a fuel cell, thus generating electric energy and heat. The limestone produced is split again by the next process into calcium oxide (CaO) and carbon dioxide (CO_2) via the heat of the fuel cell. The calcium oxide is fed back into the process.

At a later stage, the CO_2 reacts with magnesium and calcium silicate (serpentine and olivine) to form carbonates and silicon oxide (SiO_2), which are chemically stable and can be disposed. Serpentine and olivine rocks are available worldwide in sufficient quantities. Simulated calculations estimate a total efficiency of around 68%. Calculations for realistic process components show significantly lower values.

A complex plant can be constructed by combining different processes, an approach that is incomparable with conventional power plant technology. A large number of deposited products are generated by fixation of CO_2, which must be controlled logistically and technically in large plants. Providing the necessary quantities of serpentine/olivine requires extensive mining and logistic knowledge. A pilot plant is planned for 2004, and it will provide the first experience. The project can be realised only in the long-run owing to the complexity of the ZECA process and the high innovation potential.

5.2 FutureGen

FutureGen, the 'Integrated Sequestration and Hydrogen Research Initiative', is a US$1 billion government/industry partnership in designing, building and operating a practically emission-free, coal-fired electric and hydrogen production plant in the United States. The 275 MW prototype plant will serve as a large-scale engineering laboratory for testing new clean power, carbon capture and coal-to-hydrogen technologies. Virtually every aspect of the prototype plant will employ cutting-edge technology. Regarding sequestration technologies, captured CO_2 will be separated from the hydrogen possibly by novel membranes currently under development. It would then be permanently sequestered in a geological formation. Candidate reservoir(s) could include depleted oil and gas reservoirs, unmineable coal seams, deep saline aquifers, and basalt formations. Whenever fuel cells are mentioned in these technologies, it should be acknowledged that the maximum size generally exceeds one MW, therefore, for a large power plant, hundreds of fuel cells have to be operated together.

6. Technology Selection

In the past, power plant combustion systems were usually adapted to the coal quality produced in the vicinity of the site. Today, coal imports are growing. Consequently, the combustion system has to be designed to cope with different coal qualities. Also, in investment decisions, attention has to also focus on the site available for the power plant, the power plant capacity, in terms of energy economy, the probable load schedule and overall environmental legislation. The effects of these factors may vary. A site may allow continuous cooling or may have a detrimental effect on the economics of gas turbines because of the geodetic height. A reasonably priced, but very high-ash coal may point to a fluidised bed, although the need to lay a long natural gas pipeline to supply a combined cycle plant may make this particular concept uneconomical. The load schedule has considerable implications for the economics of the various processes: high investment costs can only be justified by base load operation, and high fuel costs can only be justified by peak load operation.

In discussions of the efficiency of further developed power plant processes, the deployment scenario needs to be considered. For example, there is a limitation where part load operation is concerned, thus modern combined cycle technology needs to be considered. Compared with the conventional power plant process, efficiency decreases more at part load with the gas turbine process. Hence, when part load operation is taken into account, average heat consumption is reduced for the conventional plant concerned.

When the power price structure for coal-fired power plants is considered and compared with combined cycle plants, it can be shown that variable and fixed costs are reversed (gas and steam two-thirds to one-third, coal-fired power plant one-third to two-thirds). Consequently, it is difficult to determine the economics of coal-fired power plants in certain regions. At present, however, the prices of both gas and gas turbines are rising; so that the advantage of the gas and steam combined cycle plant is declining at the same time. This confirms the need to find individual solutions to different circumstances.

Table 4-1: Assessment criteria for various power plant types (without CO_2 separation)

	η Achievable today	η Perspective	Level of develop-ment	Invest-ment cost	Load change behavior	Product utilization
Conventional steam power plant	app. 45%	> 50%	+	+	+	0
IGCC	app. 45%	> 50%	0	-	-	+
Pressurized fluidized bed	app. 42-45%	47%	0	0	0	-
Pressurized pulverized coal combustion		> 50%	-	0	+	+

In general terms, there is a site and deployment-based assessment that has to be considered from case to case (Table 4-1). Compared with the conventional coal-fired unit, the alternatives demand even higher investment costs, are more difficult to operate and have hardly any efficiency advantage. It is evident that the classic power plant process – further developed recently – has become more attractive compared with the other processes. In order to achieve efficiency of 45% or more for hard coal, the known processes should not be replaced. Instead, to increase efficiency even further, it is mainly material issues that must be addressed. The short-term and medium-term future; therefore lies with large power plant units of up to 1,000 MW (electrical), as due to economies of scale, small coal-fired power plants are not viable. The trend is towards ever-higher unit ratings, which affects the flexibility of the plant park. If no cuts are made here, the individual large new plant must have considerable dynamic capabilities. For long-term perspectives, an evaluation of the various processes has to be made, taking into account the CO_2 -free power plant, where required. The IGCC process would then have its benefits compared to the PF process with air as an oxidiser.

7. Up-to-Date Flue Gas Cleaning Technology for Coal-Fired Power Stations

The burning of organic fuels can cause the formation and emission of undesirable by-products, such as dust, SO_2, NO_x, HF, HCl or even CO_2. As the industry and power generation has grown, pollution has also risen, especially in areas of major industrial concentration.

National standards for SO_2 emissions, in the course of coal-based combustion were introduced in the US, Japan and Germany during the 1970s. In the 1980s, environmental regulations became progressively tougher and more widespread. This trend is expected to continue. Table 2 gives a general overview of the international emission standards for new coal-fired power stations.

Table 4-2: Important emission limits under international laws for new coal-fired power stations in mg/m³ *as of October 2003

	Germany* Novelle 13.BImSchV	EU	World Bank Standard
		2001/80/EG	
Capacity	> 300 MW th	> 300 MW th	> 500 MW el
NOx	200	200	750
SOx	200	200	400-2000*
Dust	20	30	50

The first step towards lowering pollutant emissions is to increase plant efficiency. This allows a reduction in fuel consumption and in the emission levels for all air polluting matter. Details of state-of-the-art technology were discussed earlier.

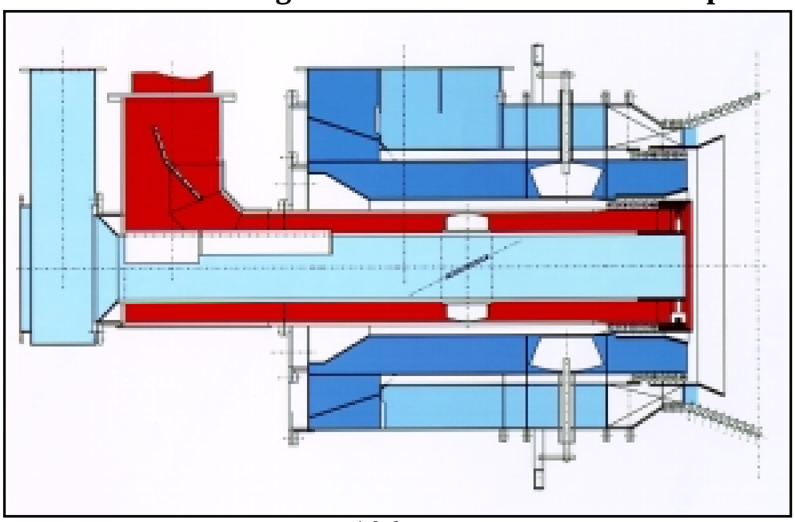
In general, the flue gas cleaning technologies described can be used both for lignite and for hard coal-fired power plants.

7.1 Primary NO_x Control Measures

Over the last twenty years, the operation of low-NO_x systems has been accompanied by systematic research and further development. The principles applied include:

- Air staging;
- Fuel staging or re-burning; and
- Flue gas re-circulation.

Fig. 4-13: From WS to DS design converted burner at Voerde power station



These have been implemented in the form of:

- Low-NO_x burner (1st generation) jet burners, turbulent burners;
- Furnace concepts (2nd generation);
- Low-NO_x burners (3rd generation) burners with a significant reduction in the air ratio in the core and fitted with additional flame stabilisers (Figure 4-13).

The main effect of all NO_x primary measures is the formation of sub-stoichiometric zones near the burners and/or in large areas in the furnace, with a view to avoiding the formation of nitrogen oxide compounds and reducing the NO_x that has already formed. Criteria to be considered, in evaluating primary-side NO_x reduction measures are:

1) NO_x concentration obtained;
2) Content of unburned combustible constituents in the filter ash;
3) Occurrence of furnace corrosion and slagging;
4) Flame stability and monitorability;
5) Partial load behaviour;
6) Shift of the heat absorption inside the boiler in the case of existing plants; and
7) Technical outlays.

Typical of lignite is the possibility of achieving the emission limits by primary measures. Whilst to achieve the stringent emission limits applying to hard coal-fired power stations (e.g., in Germany and Japan) secondary measures have to be employed.

7.2 Secondary NO_x Control Measures

In the case of hard coal-fired power stations, primary NO_x measures are not sufficient to meet the 200mg/m³ limit required, e.g., in Germany, therefore secondary measures have to be adopted. Selective reduction chemistry entails treating the flue gas with ammonia (NH_3) to chemically convert NO_x to elemental nitrogen, mainly in keeping with the following reactions:

$$1) \quad 4\,NO + 4\,NH_3 + 0_2 \rightarrow 4N_2 + 6\,H_2O$$
$$2) \quad 2\,NO_2 + 4\,HN_3 + 0_2 \rightarrow 3N_2 + 6\,H_2O$$

The reactions occur when the gas temperature is between 900°C and 1,100°C, which is the basis for the SNCR technique. In the first commercial facility in Germany, STEAG's Herne 4 power unit (500 MW), SNCR has demonstrated that removal efficiency of 50% is achievable for a very large unit. However, SNCR has proved effective only in steady state operation. During load changes, the furnace's cross-sectional temperature profile becomes too unpredictable to maintain adequate NO_x reduction.

Given this, a SCR high-dust system is used to keep NO_x below the required levels. In the presence of a suitable catalyst, however, the reaction can be employed at a gas temperature of 300°C to 400°C, which generally matches the temperature of the flue gas as it exits the boiler economiser section upstream of the air preheater. This is now the common secondary NO_x removal process, which is necessary to meet the 200 mg/m³ NO_x limit demanded in some countries for large units.

7.3 SO_2 Measures

An overview of the most commonly employed FGD processes is given in Table 4-3. The process data in this table are typical of hard coal-fired power stations.

Table 4-3: Overview of FGD processes

Semi-dry, dry processes				Wet processes			
Regeneration				Regeneration			
Without		With		Without		With	
Absorbent				Absorbent			
Lime (dry)	Lime suspension	Activated carbon (absorption)		Lime/ limestone	Ammonia	Sodium potassium hydroxide	Sodium-sulphite/ hydroxide
Method of regeneration				Method of regeneration			
---	---	Thermal		---	---	With lime	Thermal
Process temperature				Process temperature			
130	65 - 70	130		46 - 52	46 - 52	46 - 52	46 - 52
By-product				By-product			
Calcium sulphite	Calcium sulphite	SO_2 conc. Gas		Gypsum	Ammonium sulphate	Gypsum	SO_2 conc. Gas
Utilisation				Utilisation			
Wet FGD pond disposal land filling	Pond disposal landfilling anhydrite	Sulphur/ sulphuric acid		Cement and gypsum industry	Fertiliser	Cement and gypsum industry	Sulphur sulphuric acid liquid
Waste water				Waste water			
---	---	Pond disposal		Yes	---	Yes	Yes

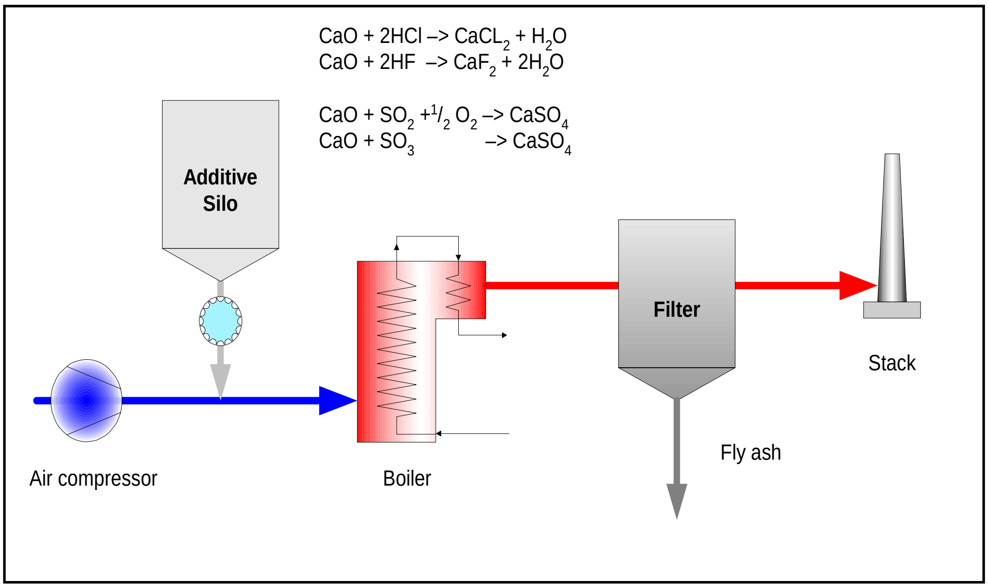
7.4 Furnace Sorbent Injection

The furnace sorbent injection (FSI) process is based on the injection of pulverized calcium-based sorbent materials, such as limestone, dolomite or their hydroxides, directly into the combustion chamber of a coal-fired boiler (Figure 4-14). When exposed to the furnace temperature, the sorbent rapidly decomposes to form reactive lime particles, which capture SO_2 to form calcium sulphite and sulphate solid. The flue gases carry this calcium sulphite/sulphate along with all the un-reacted lime out of the furnace, where the precipitator collects them with the fly ash.

Despite significant raw-gas SO_2 concentrations, limestone injection installations in Germany and Austria have functioned well in lignite service, offering the benefit of the characteristically low furnace temperature, due to the substantial chemically bound water content of this low-rank solid fuel. This simple technology has been shown to be useful in achieving cost-effective SO_2 removal efficiency levels well in excess of 60%, with a Ca/S ratio up to 4-6.

It is commercially operated in old, relatively small existing plants because of its lower capital costs, ease of retrofitting and low power consumption. It is also used in combination with humidification in the duct or a specially designed vessel to re-activate the un-reacted calcium oxide to improve SO_2 removal efficiency. The latter is called the hybrid sorbent injection process and is used commercially, achieving 70 - 80% SO_2 removal efficiency. A site-specific assessment of furnace limestone injection requires a realistic evaluation of costs, including maintenance and incidental investment. Upgrading of the existing ESP must be addressed. To avoid fouling problems, soot-blowers must be reinforced.

Fig. 4-14: Furnace sorbent injection

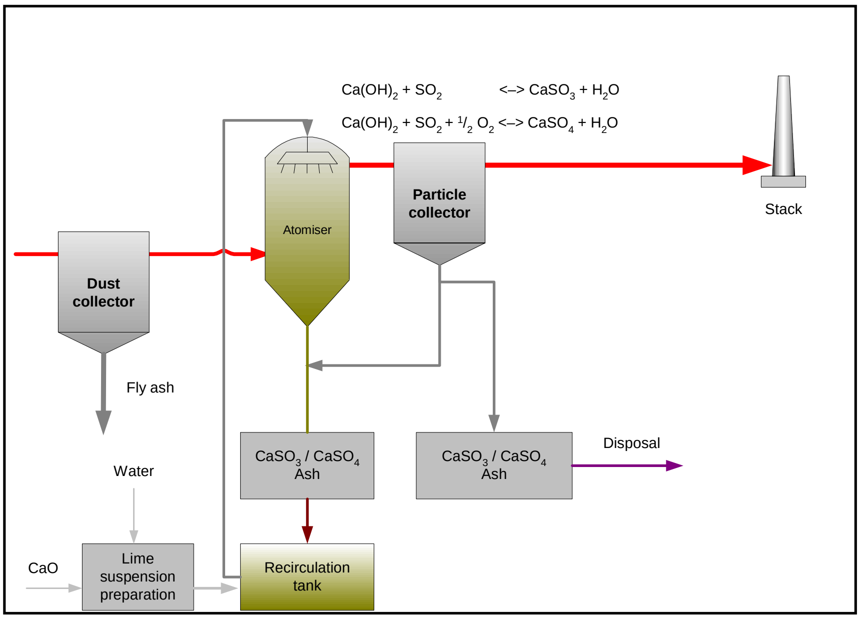


7.5 Spray Dryer / Circulating Fluid Bed Process

Major European advances in the commercial development and application of semi-dry (spray-dryer) and dry (fluid bed scrubber) flue gas de-sulphurisation technology have established the use of these processes with SO_2 removal efficiencies substantially greater than 90% and, in the case of high-sulphur coal, with removal levels virtually comparable with those achievable with wet limestone scrubbing.

The lime spray absorption process is a semi-dry process in which the flue gas comes into contact with alkaline solution or slurry in a spray dryer (Figure 4-15). The alkaline reagent slurry, mostly lime milk ($Ca(OH)_2$), is injected into the reactor in a finely atomised form. The slurry reacts with SO_2, HCl, HF and SO_3 to form a solid that is collected in a baghouse or ESP together with the remaining fly ash. The solids are stored in a silo. For a more efficient utilisation of the costly re-agent, part of the filter dust containing un-reacted re-agent is re-circulated and mixed with fresh additive.

Fig. 4-15: Spray absorption process



Furthermore, a post-reaction on the filter layer has been observed that enhances removal efficiencies. Depending on the required re-agent surplus and the margin up to water saturation temperature, de-sulphurisation efficiencies of 80-90% are achievable in low sulphur installations. Problems may arise if there is too small a temperature difference between saturation temperature and reaction temperature, as there may be a risk of scaling in the spray dryer and in the precipitator.

The merits of this process are lower maintenance needs, lower energy requirements, and lower capital costs. Drawbacks include the potential to "blind" the baghouse bags if the flue gas approaches the flue gas saturation temperature, as the potential for scale formation in the spray dryer, the higher prices for the re-agent and last, but not least, the management of the waste by-product.

Dumping the by-product was initially regarded as the only way to discard the waste, as no economic use has been developed as yet. Used in low-sulphur coal applications, the semi-dry process technology might be attractive for the retrofitting of older plants and for new coal-burning facilities.

7.6 Wet Scrubbing Technologies

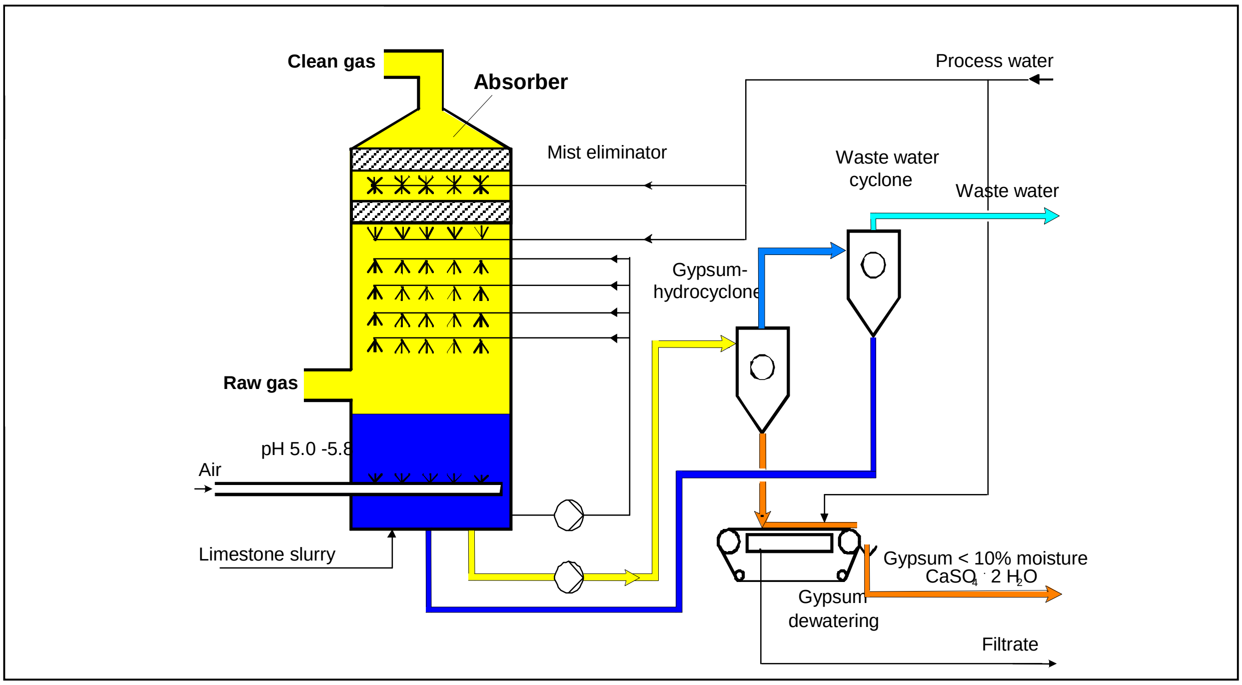
7.6.1 Limestone/Gypsum Process

The wet lime/limestone process has become the most commonly used FGD technology. In the process, the flue gas comes into contact with an aqueous solution containing lime or limestone as a sorbent. The SO_2 in the flue gas reacts with the sorbent in the absorber or scrubber, and a wet mixture of calcium sulphate and calcium sulphite is formed. In the wet lime/limestone FGD process, 90% and more SO_2 removal efficiencies are obtained with an almost stoichiometric sorbent consumption. An oxidation step results in the production of the saleable by-product gypsum ($CaSO_4{*}2H_2O$). The overall reaction of the SO_2 absorption is:

$$CaCO_3+SO_2+\frac{1}{2}O_2+2H_2O \rightarrow CaSO_4{*}2H_2O+CO_2$$

Figure 4-16 shows the wet FGD process with limestone. Most of the water consumed by the FGD plant leaves the system with the treated gas. A smaller amount is discharged as waste water, this being necessary to avoid exceeding the design chloride concentration. The water is generally replaced with the mist eliminator flushing water.

Fig. 4-16: Wet lime/limestone FGD process



The limestone required to wash out the SO_2 and produce gypsum is supplied to the FGD plant by ship, railway or truck, depending on the existing infrastructure. If no ground limestone is available, the limestone after unloading passes through a pre-crusher to achieve the particle size needed for entry into the grinding system. A classifier separates smaller gravels and insufficiently crushed particles are fed back into the pre-crusher. A bucket elevator to the storage silo conveys the pre-crushed limestone. From the silo, the limestone is fed at a controlled rate into the wet ball mill system where with the addition of water, the limestone is ground to a very fine particle size. The limestone slurry is then classified by hydrocyclone. The overflow of the cyclone is passed into the limestone slurry storage tank, from where the slurry is fed into the absorber. The underflow of the hydrocyclone, which contains the larger limestone particles, is fed back into the wet ball mill. Depending on the demands of the FGD process, limestone slurry is fed into the absorber sump.

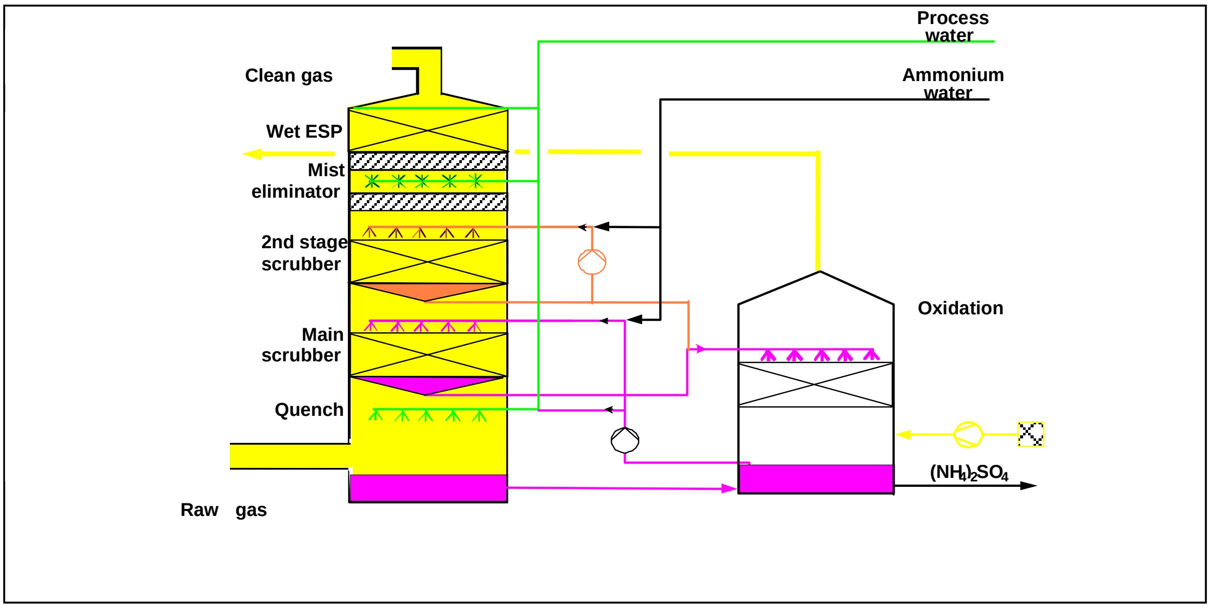
As previously mentioned, the chloride concentration should not exceed the design figure. This requires a bleeding of absorber slurry out of the system. Using gypsum bleed pumps, the slurry is fed to the de-watering station. The first de-watering stage is in a hydrocyclone station. The overflow from the hydrocyclone flows to the reclaim water tank. The underflow, which is thickened up to about the level of 60% solids, reaches the second de-watering stage, which usually consists of a vacuum belt filter, but can also use centrifuges. In this stage the gypsum is de-watered to moisture content of less than 10%. The water from this stage is also fed into the reclaim water tank. The de-watered gypsum is stored either in a gypsum silo or in sheltered storage, where it is discharged from time to time to ship, railway or truck.

7.6.2 Ammonia FGD-Process

The ammonia FGD process, also known as the Walther process, uses ammonia two-stage scrubbing to produce ammonium sulphate according to the following reactions: (Figure 4-17).

$$SO_2 + 2NH_4OH \rightarrow (NH_4)_2SO_3 + H_2O$$
$$SO_2 + (NH_4)_2SO_3 + H_2O \rightarrow 2NH_4HSO_3$$
$$NH_4HSO_3 + NH_3 \rightarrow (NH_4)_2SO_3$$
$$SO_3 + (NH_4)2SO3 \rightarrow (NH_4)_2SO_4 + SO_2$$
$$2(NH_4)_2SO_3 + O_2 \rightarrow 2(NH_4)_2SO_4$$

Fig. 4-17: Ammonia FGD process



The ammonium sulphate solution could be converted to a high-quality dry fertiliser product in an auxiliary dryer system. This process is useful in regions where no limestone is available and where gypsum cannot be re-used for the building industry.

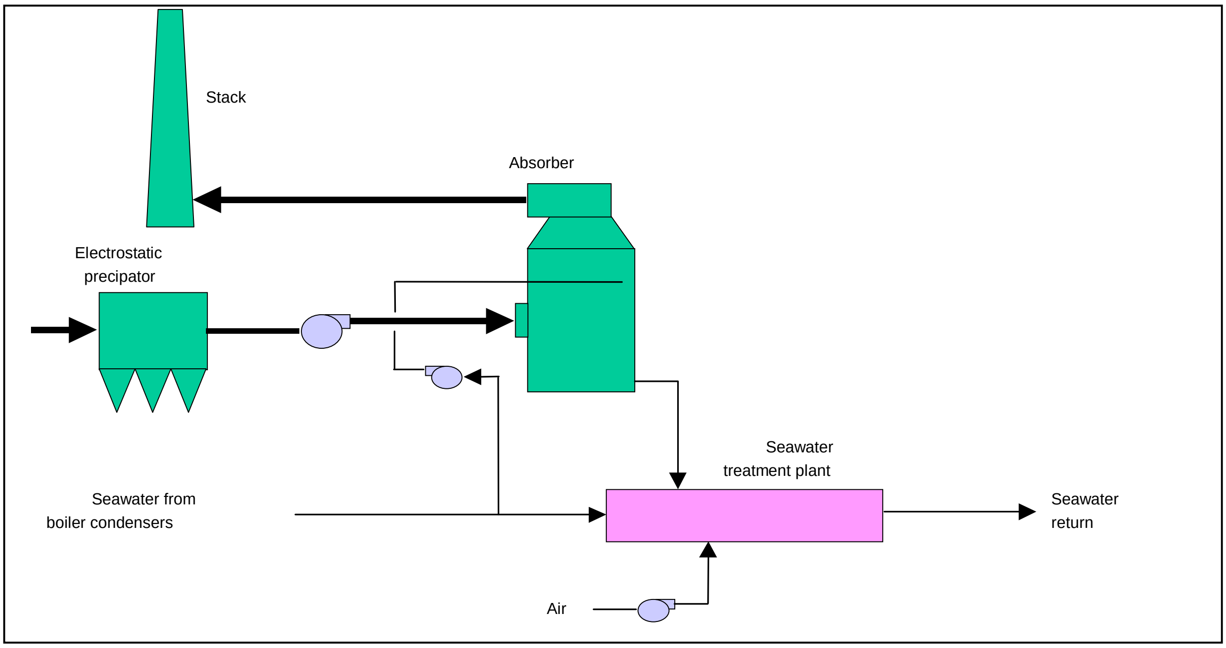
The boiler flue gas is de-dusted prior to entering the quench and scrubbing sections. The particulate removal has to be very thorough, in order to minimise impurities in the by-product ammonium sulphate. The de-dusted flue gas enters the quenching zone where it is cooled to saturation temperature by water spraying. Then the flue gas passes the scrubbing sections, flowing upstream through a double-loop, packed-bed column in counter current to the scrubbing solution. The intensive liquid/gas contact within the packed-bed results in nearly complete absorption of the SO_x pollutants. During plant operation the circulating scrubbing solution is density-controlled, and dilution is maintained to avoid plugging and blocking of the packed bed with crystal deposits. The ammonium sulphate solution from the scrubbing unit is a diluted fertiliser-grade product having a salt concentration of approx. 30% by weight. In order to produce a dry crystalline fertiliser, the liquid can be fed into an evaporation crystallisation plant, via the reaction of one ton of ammonia with two tons of sulphur oxides; the process produces approx. four tons of ammonium sulphate.

The process generates ammonium salt aerosols when the SO_x content in the flue gas is high. To absorb these aerosols, a wet electrostatic precipitator (WESP) is installed downstream of the scrubbing section. The WESP collects all aerosols contained in the clean gas, thus avoiding a visible plume at the stack outlet.

7.6.3 Seawater FGD Process

If the power plant is located near the sea, de-sulphurisation with seawater is another option because of the simple operating principle and its high reliability (Figure 4-18). This process utilises the inherent properties of seawater to absorb and neutralise sulphur dioxide. Due to the presence of bicarbonate and carbonate ions, seawater has a natural capacity to absorb and neutralise considerable quantities of sulphur dioxide. The absorbed SO_2 is converted by way of oxidation and returned to the ocean, as dissolved sulphate salts.

Fig. 4-18: Seawater FGD process



The overall reaction is:

$$SO_2 + \frac{1}{2}O_2 + 2HCO_3 \rightarrow \quad SO_4^{2-} + H_2O + 2CO_2$$

Seawater is available in large quantities at power plants located at the coast that use seawater as a cooling medium in the condensers. The downstream of the condensers, means the seawater is reused for flue gas de-sulphurisation. The FGD process itself only needs seawater and ambient air. The seawater is used on a "once through" basis to absorb the SO_2. Some of the warm cooling water is diverted to the absorption tower where it is mixed with the boiler flue gas to remove the SO_2.

Plant operation is simple, so that requirements in terms of operating and maintenance personnel are low. The absorbed sulphur dioxide is converted to sulphate, which is already a natural compound in seawater. The sulphate is completely dissolved in the seawater, so there is no solid waste product to be disposed. The removal efficiency of seawater FGD is better than 90%. The flue gas is cooled to nearly condenser cooling water outlet temperature, so there is no need for a draft, at the stack in the case of high ambient air temperatures. Given this, small reheating equipment or a stack for slight overpressure must be provided.

7.7 Criteria for selection of a FGD process

Potentially suitable processes are evaluated by taking the following aspects into account:

- SO_2 removal efficiency for coals to be burned;
- Technical status;
- Simple and reliable technology;
- Proven systems and components (references);
- Capital costs;
- Operation costs;
- Legal / environmental aspects;
- Consumables;
- By-products / wastes; and
- Landfill.

7.8 FGD By-Product Management

For a German power station, reuse of FGD by-products is essential. The possible uses of by-products is shown in Table 4-4.

Table 4-4: Possible use of FGD by-products

	Products			
Possible markets	**Gypsum**	**Spray dryer product**	**Ammon. sulphate**	**Sulphur/ sulphuric acid etc.**
Building industry	+	0	-	-
Cement works	+	(+)	-	-
Landfilling	+	+	-	-
Opencast/Deep mines	+	(+)	-	-
Road construction	+	(+)	-	-
Fertiliser	0	-	+	-
Chemical industry	-	-	0	+
Dumping	+	+	-	(+)*

+ = Fully suitable * = Elementary sulphur (+) = Of limited suitability
- = Not suitable 0 = Open

8. Conclusion

This chapter describes the technology of coal-fired power stations. Net efficiencies of some 45% or even 50% (timeframe: 2020) can be reached under certain boundary conditions. Individual evaluation of all boundary conditions is important for the selection of the appropriate technology, since no one optimal solution exists for all power plant locations.

Today's coal-fired power plant is reliable, efficient and environmentally friendly. Modern flue gas treatment technology is available for reaching the final goal. As a first step, the efficiency improvement, in terms of what is economically feasible and technically possible, should be chosen. Efficient primary NO_x measures are available. If national laws require it, SCR technology for secondary NO_x control could be implemented.

The choice of desulphurisation technology depends basically on the sulphur content of the fuel and also on the marketing potential for the residue. Today, a "coal energy conversion plant" has to obey several "masters". It is operated not only to generate power and heat efficiently, but also to generate materials, like gypsum, filter ash, granulate, etc., that have to meet certain quality requirements.

Supercritical PF-fired power plants will remain the preferred technology in the near future. In particular, recent examples in Germany have shown a tremendous improvement in efficiency. Further potential for cost reductions is being investigated for future applications.

The driving force behind all development efforts in power plant technology is the aim of achieving high thermal efficiencies together with low emission levels. This ensures CO_2 minimisation, saves limited resources and is economically efficient.

New technologies are discussed that further reduce the overall CO_2 emissions in accordance with the Kyoto agreement. Moreover, ultra low emission technologies are under development but with the disadvantage of increased coal consumption.

Much development work is necessary to assure that the new technologies have high availability and are flexible both in operation and in fuel quality. At the very least, the consequences and risks of CO_2 storage have to be determined.

Chapter 5:
Forging Internationally Consistent Energy and Coal Policies

Léopold Janssens, Secretary-General and Dr. Christopher Cosack, Euracoal, Belgium

Key messages:

- Coal-related policies should be based on coal's true performance and not on outdated perceptions. Coal needs to update its obsolete image that still prevails among policy makers and the public.
- Policies relating to the development of the coal industry need to be based on a sustainable development strategy optimising economic, social and environmental goals.
- Coal, with its geographically balanced and abundant resource base, will remain vital for energy security policies.
- The global energy scene is changing fundamentally. It is therefore crucial to keep international coal trade free of restrictions.
- Policy frameworks and financial incentives should encourage the construction of clean coal-based power plants.
- International energy and climate policies should assist the transfer of clean coal technologies to developing and emerging countries.
- Given the magnitude of future global energy requirements, there is an urgent need for governments to increase support for research and development of clean coal technologies, including carbon sequestration.
- Governments are urged to more widely ratify and apply the ILO Convention on Safety and Health in Mines.
- Policies of restructuring a mining region should address not only the closure of coal mines, but include a programme to revitalise the affected region. This is a very long and extremely costly process and requires thoughtfully designed policies.
- Taxation policies should not disrupt the existing security of energy supply.
- International trade policies should not discriminate the provision of services for the coal industry against those of other energy carriers.

1. Introduction

The global energy scene is changing fundamentally. Energy policy makers must adopt their strategies in order to achieve a sustainable, economical, environmental and social development. Providing energy to those who do not yet have access to commercial supplies is, and will remain, the main energy policy challenge.

The coal sector has to face many challenges, with very promising and sustainable objectives. To reach these objectives, however, coal needs to change its obsolete image that still prevails among most policy makers.

In reality, coal reserves are abundant throughout the whole world, delivering a reliable, high quality, clean and affordable fuel to all consumers. The experience of the past combined with adequate policies result in modern mining technologies, increasing industrial efficiencies, restructuring and reclamation of mined areas, improving pollution control while handling and transporting coal.

The worldwide need for coal as a fuel to generate electricity can hardly be modified. Creative policies and financial incentives should encourage the construction of high-tech power plants and also assist the transfer of these new technologies to developing countries. Advanced clean coal technologies, both readily available and under development, cannot only help cover the growing global electricity demand, but also reduce the environmental impact of coal burning.

In the long-term perspective, particular attention should be paid to R & D for future techniques of carbon mitigation, capture and sequestration. The greenhouse gases produced by humans with the possible consequences on the global climate should bring the policy makers to worldwide rational and common objectives and decisions.

The increasing number of mergers in the energy sector - including coal groups - results in a worldwide dominant position in some market segments. The frequent simultaneous restructuring should be accompanied by adequate social policies.

The global development of the coal trading market entails new behaviour patterns of buyers and producers. How far do they guarantee the security of supply?

2. Energy security policies

Energy policymakers face the issue of security of supply with increasing frequency and urgency. As established oil resources tend towards depletion, new production wells are increasingly situated in less politically stable parts of the world. Major gas producers are to be found in just a few regions and they are becoming increasingly dominant on the global market. Coal, on the other hand, is evenly distributed around the world and at current consumption rates, coal deposits will last for another 200 years or more. By contrast, based on current reserve/production ratios, oil and gas reserves are expected to last only 40 and 65 years respectively.

The dependence of OECD countries on energy imports will continue to grow in the years to come. Oil and gas reserves will be increasingly concentrated in a few supplier countries. Non-OECD countries, such as those within OPEC, will control oil supplies and hence fuel prices. The dependence of OECD countries on oil imports is expected to grow from 54% in 1997 to 70% by the year 2020 - an increase of almost 30%. A large proportion of the growth in imports will come from the OPEC cartel, with this group's share of global oil production rising from 26% to 41%. At the same time, OECD nations will become increasingly dependent on gas imported from Russia, North Africa and the Middle East.

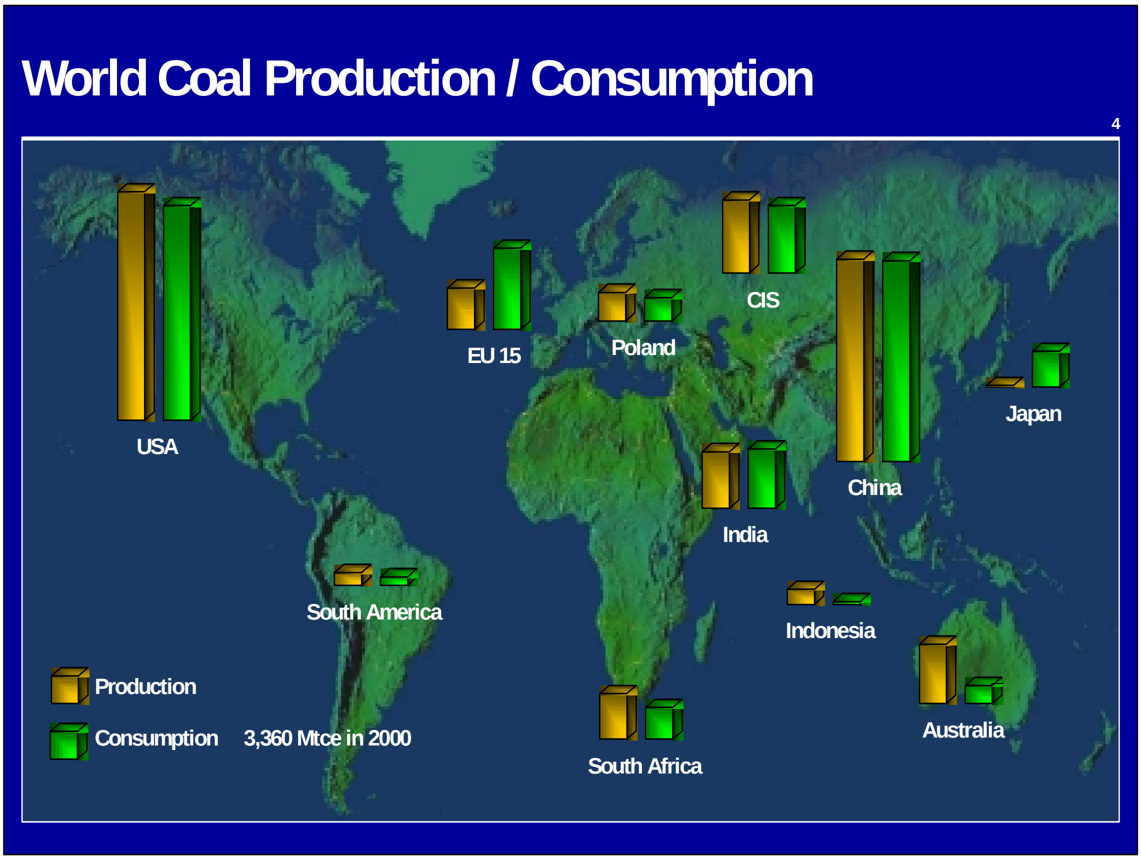
With the largest oil and gas reserves located mainly in areas affected by political unrest - especially the "strategic eclipse" which stretches from the Persian Gulf up to the Caspian Sea - OECD energy supplies will become increasingly vulnerable and disruptions to world energy supplies more likely.

Over the next 30 years, the global production of coal will increase by some 50% to reach a total world output of 5.2 Gt. However, according to the World Energy Outlook (2002), the proportion of world primary energy covered by coal will fall only slightly, from 26% in 2000 to 24% in 2030 and 22% in 2050.

3. Matching security and affordability

Coal is available at affordable prices on a worldwide basis. With its balanced geographic distribution, coal can be imported at competitive prices almost anywhere in the world. Affordable energy from coal is vital for building internationally competitive industries and providing basic household services, in particular for many developing countries.

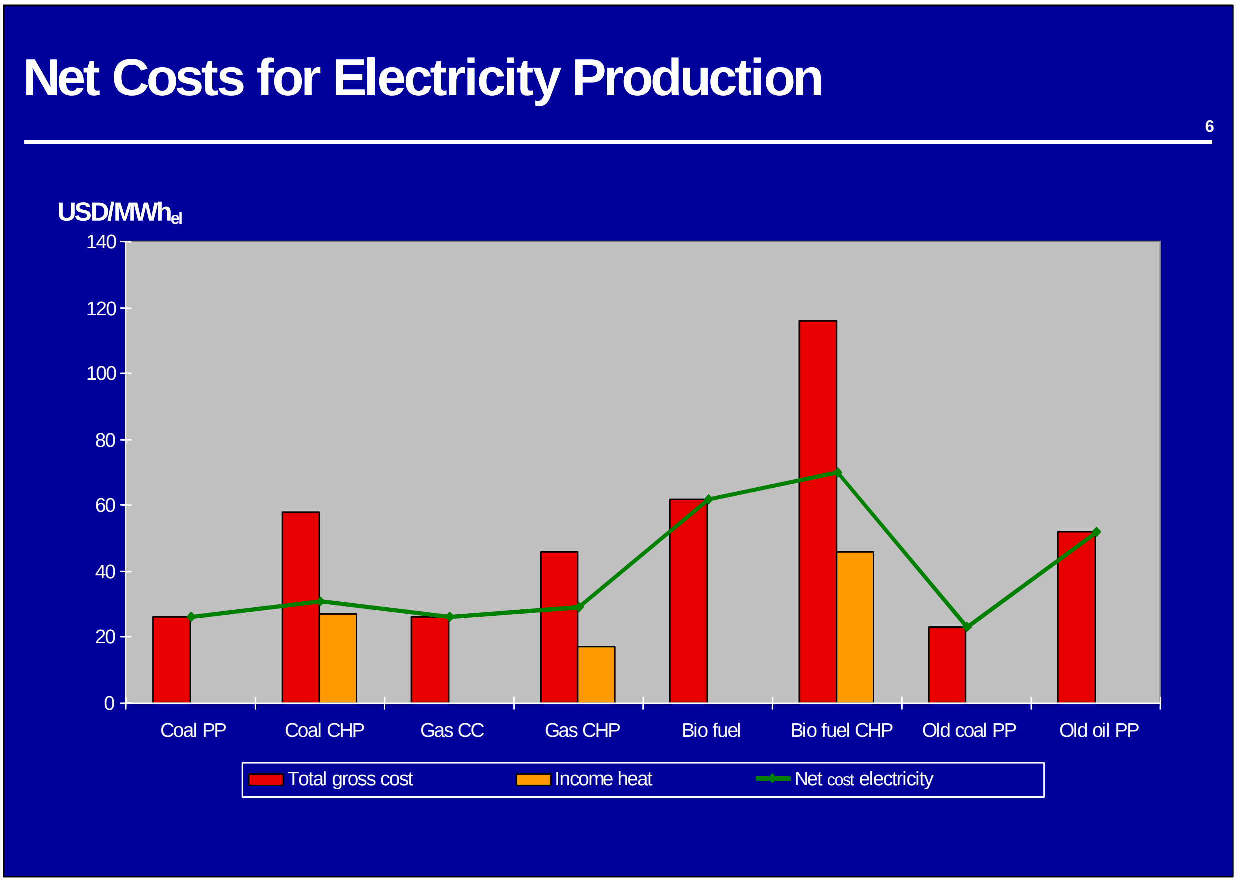
Fig. 5-1: World Coal Production/Consumption



Compared with oil and gas, coal prices have remained relatively stable because there is a competitive global market for coal. While oil and gas prices have for many years been subject to wide fluctuations and considerable instability, particularly with OPEC exercising its power. Furthermore, all the main forecasters expect a long-term trend of rising oil and gas prices, but not for coal. The reason for this is increasing production costs following depletion of the most economically viable oil deposits. Coal, on the other hand, still has considerable potential to offset any upward pressure on prices - even in the long-term - through improved productivity and increasing output from the most efficient coal producing regions. It is therefore vital to keep international coal trade free of restrictions.

In the power generation sector, which coal represents 62% of the main market, coal is already a cheaper source than any other fossil fuel. At current price levels, the cost of coal-fired power generation is comparable with that of gas-fired. This applies to both conventional and modern power plant technology, as well as to combined heat and power generation. However, against a background of rapidly liberalised energy markets and of growing uncertainties about future environmental policies, long-term capital investment in coal-fired plant carries unattractive risks. The competitive position of coal in the world energy economy is therefore dependent, to a large extent, on whether the political climate supports investment in new coal-fired power stations.

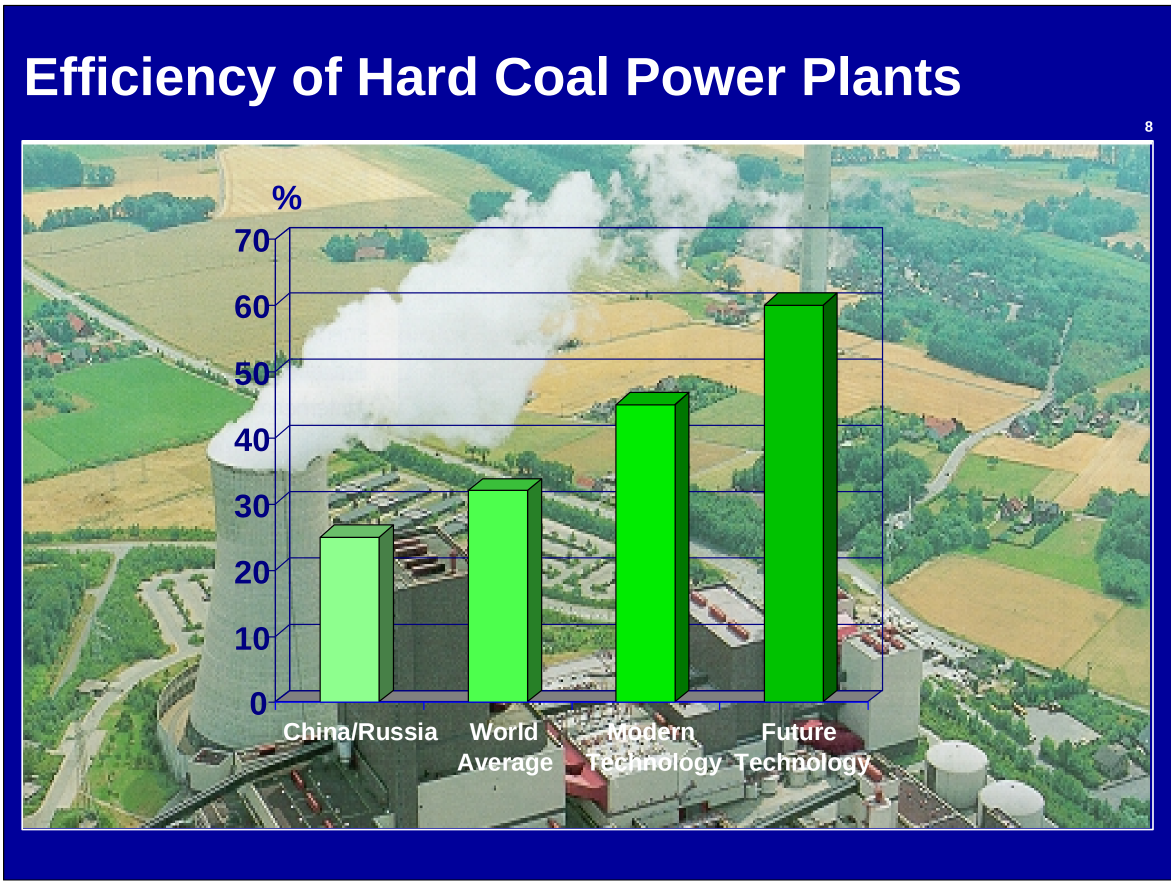
Fig. 5-2: Net Costs for Electricity Production



4. Environmental policies

Unfortunately, coal is often criticised and perceived negatively by the public because of its past environmental impact.
However, the clean coal technologies currently available are capable of reducing much of the local and regional environmental impact of coal use. This applies to both coal-based electricity generation and the use of coal for steel making. For example, desulphurisation and nitrogen-removal plants substantially reduce pollutant emissions and modern power station technologies, such as gasification also improve efficiency.

Fig. 5-3: Efficiency of Hard Coal Power Plants

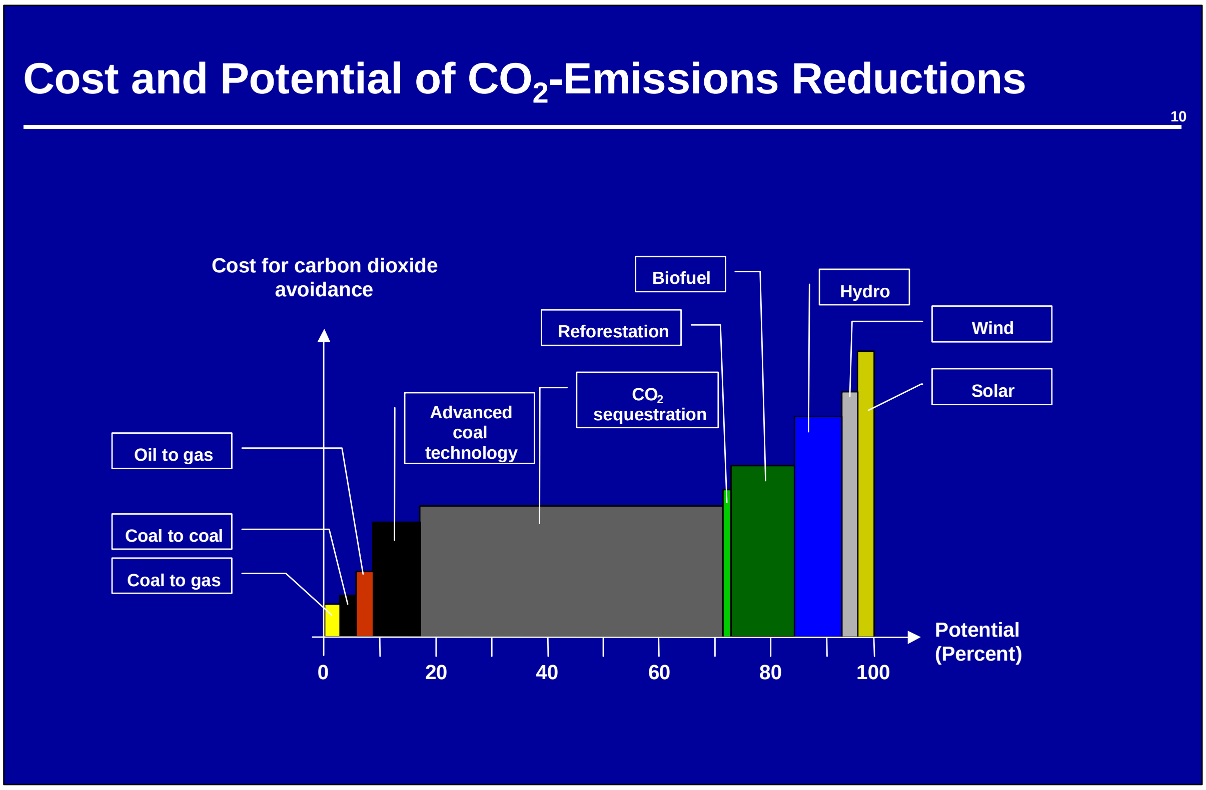


While clean coal technologies are widely available in the western industrialised countries, most of the developing and emerging nations - including major coal consumers such as China, India and Russia - still have an enormous potential for reducing their emission levels using relatively conventional technologies. Increasing the efficiency of coal consumption in these countries can make the greatest and most cost-effective contribution to a reduction in global greenhouse gas emissions from coal utilisation. A key statement at the 9th Session of the UN Commission on Sustainable Development was that "...environmentally sound, and cost-effective technological options exist and should be made available and facilitated by developed countries to developing countries as well as countries with economies in transition with a view to making energy for sustainable development a reality." Clean coal technologies would benefit not only local air quality but would also reduce global CO_2 emissions.

However, the global application of clean coal technologies requires the transfer of technology to developing and emerging countries and the support of western industrialised nations. Financing schemes are needed for the construction of modern coal-fired power stations - particularly large-scale generating plant with future efficiency rates of some 50%. Incentives must be provided for the export of modern power station systems; only then can clean coal technologies contribute significantly to the global climate and environmental protection.

It is important that international energy and climate policies - such as the Kyoto Protocol's Flexible Mechanisms - create incentives for the export of clean and efficient coal technologies. The Kyoto Protocol will, if sufficiently ratified, come into force in 2008.

Fig. 5-4: Cost and Potential of CO^2-Emissions Reductions



The full and interlinked application of its flexible mechanisms - Emissions Trading (ET), Joint Implementation (JI) and Clean Development Mechanism (CDM) - should allow companies in the industrialised countries to compensate for their emissions through emission reductions in countries with Kyoto commitments and in developing countries. The JI projects generate credits for OECD countries through projects in countries with economies in transition. CDM projects will generate credits for OECD and EIT (Economies in Transition) countries through projects in developing countries. An EU Emission Rights Trading Scheme is expected to start in 2005, for which industrial sector targets will be set. This system should be made compatible with the worldwide Kyoto Emissions Trading system.

It is clear that the supply of affordable energy, particularly by modernising power plants, along with a flourishing economy are the basic components required to achieve today's demanding environmental objectives. Coal can play its role in this regard and should not be discriminated against.

5. Research & Development policies

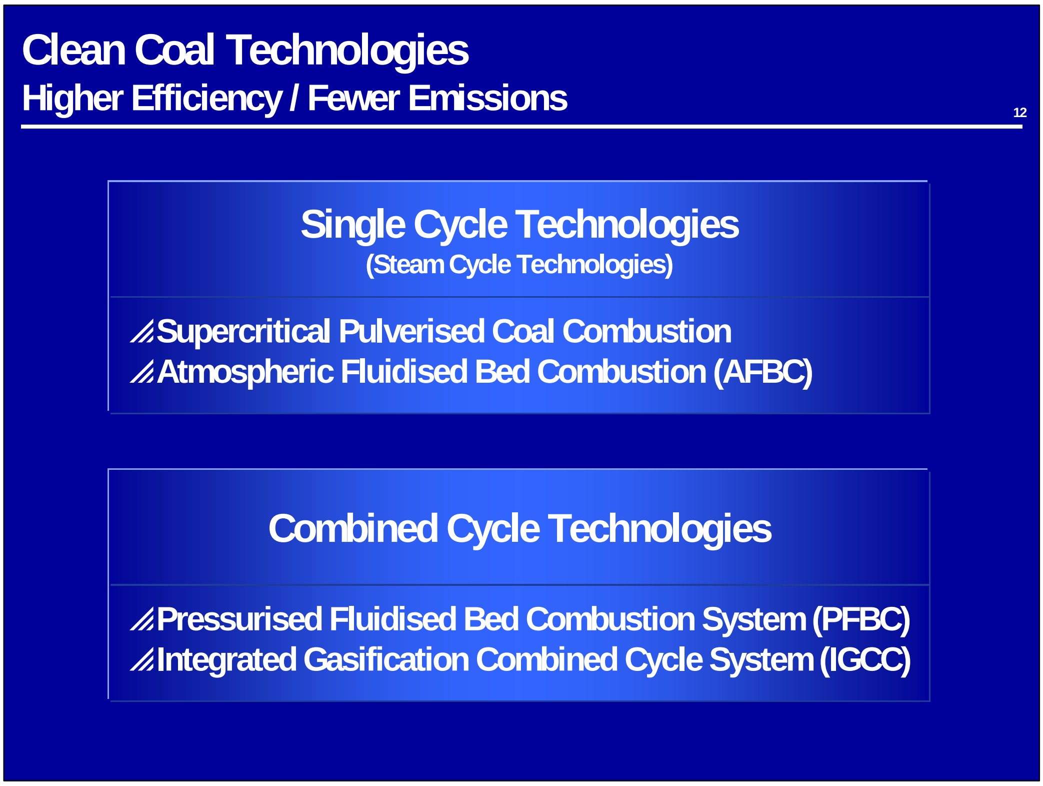
Given the magnitude of future energy requirements, it is urgent to increase research and development efforts, shared between the public and private sectors. There is a significant role for governments in encouraging partnerships, and collaboration between the private sector and other nations.

World use of electricity is expected to have doubled by 2030. More than 70% of all electricity generated globally in 2030, is projected to come from power plants that consume fossil fuels, with coal's share increasing from 38% in 2000 to 45% in 2030; according the projections of the EU WETO report (World energy, technology and climate policy outlook 2030) published in 2003.

Coal is a competitive fuel for the generation of electricity, yet there are growing concerns regarding environmental issues arising from its consumption, particularly in respect of SO_x, NO_x, CO_2 and particulates emissions.

These environmental challenges can be met by a range of technological measures known collectively as clean coal technologies (CCT) that raise the coal-to-electricity efficiency of power plants and substantially reduce the level of emissions per unit of electricity output.

Fig. 5-5: Clean Coal Technologies

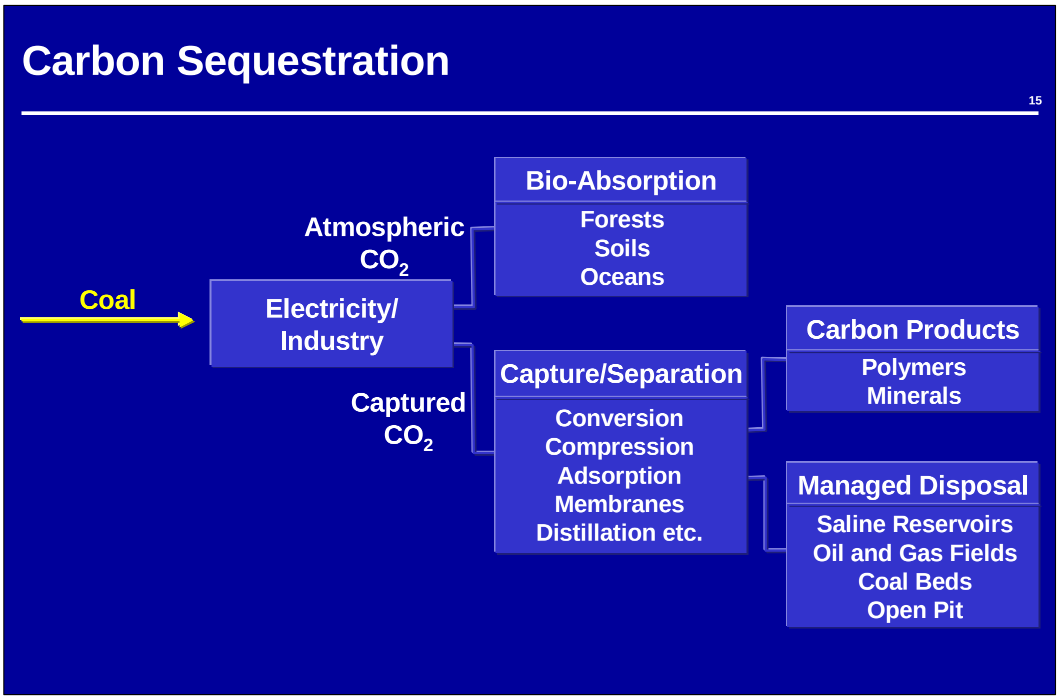


Switching to a new type of technology is not only a matter of encouraging the appropriate R & D. Given the high initial costs and uncertainties in timing, it is unlikely that private industry will be willing to take matters forward without some form of partnership with or underwriting from governments. International partnership in R & D is certainly a favourable way of spreading these risks and giving the financial backing that both industry and governments would wish to see.

Government aids and incentives for R & D vary from one country to the other. Mainly coal producing countries have policies encouraging cleaner coal technologies. For instance, one of the key elements in the US National Energy Policy is the Clean Coal Power Initiative. This is a co-operative cost-shared programme between government and industry to demonstrate emerging technologies in coal-based power generation and to accelerate their implementation to commercialisation. The Cooperative Research Centre (CRC) is a successful Australian initiative that provides government financial assistance to establish collaborative research programmes involving industry and research partners from numerous organisations. In Japan's New Sunshine Project, the New Energy and International Technology Development Organisation (NEDO) played the central role in the development of Japan's unique coal liquefaction technology.

In contrast, limited funding is made available by the EU for research into clean energy systems (geared in particular to renewables and not to clean coal technology) and carbon capture and sequestration through its sixth R & D Framework Programme. The Research Fund for Coal and Steel also offers some financial assistance for coal utilisation projects using revenues generated from assets contributed by these two industries under the former ECSC Treaty.

Fig. 5-6: Carbon Sequestration



The need of the private sector to network with technical research institutes and universities, supported by financial incentives from national governments or the European Union, is essential for a performing research activity. Worldwide, major coal producers and other interested private companies are investing in collaborative research for clean technology.

A Charter on carbon dioxide (CO_2) was signed in June 2003, which will lead to the creation of the Carbon Sequestration Leadership Forum, through which Australia, Brazil, Canada, China, Colombia, the European Union, Italy, India, Japan, Mexico, Norway, Russia, the UK and the US, will attempt to stimulate research into how CO_2 produced through burning fossil fuels can be captured at source and be stored deep underground.

6. International policies on safety and health in coal mines

Pursuing its long-lasting efforts, the International Labour Organisation (ILO) adopted Convention Nr. 176 on Safety and Health in Mines, including coal mines, in 1995. This Convention, which came into force in 1998, provides a legal and institutional framework for "preventing any fatalities, injuries or ill health affecting workers or members of the public, or damage to the environment, arising from mining operations". It calls for the designation of a competent supervisory authority, for inspections, reporting and investigating fatal and serious accidents, related statistics, and participation of workers in measures relating to safety and health at the work place. Employers are to take preventive and protective measures, including the preparation of an emergency response plan, training and information of workers, first aid and access to medical facilities. The Convention has so far been ratified by Armenia, Austria, Botswana, the Czech Republic, Finland, Germany, Ireland, Lebanon, Norway, Philippines, Poland, Portugal, Slovakia, South Africa, Spain, Sweden, the United States and Zambia.

The ILO ought to be commended for bringing health and safety issues to the attention of the international community and for setting a framework for national action. It must be emphasised, that the ratification of the Convention, its implementation by national legislation and the setting of specific health and safety standards, targets and calendars of achievement is left to the discretion of the countries concerned. It is in these areas, that the coal mining industry could play a stimulating role in offering advice and transferring good practice.

7. Labour market and industrial development policies

In economic terms, security of supply and affordability are powerful arguments in favour of coal, together with its abundant reserves. The social benefits of job creation in modern coal mines and in coal-fired plants are also recognised in many coal producing countries.

Policies relating to labour and industrial development need to be based on a sustainable development strategy. The significant technological changes in the coal sector require vocational and continued training. Training is indeed a long-term process and should be considered as a tool for industrial competitiveness as well as a contribution to personal development.

8. Restructuring and privatisation policies

Coal mining has developed rapidly since the second half of the 19th century and has made a major contribution to the industrial revolution, employing millions of miners throughout the world.

Although Europe's coal production gradually declined, coal has remained a predominant fuel in China, India, the US, the former USSR, Australia, South Africa, Poland and many other European countries (see Chapter 1). Economic considerations explain the discrepancy between coal output rates in Western Europe and other continents, where coal recovery techniques are largely based on opencast mining, which is less costly than deep mining. The reduction of coal production in Western Europe is therefore not due to lack of energy demand nor to shortages of coal reserves.

In Western Europe, the restructuring of the coal sector is part of a transition from the industrial era to a post-industrial society. There has been a dramatic reduction in employment in the coal sector over the past fifty years; today there is only a fraction of 1955 employment. The restructuring policy was developed within the European Coal and Steel Community (ECSC) and supported by the member states and the social partners in the social dialogue and tripartite consultations. It is obvious that without this political strategy and these budgets from public authorities, this entire operation would have been far more difficult. The restructuring process has proved to be very costly and very long. At least, it can be claimed that, in general, this process of decline was well organised and socially acceptable. At the expiry of the ECSC Treaty in July 2002, a new EU regulation on state aid to the coal industry was agreed and applied until 2010.

Any restructuring is a very long-term and, ultimately, also an extremely costly process. It must therefore be planned and prepared from the moment the decision to restructure has been taken. Restructuring should take place at the same time as the creation of new jobs and the cut-back in mining activity.

The money intended to subsidise the redundancies needs to be converted into activities and initiatives oriented towards the future: diversification of activities or industries and creation of jobs outside the coal sector.

Restructuring policies include: the major objectives, the programmes, the measures, the organisation and management of operations, which also includes monitoring and assessment, the availability of financial instruments and budgets. The restructuring process affects all areas of social life and therefore, the social and economic actors, internal and external, must participate. It is an integrated process of combined mental, social, economic and physical factors.

The bodies responsible for regional development or economic restructuring are very important. If they do not exist in a given region, these bodies must be created and provided with sufficient means in favour of regional development and conversion. It is necessary to organise and create these skills in the affected region: skills in the field of infrastructure, management, to prepare and develop programmes and project management. These institutions are not bureaucratic; their aim is to stimulate local development and to innovate.

Considerable financial resources must be released to create new industries, to create new jobs and to train the former employees for these new jobs, not to defray the cost of surplus labour. These resources will have to be channelled appropriately at local level to help build a future full of opportunities and possibilities instead of protecting development far from the realities of the open market and cultivating a past based on reminiscences and guarantees leading straight to a social, cultural and economic dead end.

The tendency of liberal policies to leave the selection process to the market will lead to a rapid segregation of the viable mines from the others. Most of the countries throughout the world opt for the restructuring of the nationalised coal industry before launching a privatisation programme. This approach naturally obviously represents an extraordinary burden for both the national and regional budgets. The unbundling of non-mining activities, e.g. power generation, should be avoided. A package combining e.g. an electric power company and an adjacent mine (typically for lignite mines) should be offered to private investors.

Restructuring a mining region means not only the closure of a coal pit, it necessarily includes a full programme to help the affected region develop a new social and economic way of life. It is a very expensive and long-term operation that lasts for decades. On the other hand, it liberates the enormous productivity potential of coal and allows the remaining coal mines to improve their price competitiveness.

9. Carbon taxation policies

The objective of reducing the impact of energy on CO_2 emissions requires a policy that supports efficiency improvements, stimulates the development of technologies to sequestrate and deposit the carbon content and finally encourages energy savings.

An ideal policy that does not fundamentally change our way of life or damage the economy, including social aspects, even by reducing the impact of energy sources with high carbon content, will never exist. Reduction of CO_2 emissions may result from switching from fossil fuels with high carbon content to energy sources with lower or no CO_2 emissions, particularly for power generation. However, in taking these strategic decisions, other energy priority objectives need to be considered, such as security of supply, competitiveness, and most importantly, the social, economic and also environmental impact of such measures, as well as the existing energy balance or energy-mix in the countries concerned.

Carbon taxes are claimed to be an attractive means of protecting the climate by reducing carbon emissions, while also raising state revenues. In the last few years, as part of the hysteria surrounding climate change, more and more energy or carbon taxes have been introduced under the guise of the commitments to reduce emissions of pollutants contained in the Kyoto Protocol. During the past decades, there have been energy taxes all over the world, in particular in the form of taxes on oil products.

This form of taxation also threatens jobs, first of all directly both in the mining industry and in all energy-intensive sectors of industry, and then also indirectly because industrial customers will attempt to offset the added costs of taxation by restructuring, which will have a negative impact on employment. This serious impact on employment, as well as on social and regional cohesion, is bound to occur and, regardless of the intended gradual introduction of the tax, the reaction and the impact will be immediate. This negative impact on employment in general is all the more serious because energy products are taxed unilaterally. There is definitely a risk that energy-intensive industries, in particular, would relocate business operations to countries with more favourable taxation systems. This kind of tax-induced shift of production to third world countries, which have lower environmental protection requirements, would lead to deterioration in the global environmental balance.

Additional taxation, making the consumption of energy at national level more expensive, is also damaging to environmental policies. It deprives the economy of the resources urgently required for research and investment aiming to improve energy efficiency and environmental policies to support such projects and the worldwide dissemination of the knowledge, which the industry of many countries has acquired in the field of efficient procurement and use of energy.

Energy taxation will cause distortions to the existing balanced energy mix of many countries. The existing harmony and security of energy supplies of each country should not be disrupted as a consequence of taxation. This should continue to be a constant concern of public authorities. An adequate energy supply is an absolute prerequisite for a modern economy.

There may be a role for general energy taxation but only as part of a wider package of environmental measures. Greenhouse gas emissions need to be reduced, but with the least expense to national economies and not be forced by the substitution of certain fuels but by technological progress in all parts of the energy sector.

A directive on energy taxation, based on minimum taxation levels, was approved by the European Union in March 2003. However, it is unsure whether tax harmonisation can be achieved, considering the wide variation of existing national energy taxation levels in Europe.

10. International trade policies

While energy issues were not discussed in GATT, ‘energy services’, as opposed to ‘energy as a good’, are gaining prominence in the World Trade Organisation as part of negotiations under the General Agreement on Trade and Services (GATS) in its “Doha Development Agenda”. The focus is on a definition of energy services (rendered during energy exploration, production, transport etc.) as a precondition for future negotiations on market access of service providers (alleviation of tariffs and non-tariff barriers), on the granting of the most-favoured nation status and national treatment, or on additional commitments (transfer of technology, access to grids, taxation of imports, subsidies, restructuring, etc.). The negotiations of the classification will therefore have implications on energy policies and on their interaction with other, in particular environmental and developmental, policies. Proposals made so far deal with services in the oil and gas industries. Coal, primarily a trading “commodity”, is not comparatively involved in service activities and, hence, not mentioned (UNCTAD: Energy and environmental services: negotiating objectives and development priorities, New York and Geneva, 2003). However, as coal demand and supply expands (see Chapter 6), and as the coal industry becomes increasingly technology and service-intensive, the industry should ensure that the GATS negotiations under way do not discriminate services in coal mining etc. against those of other energy carriers.

11. Policy conclusions

Coal has a future as a sustainable energy source in combination with modern technology. It has the potential to meet the forecast growth in consumption and to support a robust energy supply strategy. Because of climate change concerns and the possible link with anthropogenic emissions, improved utilisation of fossil fuels is increasingly demanded not only in the industrialised countries which have agreed to high CO_2 reduction targets under the Kyoto Protocol but also in developing countries.

As described above, there are many high-efficiency technologies available for power generation. There is still room for pro-active government policies. Research and development in advanced CCT needs to be pursued urgently. Sustainability, in the sense of security of supply, environmental protection and climate control requires that the political establishment support CCT. The role of coal in the labour market and industrial development policies should be maintained in government policies. A key contribution by the international financial community would be the development of financing methods to enable the construction of state-of-the-art coal power stations in developing, emerging and developed countries. Carbon credits against any agreed national CO_2 reduction targets will be an important element in this context.

The power industry plays a key role in making access to affordable power more widespread, in safeguarding uninterrupted supplies and in promoting the social and environmental benefits of commercial energy services. Innovative programmes, together with political measures must be initiated now if coal is to play its vital role over the coming decades.

Coal will play an important role in energy systems that support sustainable development for the foreseeable future. This is because of coal’s unique combination of advantages: it is affordable, safe to transport and store, and is available from a wide range of sources. Coal therefore remains essential in achieving a diverse, balanced and secure energy mix in developed countries and it can also meet the growing energy needs of many developing countries.

Chapter 6: Global and Regional Coal Demand Perspectives to 2030 and Beyond

Dr. K. Brendow, WEC

Key messages:

- Market-driven projections anticipate world coal demand to increase during the entire 21st century. According to sources, the increase during 2000-2030 would range from about 50 to 100%.
- Under market conditions, the share of coal in world primary energy supplies, at 26% in 2000, would decline to 24% in 2020 and 22% in 2050 and 2100. In the case of strong carbon constrained policies the share of coal would fall to 10 to 11% in 2050 and 5% in 2100, which corresponds to 2.1 and 1.4 Gt, respectively.
- The major competitor of coal would be gas, particularly under the assumption of CO_2 emission constraints, although marginal gas is hardly better in terms of life cycle greenhouse gas emissions than marginal oil or coal.
- Electricity generators would remain the predominant customer for coal. By 2030, coal would cover 45% of world electricity generation compared with 37% in 2000.
- Cumulative investments in coal mining, shipping and power generation during 2001-2030 would amount to US$1900 billion.
- Almost nil in 2000, advanced coal combustion technologies would cover 33% of world power generation in 2030, and 72% of coal-based power generation.
- Even more expensive advanced clean coal-based power generation technologies could noticeably displace gas-fired combined cycle plants.
- The worldwide replacement of old coal power plants by advanced coal-based electricity generation would reduce world CO_2 emissions by 7 - 8%.
- For the next two decades or so, advanced coal-based power plant technologies may well be the most effective single technology option to combat climate change, bridging the time for coal sequestration to gain maturity.
- Against these realities and perspectives, coal's image remains poor. The global coal and associated industries would be well advised to join forces in a proactive campaign highlighting the potential of sustainable development from coal. Acceptance by the public and more balanced policies are at that price.
- Coal is not part of the problem of sustainability and energy poverty, but rather it is part of the solution.

1. Introduction

This chapter describes eleven projections of global and regional coal demand to 2030 and beyond, made during 1977-2003 by the World Energy Council (WEC), the International Institute for Applied Systems Analysis (IIASA), the International Energy Agency (IEA) and the European Commission (Directorate-General for Energy; Directorate-General for Research) (for a listing, see "Sources" and Table 6-1).

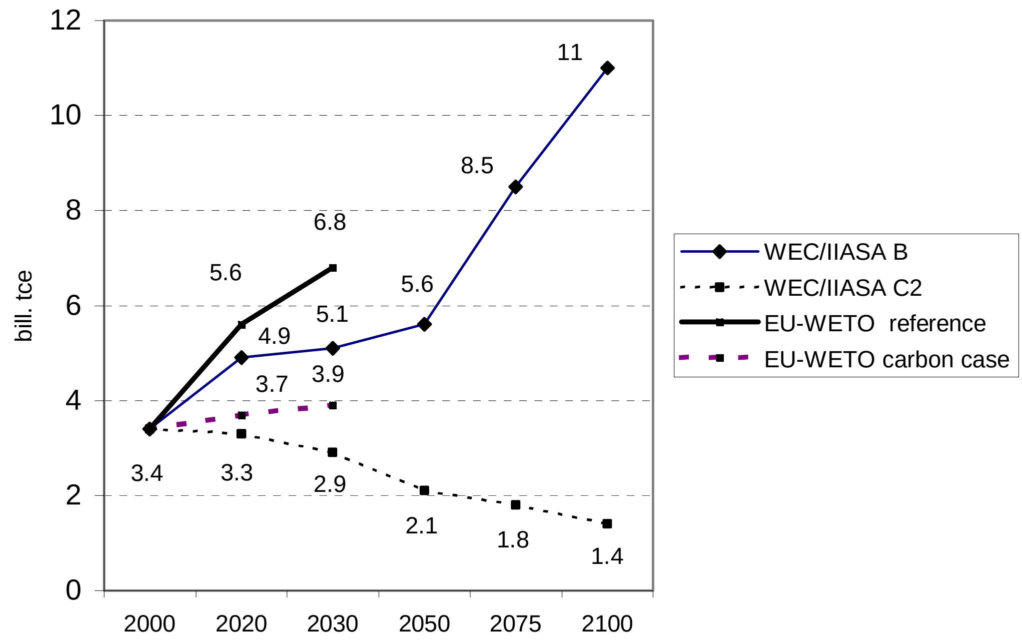
It may be useful to recall the strengths and limitations of scenario projections. They describe how developments would materialise if assumed conditions were met. They are not forecasts of what is likely to happen, even though certain scenarios may be considered as more likely than others.

All projections described are quite sophisticated in methodological terms. They start from assumptions regarding the macro-economic, demographic and policy environment before addressing key factors impacting on primary energy demand and supply generally. Next, within this overall framework, the role of coal is estimated taking into account its cost and price, environmental impact, technological potential, competitive strength, reserves and government policy, relative to other supply and demand (efficiency) options. Thus, projections of coal demand are not straightforward extrapolations of past coal demand although such an approach could be justified for short-term projections, due to the inertia of energy systems.

Given the uncertainty and volatility of the various influencing factors, there is a temptation to increase the number of scenarios beyond the traditional baseline/reference, low and high scenarios, or to enhance the representativeness, hence complexity, of the reference model. WEC/IIASA in the publication "Global Energy Perspectives" have developed twelve scenarios, while IEA (in World Energy Outlook edition 2002) refined its World Energy (reference) Model by adding new modules, disaggregating geographic regions and developing an alternative policy scenario. The European Commission's WETO projection is a "business and technical change as usual" model, serving as a benchmark for an alternative carbon abatement projection.

These approaches point to the ultimate purpose of scenarios: besides offering a better understanding of the "mechanics" of energy developments, projections suggest the need for, and leverages of, remedial action, - by governments in terms of policy and by industry in terms of business strategy.

Graph 6-1: World coal demand projections



2. Projected Coal Demand to 2030 and Beyond

2.1. Global Projections

2.1.1 The tonnages required

Table 6-1 shows coal demand in absolute terms for various time horizons during 2000-2100, as estimated during 1977-2003. The message is as follows:

i) **Time horizon 2000**: the projections made prior to 2000 overestimated coal demand in 2000 by between 16 and 25%; the accuracy improved as the year 2000 approached.

ii) **Time horizon 2010**: for 2000-2010, coal demand is projected to increase by between 13 and 39%, the lower estimate being the more recent.

iii) **Time horizon 2020**: nine of the ten projections anticipate a significant increase during 2000-2020 ranging from 33% to 180% (Table 6-1), with WEC/IIASA's "middle course" scenario B estimating a 44% growth (Graph 6-1). The expansion is entirely due to increased demand from power generation, while demand by the iron and steel industry and households is expected to fall [88]. Even in EU-WETO's carbon abatement case, coal demand would rise, while in WEC/IIASA's carbon-constrained scenario C2 coal demand would remain practically at the 2000 level.

iv) **Time horizon 2030**: in 2000, in its reference scenario, IEA estimated world coal demand to grow by 53% to 2030. EU-WETO projected a 94% increase in its reference scenario and even a 13% increase in its carbon abatement case.

[88] RWE Rheinbraun AG, *World Market for Hard Coal*, edition 2002, p. 9

v) **Time horizon 2050**: projections for 2000-2050 differ according to scenarios. In the WEC/IIASA scenario B, coal demand would increase by 72%, i.e. from 3.4 Gt to 5.9Gt. However, demand would decrease in the CO_2-constrained scenario C2 by 37%. Even in this scenario (from a coal perspective: worst), coal demand would stand in 2050 at two-thirds of coal demand in 2000 or 2.2 Gtce.

vi) **Time horizon 2100**: WEC/IIASA projections for 2000-2100 show a growing divergence. In middle course scenario B, demand for coal would grow by 220% to 2100 or to about 11 Gt, while in the CO_2-constrained scenario C2 demand would fall to 42% of coal demand in 2000 or 1.4 Gt.

In essence: all market-driven projections anticipate world coal demand to increase during 2000-2020 (IEA) and 2030 (EU-WETO), and WEC/IIASA expect this trend to continue to 2050 and 2100**.** Even in a carbon-constrained world, coal demand in 2020 would still be close to (WEC/IIASA C2) or higher (EU-WETO carbon abatement case) than its 2000 level. However by 2050, under such constraints, coal demand would have declined in comparison with 2000 by one third (WEC/IIASA C2). Coal would not be phased out by 2100.

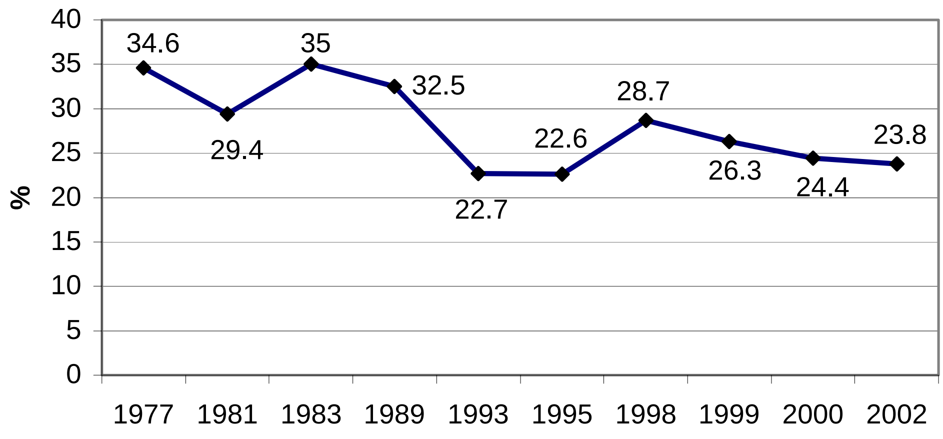
2.1.2 Growth rates

In a market-driven perspective, growth rates of coal demand during 2000-2030 oscillate typically around 2% per year, with EU and WEC/IIASA estimates lying above, and IEA estimates below that number. At those rates, coal supply could smoothly adapt to demand.

2.1.3 Market shares

Table 6-1 and Graph 6-2 shows the world market shares of coal for 2020 as anticipated during 1977-2003 in the eleven projections reviewed.

Graph 6-2: Projected world market share of coal for 2020by IEA and WEC/IIASA



i) **Time horizon 2000**: the projection made in 1977 for 2000 (25.8%) accurately "hit" the market share actually reached in 2000 (25.8%). The subsequent projections during the 1980's anticipated an increase of up to 31%, which did not materialise.

ii) **Time horizon 2010**: the 2000 experience may have prompted scenario writers to assess the market share of coal for 2010 more prudently. As time progressed, anticipated market shares for 2010 decreased to 24.3% (projected in 2002).

iii) **Time horizon 2020**: oscillating between a high 34.6% (projected in 1977) and a low 22.6% (projected in 1995), the more recent scenarios "zero in" on a market share of about 24% in 2020. Much (60%) of this downward adjustment is due to the downscaling of projected total primary energy demand for 2020, from 19 Gtoe (1977) to 13.2 Gtoe (2002)[89].

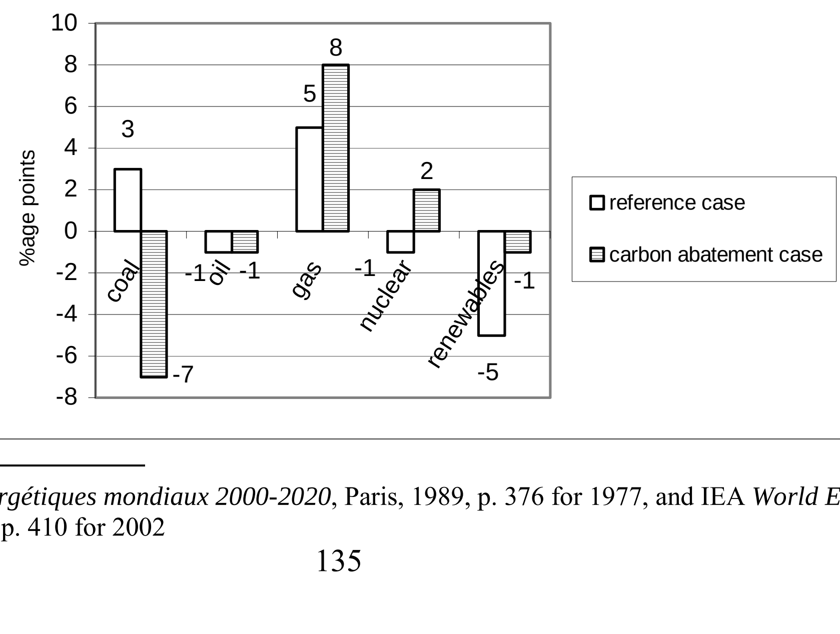
iv) **Time horizon 2030**: under market conditions, IEA projects a share of (slightly below) 24% and EU-WETO (reference scenario) of 28%. In its carbon abatement case, EU-WETO estimates a decrease to 18%.

v) **Time horizon 2050-2100**: in its market-driven scenario B, WEC/IIASA anticipates the share of coal to decline to about 22% in 2050 and 2100, while in its carbon-constrained scenario C2, the market share would fall to 10.5% and 5% respectively.

In essence: in market-driven scenarios, the share of coal, at 24% in 2020, would slowly decline to about 22% in 2050. Carbon-constraining policies would reduce the share of coal as of 2020 (WEC/IIASA) or 2030 (EU-WETO), - down to 11% in 2050 (WEC/IIASA C2). Even in such a scenario, coal would contribute as much as 2.1 Gtce in 2050 compared with 3.4 Gtce in 2000.

The main short-term competitor for coal is natural gas, particularly under carbon control policies, although marginal gas is hardly better (in terms of life cycle GHG emissions) than marginal oil or coal given its remote origin and its relatively inefficient use as a mid or peak-load fuel for power generation. But also in market-driven scenarios, gas gains more market shares than coal, - illustrative of its anticipated competitive edge in the low and medium load segments. Under carbon abatement policies, nuclear power and renewables are also expected to gain market shares. Oil would practically maintain its market position in either scenario (Table 6-2 and Graph 6-3).

Graph 6-3: Gain/loss of world market shares of primary energy sources, in %age points, 1990-2030,
source EU-WETO 2003, p. 103



[89] CME, *Horizons énergétiques mondiaux 2000-2020*, Paris, 1989, p. 376 for 1977, and IEA *World Energy Outlook edition 2002*, p. 410 for 2002

2.2 Regional Projections

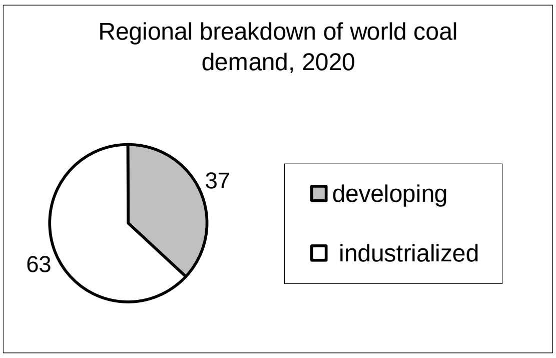
All eleven projections offer a regional breakdown of world coal demand, but their comparability is impaired by differences in regional desegregations, time horizons, base years and assumptions. The most recent projections of WEC/IIASA (of 1998), IEA (of 2002) and EU-WETO (of 2003) are reproduced in Table 6-3 and Graphs 6-4 to 6-6.

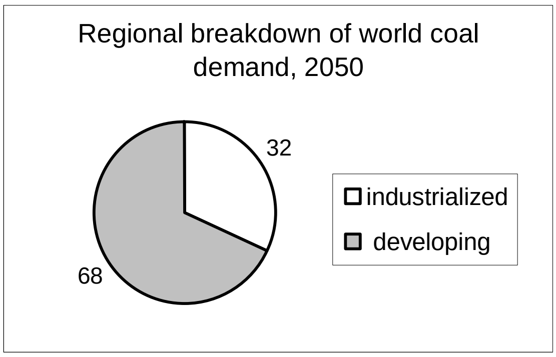
i.) **For 2020**, both WEC/IIASA (scenario B) and IEA (reference scenario) agree on rising coal demand everywhere except in Western Europe/OECD Europe. Most of the increase (WEC/IIASA: 76%; IEA: 86%) would occur in developing countries, particularly China [90], East and South Asia. Accounting for 37% of world coal demand in 1990, developing countries would account for 68% in 2020. The market share of coal would, however, also decline in these regions. In the WEC/IIASA carbon-constrained scenario C2, demand would also fall in North America, the CIS and Pacific OECD (Australia, New Zealand).

ii.) **For 2030**, in its reference scenario, EU-WETO projects increases everywhere, except for Western Europe (- 1.8%). The increases are strongest in Africa and the Middle East (+ 363%), Asia (+ 160%), Latin America (+ 89%) and North America (+ 40%). In the EU-WETO Carbon Abatement case, coal demand would fall, mostly in the EU and accession countries (- 61%), North America (- 48%) and CIS (- 45%).

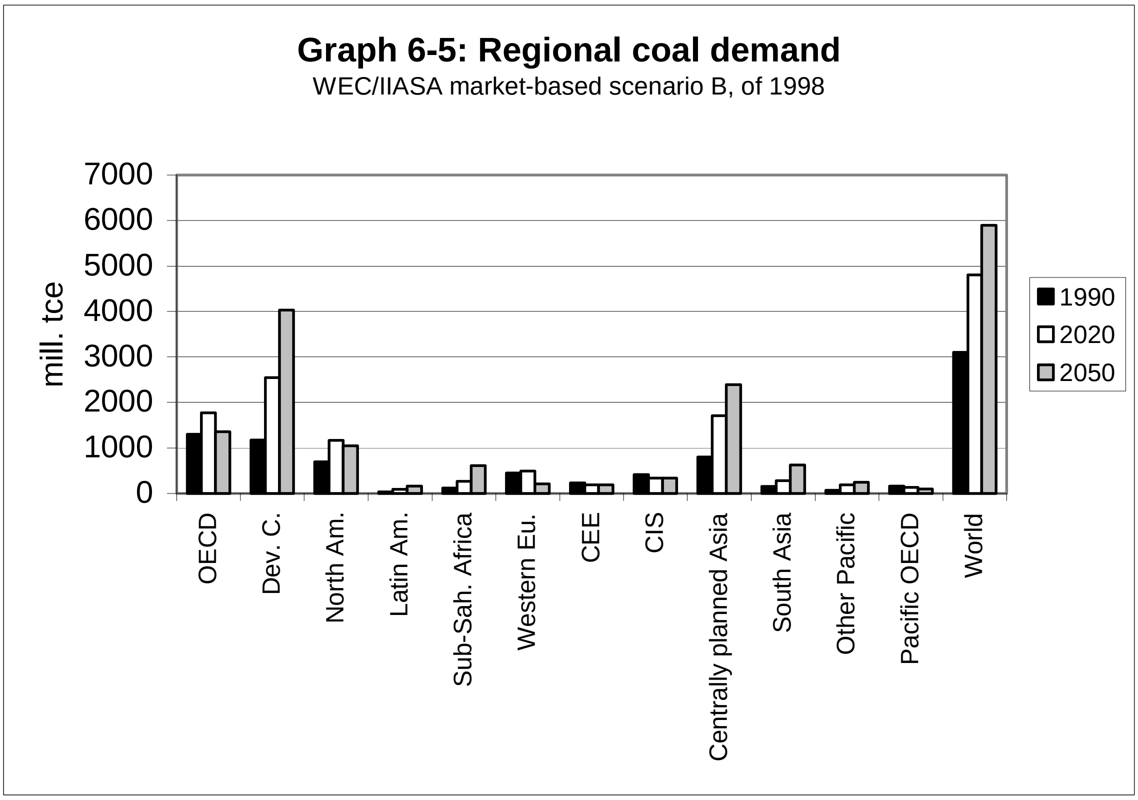
iii.) **For 2050**, the WEC/IIASA market-driven scenario B confirms the trends anticipated for 2020. The developing countries would account for 68% of coal demand. By contrast, carbon constraints would reduce coal consumption in the developed world, but also in China, Pakistan or India. However, the impact of carbon constraints appears to be less in the developing countries, where coal demand even continues to increase in comparison with 2020 in Latin America and sub-Saharan Africa.

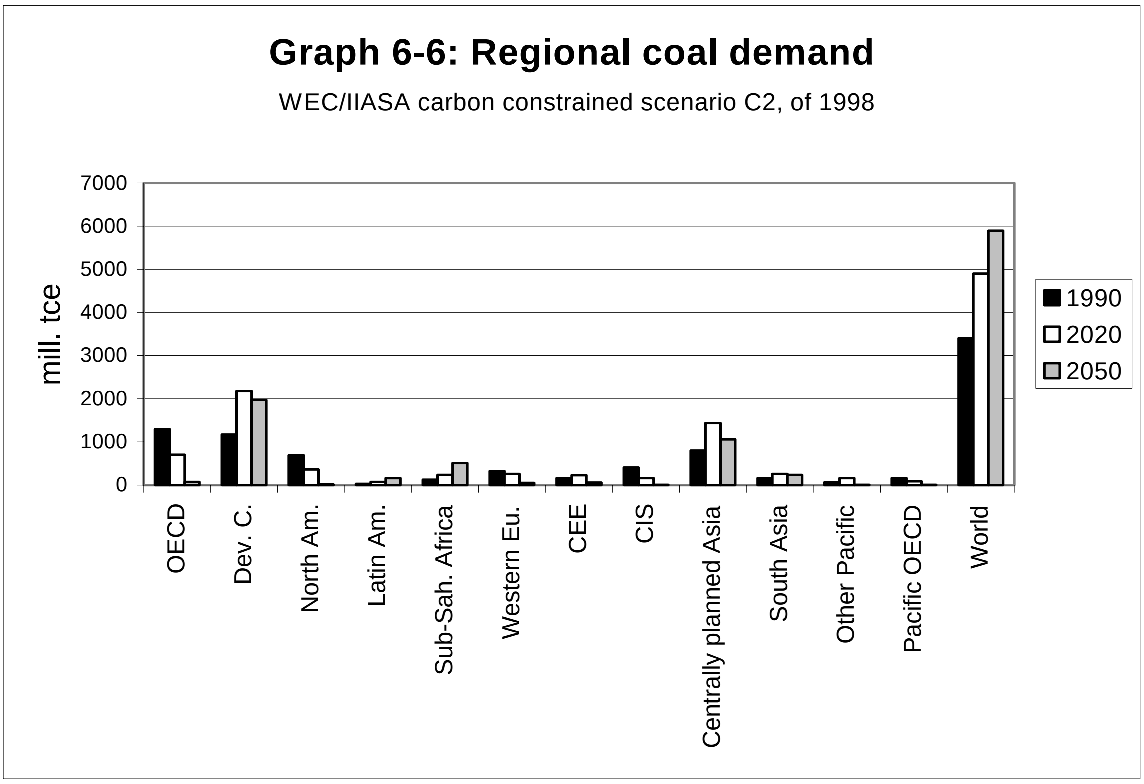
Graph 6-4: Regional Breakdown World Coal Demand 2020 & 2050





[90] Projections for China have been called into question due to policy change, see Rheinbraun News, *World Market for Hard Coal*, January 2000, p. 17





In essence: coal demand would steadily shift, absolutely and relatively, from the industrialised to the developing countries, particularly in a carbon-constrained energy world.

3. The Drivers

What are the drivers behind the projected coal demand? What is their relative importance? Are drivers differently assessed in the various projections?

3.1 From Single Drivers to Interacting Models

All projections place coal demand in a general energy and macro-economic context. No projections extrapolated future coal demand on the basis of past experience, despite the evident inertia of coal demand and supply systems. Justifiable for short-term projections, this approach is indeed not appropriate for longer-term projections, which need to capture structural change.

From 1977 to 2003, the projections reviewed in this Chapter have grown in representativeness of realities and in complexity. At the beginning based on a few, isolated factors (supplemented by qualitative reasoning), projections expanded into econometric models quantifying an ever-growing number of drivers, their conditions, interaction and feedback. Simple and transparent at the outset, projections have become incomprehensible for the non-professional reader, who remains unaware of the assumptions made somewhere in the depth of the models. This is particularly true in cases, where one reference model is used, while the alternative approach of building several scenarios with distinct socio-economic and policy features appears more “user-friendly”.

3.2 Relevant Drivers and their Hierarchy

Simple or complex, the various projections agree on the relevance of the following drivers for coal demand:

- The inertia of capital- and technology-intensive energy systems;
- Absence of major discontinuities and catastrophes;
- Economic growth and structural change;
- Demographic growth;
- Evolution of coal prices relative to other, particularly oil, prices;
- Environmental regulations, in particular on SO_2 and CO_2 emissions;
- Evolution and deployment of energy technologies, in particular of clean coal combustion;
- Capital stock turnover and investments in the coal industry and in major customer sectors;
- Relative resource availability and supply costs;
- Security of supply, labour market and industrial development policies;
- Technology transfer and international cooperation.

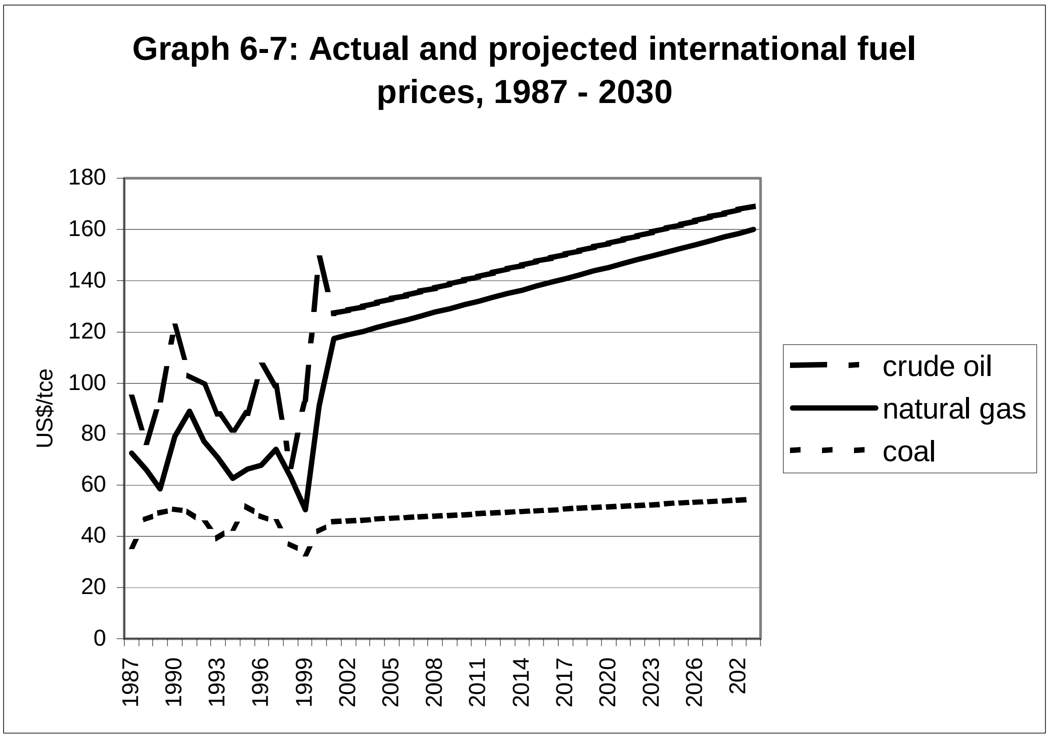
The open issue is the relative importance of these factors in shaping coal demand. None of the published projections explicitly indicate to which extent each of the various drivers “explains” future coal demand (sensitivity analysis). The above list, thus, merely reflects the frequency and sequence with which the various drivers were mentioned.

3.3 Coal Price Projections

A major factor for coal's role in the world energy market is it's low and stable, even slightly decreasing trading price. As noted in the contribution of Lidia Gawlik[91], there is not a single world coal market and, hence, no single price. But average import and export prices for steam and coking coal have tended to fall over the last fifteen years. By 2001, coal was traded to north-west Europe at about 46 US$/tce, gas (EU import, cif) at 117 US$/tce and crude oil (Brent, spot) at 127 US$/tce.

Projections are notoriously difficult. EU and IEA concur in projecting stable coal import prices for their member countries during 1997-2010, while IBRD projects even a 16% decrease of US export prices, fob. Lidia Gawlik suggests that competition and cost reductions could lead to a 17% reduction of cif coal prices in Europe between 2000 and 2020.

By contrast, the EU-WETO reference scenario[92] projects stable, then slowly rising international coal prices exceeding present levels by 15 to 35% by 2030, according to the market. Then, coal prices, at €10/barrel, would compare with 35 €/barrel for oil and 28 to 33 €/barrel for gas. Coal's rising comparative price advantage is said to be due to the abundance of resources and the potential of significant productivity gains in mining. Indeed, as noted in Chapter 2, productivity in coal mining in a group of countries accounting for 39% of world coal production, had increased by 9.6% per year during 1985-2001; there is no reason why this trend should not continue, given the advances in restructuring of the coal industries in developing countries and the rising share of opencast mining.



Source :IEA, World Energy Outlook 2002, p. 49

[91] Lidia Gawlik, Actual and projected coal prices: an interfuel comparison; see authors papers
[92] EU-WETO, op. cit. p. 23

3.4 Carbon Constraining Policies

The carbon-constrained scenarios are normative scenarios in the sense that a given CO_2 target has to be achieved [93], whatever competing goals of development and the difficulties of implementation. This driver, if it were to become effective, would initiate a relative and absolute decline of coal as of 2020 (IEA, WEC/IIASA C2)) or 2030 (EU-WETO carbon abatement case) (see Graph 6-3 and Section 2.1 above), unless counteracted by clean coal combustion and carbon sequestration.

3.5 Clean Coal Combustion[94]

Advanced coal combustion technologies are expected to be deployed in all scenarios. Thus, the EU-WETO reference scenario projects the share of such combustion technologies to reach 33% of total world power generation, or 72% of coal-based power generation, by 2030[95] (starting from practically nil in 2000). Electricity generation based on conventional pulverized coal combustion would decline from 37% in 2000 to 12% in 2030. By that year, coal would cover 45% of world electricity demand compared with 37% in 2000, due to its competitiveness and enhanced environmental record.

EU-WETO maintains that accelerated technology development of supercritical coal combustion and integrated coal gasification combined cycles would further enhance coal's competitiveness and coal could actually displace gas-fired combined cycles at regimes as low as 4500 hours per year[96].

The impact of clean coal combustion technologies on CO_2 emissions depends on which fuel would be replaced. Replacing gas or nuclear plants, advanced clean coal technologies would produce no reduction. Assuming that clean coal combustion fully replaces conventional combustion, the deployment of these technologies would avoid 7.5% of present CO_2 emissions or 1.8 Gt of CO_2 [97]. For the next two decades or so, this may well be the most effective single technology option to combat climate change, thereby allowing carbon sequestration to gain maturity.

3.6 Carbon sequestration

Coal does have every interest to develop carbon capture and disposal technologies to technical and commercial maturity in the next 15 to 20 years. International research is underway, such as the "Zero Emission Coal to Hydrogen Alliance" (ZECA), the US DOE "Vision 21" or President Bush's "FutureGen" Programme. The EU Framework Programmes for Research and Technological Development for 2002-2006 include a chapter on capture and sequestration of CO_2. A Charter on carbon dioxide (CO_2) was signed in June 2003, creating the Carbon Sequestration Leadership Forum; 13 countries and the EU participate. The IEA Clean Coal Centre is since long active in CO_2 emission analysis and control [98].

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[93] WEC/IIASA, *Global Energy Perspectives to 2050 and Beyond*, London 1995, p. 7
[94] an assessment of the various technologies can be found in Chapter 4
[95] EU-WETO, ibid., p. 130
[96] EU-WETO, op. cit., p. 74
[97] Karl A. Theis, *Realistische Chancen durch Technologieoffensive nutzen*, in Energiewirtschaftliche Tagesfragen, Mai 2003, p. 294
[98] Paper contributed by John Topper on "International research on clean coal"

4. The Implications of Coal Demand Growth

What are the projected implications of a share of coal in global energy demand of between 20.2% and 25% (Table 6-1)?

i) On **reserves**: only about 25% of economically recoverable world coal reserves would have been utilised. This compares with the depletion of 84% of presently known conventional oil reserves and 64% of gas reserves[99].
ii) On **carbon emissions**: During 2001-2025, the increase of CO_2 emissions from coal (+1.1 Gt of carbon) would be lower than from gas (+1.3 Gt) and oil (+1.5 Gt)[100].
iii) On **welfare**: economic growth depends on macro-economic framework conditions and on the availability of energy, less on the type of energy strategy or scenario. World per capita would grow from US$4850 in 1990 to US$6710 in 2020 in WEC/IIASA middle range scenario B, and somewhat (0.1% per year) faster to US$6850 in its carbon constrained scenario C2. Apparently, the income effects of the more supply and employment-oriented scenario B equal those of scenario C2 fostering efficiency and demand side management.
iv) On **investment**: cumulative investments in coal mining, shipping and port facilities during 2001-2030 amount to US$398 billion, according to IEA [101]. If coal-based power generation was added, the investment needs would rise to US$1900 billion, which is 12% of the world's total energy supply investment need.

In essence: By 2030 and whatever the scenario, resources are not a problem for coal. CO_2 emissions would be an issue in a carbon-constrained world if not mitigated by the worldwide replacement of old by advanced clean coal combustion technologies and carbon sequestration. Whether market-driven or carbon constrained, the type of energy policy scenario would hardly impact on welfare growth. As to competition between coal, oil and gas in electricity generation, EU-WETO[102] estimates that even more expensive advanced clean coal combustion technologies could noticeably displace gas-fired combined cycle plants in regions with "reasonably cheap gas prices" at regimes higher than 6500 hours per year and even 4500 hours per year.

5. The Challenge: A New Image, A New Strategy For Coal [103]

Charlotte Griffiths' notes in her contribution that despite the significant growth of coal demand; coal's image is poor. In fact, the industry's efforts to improve coal's image have been – and remain – inadequate. For too long now the coal industry has failed to appreciate that the rest of the world does not have the same knowledge and understanding of coal as a key commodity and the crucial and enduring contribution it makes to today's society. The industry has made efforts to engage its critics, but this has been largely limited to the national level and undertaken in a reactive and defensive manner rather than through proactive measures.

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[99] WEC/IIASA, op. cit., p. 36 and C 1
[100] USDOE, *International Energy Outlook 2003*, Washington, May 2003, p. 79 and 13
[101] IEA, *World Energy Investment Outlook*, Paris 2003, p. 46, 277-338, 349
[102] EU_WETO, ibid., p. 74
[103] Excerpted from Charlotte Griffiths: The Global Image of Coal, see authors papers

As a result, in the public perception, coal appears to be part of the problem of sustainable development, while reality and the projections suggest that coal is actually part of the solution. Thus, it is overdue for the global coal community to commit to remedial, proactive action.

For instance, what a different world it would be if the global coal community committed to:

i) Developing a 'Common Strategy for Future Action'. By focusing on the similarities and not the differences, a shared, forward-thinking strategy based on (i) communication, (ii) advocacy, and (iii) concrete public awareness actions ought to be developed that would serve to improve coal's image, by addressing the issues that challenge the role of coal in the transition to a more sustainable society. Such a strategy could then be tailored to meet specific national and regional/local circumstances. This could be initially drafted by marshalling the expertise of all existing national, regional and global coal associations.

ii) Establishing a 'Sustainable Development from Coal' Fund. This fund would support and finance the development of regional centres for 'sustainable development from coal' to implement the 'common strategy for future action' at regional and national levels. The centres would be tasked with building local capacity to deliver sustainable energy from coal in an environmentally acceptable manner through the funding of projects and technology transfer. The opportunity of basing such centres at UN regional commissions (e.g. ECA, ECE, ESCAP and ECLAC) could be explored, as this would offer the potential for significantly reduced overheads, access to UN networks and expertise, and the linkage of coal with other efforts in the sustainable development arena.

iii) Actively work with industry organisations such as the World Coal Institute (WCI), particularly in its efforts to give practical effect to promoting coal's role in sustainable development, where WCI has identified five key actions:
   - To minimise coal production impacts on the biosphere (land, water) and on local communities;
   - To improve the technical and economic efficiency of energy conversion, thereby minimising resource use;
   - To significantly reduce 'per unit' emissions from the production and use of coal;
   - To contribute to the efficient and beneficial transfer of new and advanced cleaner coal technologies to enhance their global uptake and to assist in meeting the needs of developing countries (recognising their legitimate development aspirations and the low energy efficiency of existing thermal plant); and
   - To support individual coal companies on community development initiatives to address local sustainability issues, providing enhanced economic and social opportunities relevant to the location and scale of their operations.

iv) Identifying opportunities for improvement and facilitating capacity building and technology transfer initiatives where unacceptable practices and operations exist (both in terms of production and consumption) and allow the continued evidence of an industry falling behind community expectations and standards;

v) Collaborating with and assisting research agencies and institutions on the development of the next generation of technologies that will improve coal's environmental performance at all stages of the coal cycle and to facilitate the early commercialisation of such technologies.

vi) Building local capacity to deliver sustainable energy from the environmentally-acceptable use of coal for those currently without access to modern energy where coal resources provide the most appropriate and affordable energy supply source; and

vii) Encouraging all stakeholder groups within the coal industry to work together to achieve results that will significantly contribute to the task of achieving international sustainable development aspirations and the UN Millennium development goals.

Failure to improve coal's image and public acceptance may jeopardise the contribution coal is projected to make to sustainable development.

6. Summary

In the course of the last 25 years, projections of world coal demand "zeroed-in" on a market share of about 24% by 2020, equivalent to 4.5 to 4.8 Gtce, compared with 3.4 Gtce in 2000. This growth of about 40% is entirely due to increased demand from power stations.

Growing in representatively and sophistication, the projections identified and quantified, the drivers behind these hypothetical developments are:

- Coal's vast and widely distributed reserve base;
- Favourable price relations in comparison with competing fuels;
- Its positive impact on employment and industrial development particularly in developing countries;
- Its low specific investment requirements in comparison with its main competitor,
- Its vast productivity potential in mining; and
- Anticipated progress in the deployment and competitiveness of clean coal combustion and pollution control.

As these factors unfold differently in the various regions, coal demand would evolve differently, with the developing countries steadily increasing their share from 37% in 1990 to 68% in 2050. Coal demand would fall in Western Europe.

The "spread" of projections becomes more significant as of 2020-2030. In market-driven scenarios, coal demand would continue to grow, indeed triple by 2100. But it would fall in a CO_2-constrained world, less in the developing, more in the industrialised countries. Yet, even under such assumptions, coal would not be phased out in 2050 or 2100, when world coal demand would still equal 64% and 42%, respectively, of coal demand in 2000.

Coal's potentialities needs to be implemented. One important barrier is public perception. Pro-active action by industry is required in terms of awareness campaigns, regional activities fostering "sustainable development from coal", and greater industry involvement in international industry organisations, intergovernmental bodies and research activities.

Coal is part of the solution of sustainable development and not part of the problem.

Sources:

- WEC, *World Energy Perspectives to 2020*, London 1977
- IIASA, Energy in a finite world, Vienna 1981
- WEC, *Energy 2000-2002: global balance and regional tensions*, London 1983
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- European Commission, *World energy, technology and climate policy outlook 2030*, Brussels 2003
- RWE Rheinbraun AG, *World Market for Hard Coal*, edition 2002, Cologne 2002
- World Coal Institute, *Sustainable Entrepreneurship – the way forward for the coal industry*, 2001

Table 6-1: Evolution of global coal demand projections to 2050 and beyond, in Mtce and in % of total primary energy supplies

Source	Year of projection	2000	2010	2020	2030	2050	2100	Remarks
1. WEC, World Energy Perspectives to 2020, London	1977	4220 25.8%	-	9440 34.6%	-	-	-	quoted in (4) , p. 376
2. IIASA, Energy in a Finite world, Vienna	1981	4220 29%	-	5860 29.4%	-	-	-	
3. WEC, Energy 2000-2002: Global Balance and Regional Tensions, London	1983	4150 31%	-	6580 35%	-	-	-	
4. CME, Horizons énergétiques mondiaux 2000-2020, Paris	1989	4000 30%	-	5790 32.5%	-	-	-	p. 255, 280, 376
5. WEC, Energy for Tomorrow's World, London	1993	-	-	4340 22.7%	-	-	-	p. 106, 282
6. WEC/IIASA, Global Energy Perspectives to 2050 and Beyond	1995 and 1998	-	-	4900 – 3290 25-20.2%	-	5860 – 2145 21-10.5%	11000- 1430 22-5%	appendix C, p. 46, 52, 53, scenarios B and C
7. IEA, World Energy Outlook 1998 edition, Paris	1998	-	4675 28.4%	5800 28.7%	-	-	-	business-as-usual scenario
8. European Commission, Economic foundations for Energy Policy	1999	-	4170 25%	5610 26.3%	-	-	-	
9. IEA, World Energy Outlook 2000 edition, Paris	2000	-	4030 24..8%	4790 24.4%	5160 23.6%	-	-	reference scenario
10. IEA, World Energy Outlook, 2002 edition, Paris	2002	-	3865 24..3%	4470 23.8%		-	-	business and technology as usual reference scenario
11. EU, WETO, Brussels, 2003	2003	3415	-	-	6800 28%- 3900 18%	-		carbon abatement case
tatistical note: 1 tce = 0.693 toe; in some cases, coal is defined to comprise also combustible renewables and waste; actual coal demand in 2000: 3368 Mt or 25.7%								

Table 6-2: World market shares of primary energy sources 1990 and 2030

Energy source	1990		Reference case 2030		Carbon abatement case 2030	
	Mtoe	**Market Share in %**	**Mtoe**	**Market Share in %**	**Mtoe**	**Market Share in %**
Coal	2.2	25	4.7	28	2.7	18
Oil	3.1	36	5.9	35	5.4	35
Natural gas	1.7	20	4.3	25	4.3	28
Nuclear	0.5	6	0.9	5	1.2	8
Renewables	1.1	13	1.4	8	1.8	12
TOTAL	**8.7**	**100**	**17.1**	**100**	**15.2**	**100**

Source: EU Commission, DG Research: World Energy, Technology And Climate Policy Outlook 2030 (WETO), Brussels 2003, page 103

Table 6-3: Evolution of regional coal demand projections to 2020-2050, in Mtce and in % of total primary energy supplies

Region	1990		2020		2050	
	Mtce	%	Mtce	%	Mtce	%
1. OECD (status 1995)	1300	21.8	1770-700	24-13	1360-70	17-2
2. Developing countries	1170	26.8	2540-2175	27-25	4030-1970	24-14
3. North America	690	22.0	1160-355	29-14	1040-15	24-1
4. Latin America, Caribbean	30	3.5	90-75	6-5.1	160-155	6-8
5. Sub-Saharan Africa	120	29.6	260-240	27-26	610-510	30-27
6. Western Europe	320	21.7	490-260	19-13	210-50	8-3
7. Central and Eastern Europe	160	47.2	185-230	40-36	190-60	30-12
8. CIS	405	20.3	340-160	18-12	340-7	12-5
9. Centrally planned Asia (China, PDR Korea, etc.)	800	58.9	1710-1440	57-55	2390-1060	47-29
10. South Asia (Pakistan, India, etc.)	155	24.3	280-255	21-20	620-240	24-10
11. Other Pacific Asia (Malaysia, Philippines, etc.)	65	10.1	190-160	14-13	240-10	10-0
12. Pacific OECD (Australia, New Zealand)	160	20.3	130-85	14-12	100-5	12-0
higher number: market-driven scenario B, lower number scenario C2 $C0_2$-constrained, new nuclear						

Source: WEC/IIASA, Global Energy Perspectives to 2050 and Beyond, updated 1998; year of projection 1995

Table 6-4: Evolution of regional coal demand projections to 2010-2030, in Mtce and in % of total primary energy supplies

Region	2000		2010		2020		2030	
	Mtce	%	Mtce	%	Mtce	%	Mtce	%
1. OECD (status 2002)	1550	20	1560	18	1660	18	1690	17
2. Developing countries	1515	39	1945	36	2460	34	3095	33
3. North America	830	21	840	19	930	19	980	18
4. OECD Europe	455	18	425	15	410	14	405	12
5. EU	305	15	270	12	265	11	260	10
6. OECD Pacific (Japan, Australia, Korea, New Zealand)	260	22	290	20	315	20	310	18
7. Transition economies excl. Russia	305	21	360	21	355	18	370	17
8. Russia	160	18	190	18	180	15	180	14
9. China	940	69	1220	66	1515	62	1830	60
10. East Asia (Indonesia, Malaysia, PDR Korea, Philippines)	160	27	230	26	315	26	440	29
11. South Asia (India, Pakistan)	240	47	295	41	380	38	495	37
12. Latin America	30	6	40	5	50	5	60	5
13. Africa	130	37	150	31	190	27	250	25
14. World	3368	25.6	3865	24.3	4470	23.8	5160	23.6

Source: IEA, World Energy Outlook 2002 edition; year of projection 2002

Table 6-5: Evolution of regional coal demand projections to 2030, in Mtce and in % of total primary energy supplies

Region	2000		2030		Percentage change
	Mtce	%	Mtce	%	
Western Europe	458	15	450	16	- 1.8
CIS/CEE	336	20	388	15	+ 15
North America	877	24	1228	28	+ 40
Japan, Pacific	183	20	229	20	+ 25
Africa, Middle East	117	10	541	21	+ 363
Latin America	44	5	83	5	+ 89
Asia	1481	40	3858	42	+ 160
World	**3500**	**24**	**6800**	**28**	**+ 94**

Source: EU Commission, DG Research: World Energy, Technology And Climate Policy Outlook 2030 (WETO), Brussels 2003, Annex 2, business-and-technical-change-as-usual case

Part II:

COAL STATISTICS

Table 1: Total World Primary Energy Supply (Mtoe)

Specification	1971	1978	1986	1990	1995	2000
Coal	1 442	1 702	2 042	2 201	2 261	2 340
Crude Oil	2 338	3067	2 886	3 060	3 196	3 474
Gas	895	1 134	1 443	1 671	1 821	2 101
Nuclear	29	163	418	525	608	676
Hydro	104	138	175	187	251	277
Renewable [1)]	650	756	905	974	1 005	1 095
Total World	**5 458**	**6 960**	**7 869**	**8 618**	**9 142**	**9 963**

Source: IEA, *Energy Balances of Non-OECD Countries* 2002, pages II 224 to II 231 and II 272 to II 297
[1)] Geothermal, Solar, Wind, Combustible Renewables and Waste

Table 2: World Primary Energy Supply – Regional Aggregate (Mtoe)

Specification	1971	1978	1986	1990	1995	2000
Africa	200	261	365	398	447	508
Latin America	203	271	317	338	391	456
Asia	349	465	636	775	959	1 123
China	395	596	738	881	1 080	1 163
Non-OECD Europe	86	126	146	141	104	95
Former USSR	789	1 071	1 296	1 348	969	921
Middle East	50	95	193	223	308	381
OECD North America	1 782	2 147	2 088 519	2 260	2 452 759	2 704
OECD Pacific	346	447	519	633	759	847
OECD Europe	1 258	1 481	1 572	1 621	1 673	1 765
OECD Total	3 386	4 075	4 179	4 514	4 884	5 316
World Total	**5 458**	**6 960**	**7 870**	**8 618**	**9 142**	**9 963**

Source: IEA, *Energy Balances of Non-OECD Countries,* 2002 , pages II 292 to II 297

Table 3: Primary Energy Supply/Population – Regional Aggregate (toe per capita)

Region	1971	1978	1986	1990	1995	2000
Africa	0.54	0.59	0.65	0.64	0.63	0.64
Latin America	0.86	0.97	0.97	0.96	1.02	1.10
Asia	0.33	0.38	0.43	0.49	0.55	0.59
China	0.47	0.62	0.69	0.77	0.89	0.92
Non-OECD Europe	1.63	2.24	2.47	2.35	1.78	1.64
Former USSR	3.22	4.10	4.63	4.66	3.32	3.18
Middle East	0.75	1.11	1.69	1.71	2.08	2.30
OECD North America	6.37	6.95	6.10	6.29	6.40	6.70
OECD Pacific	2.25	2.64	2.85	3.39	3.94	4.30
OECD Europe	2.81	3.16	3.23	3.26	3.27	3.39
OECD Total	3.84	4.31	4.13	4.33	4.49	4.74
World Total	**1.46**	**1.63**	**1.61**	**1.65**	**1.62**	**1.65**

Source: IEA, *Energy Balances of Non OECD Countries,* 2002, pages II 468 to II 473

Table 4: Proved Recoverable Coal Resources – at the end of 2002 (Mt)

Region	Bituminous	Sub-bituminous	Brown Coal (lignite)	Total Hard Coal
Africa	50 162	171	3	50 336
of which:				
South Africa	48 750	-	-	48 750
North America	115 669	103 332	35 614	254 615
of which:				
US	111 338	101 978	33 327	246 673
South America	7 701	12 068	124	19 893
of which:				
Colombia	6 230	381	-	6 611
Asia	183 358	36 368	38 367	258 093
of which:				
China	62 200	33 700	18 600	114 500
India	90 085	-	2 360	92 445
Kazkhstan	28 151	-	3 128	31 279
Europe	82 827	117 982	45 826	246 635
of which:				
Germany	183	-	6 556	6 739
Poland	14 000	-	-	14 000
Russian Fed.	49 088	97 472	10 450	157 010
Ukraine	16 274	15 946	1 933	34 153
Middle East	419			419
Oceania	38 635	2 405	38 033	79 073
of which:				
Australia	38 600	2 200	37 700	78 500
World Total	**478 771**	**272 326**	**157 967**	**90 9064**

Source: WEC, *Survey of Energy Resources,* 2004

Table 5: World Hard Coal Balance (Mt)

Specification	1960	1970	1980	1985	1990	1995	2000	2002
Hard coal production								
Coking coal	..	..	544	516	538	548	491	502
Steam coal	..	..	2 262	2 683	2 993	3 117	3 143	3 335
Total	**1991**	**2208**	**2 806**	**3 198**	**3 531**	**3 665**	**3 633**	**3 837**
Hard coal imports								
Coking coal	..	..	141	166	175	186	190	188
Steam coal	..	..	117	178	217	297	418	471
Total	**95**	**177**	**257**	**344**	**391**	**483**	**608**	**659**
Hard coal exports								
Coking coal	..	..	138	158	176	187	181	189
Steam coal	..	..	125	188	225	307	419	451
Total	**113**	**167**	**263**	**345**	**401**	**493**	**599**	**640**
Hard coal consumption								
Coking coal	..	..	548	520	536	547	501	496
Steam coal			2 230	2 680	2 969	3 111	3 242	3 357
Total	..	..	**2 778**	**3 201**	**3 505**	**3 658**	**3 743**	**3 853**

Source: IEA, *Coal Information,* 2003, tables 1.7 to 1.14

Table 6: Hard Coal Production – Selected Countries (Mt)

Specification	1960	1970	1980	1985	1990	1995	2000	2002
World	**1 990.7**	**2 207.6**	**2 805.6**	**3 198.2**	**3 531.1**	**3 665.4**	**3 633.2**	**3837.0**
Belgium	22.5	11.4	8.0	7.7	2.4	0.6	0.4	-
France	56.0	37.8	20.2	17.1	11.2	8.5	3.8	1.9
Germany	148.0	118.0	94.5	88.8	76.6	58.9	37.4	29.2
Spain	13.8	10.8	12.8	16.1	14.9	13.7	11.3	9.8
UK	197.8	147.1	130.1	94.0	92.8	53.0	31.2	29.5
Poland	104.4	140.1	193.1	191.6	147.7	137.2	103.3	102.6
Russia	172.9	206.9	245.8	254.8	237.5	162.4	152.3	163.6
US	391.5	550.4	710.2	735.9	853.6	858.6	895.2	916.7
Australia	21.9	45.4	72.4	117.5	158.8	191.1	239.4	276.0
China	337.2	354.0	620.2	837.3	1 050.7	1 343.0	1 231.2	1326.0
Japan	57.5	40.9	18.0	16.4	8.3	6.3	3.0	-
India	52.6	73.7	111.5	151.4	210.5	268.7	310.4	333.7
South Africa	38.2	54.6	115.1	173.5	174.8	206.2	224.2	223.0
Canada	6.4	8.0	20.2	34.3	37.7	38.6	33.8	29.7
Colombia	2.6	2.8	4.2	8.8	21.4	25.7	32.7	40.4
Indonesia	0.7	0.2	0.3	2.0	10.5	41.1	76.6	101.2
North Korea	6.7	21.8	34.1	40.0	35.7	23.7	22.5	25.9
South Korea	5.3	12.4	18.6	22.5	17.2	5.7	4.1	3.3

Source: IEA, *Coal Information*, 2003, tables 1.8 and 1.8b

Table 7: Hard Coal Production – Regional Aggregate (Mt)

Specification	1960	1970	1980	1985	1990	1995	2000	2002
Europe	598.1	516.3	500.2	456.2	376.4	293.6	209,2	195.8
Former USSR	374.9	475.4	553.0	569.0	543.0	325.9	302.5	317.3
North America	398.0	558.4	733.4	774.0	894.3	898.9	931.2	948.1
Latin America	7.3	10.2	11.0	18.3	30.7	36.3	53.3	55.7
Asia	544.3	540.2	813.4	1 081.9	1 343.4	1 703.3	1 663.9	1899.9
Australia & New Zealand	24.8	47.6	74.3	119.8	161.3	194.3	242.8	280.2
Africa	43.3	59.5	120.2	179.0	182.1	213.1	230.3	229.9
World	**1 990.7**	**2 207.6**	**2 805.6**	**3 198.2**	**3 531.1**	**3 665.4**	**3 633,2**	**3 837.0**

Source: IEA, *Coal Information*, 2003, table 1.7

Table 8: Coking Coal Production – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**543.5**	**515.5**	**538.0**	**548.4**	**490.5**	**501.9**
Belgium	4.0	3.5	-	-	-	-
France	4.1	3.4	1.8	0.4	-	-
Germany	56.0	51.4	44.6	31.7	18.8	18.0
UK	10.0	2.6	1.6	0.6	0.3	0.4
Poland	27.3	33.0	28.8	28.7	17.2	15.9
Russia	90.0	91.1	85.5	55.6	51.0	53.4
US	117.7	89.5	93.3	77.2	55.1	41.2
Australia	42.7	55.9	65.3	79.7	104.4	114.0
China	68.2	68.4	85.7	148.0	123.9	134.8
India	30.2	32.3	41.2	35.2	27.6	26.2
South Africa	10.6	11.1	9.3	3.9	1.5	1.3

Source: IEA, *Coal Information,* 2003, tables 1.15 and 1.17

Table 9: Steam Coal Production – Selected Countries (Mt)

Specification	**1980**	**1985**	**1990**	**1995**	**2000**	**2002**
World	**2 262.1**	**2 682.7**	**2 993.2**	**3 117,0**	**3 142.6**	**3 335.1**
Belgium	4.0	4.2	2.4	0.6	0.4	-
France	16.1	13.7	9,4	8.1	3.8	1.9
Germany	38.5	37.4	32.0	27.2	18.5	11.2
Spain	11.5	15.2	14.6	13.7	11.3	9.8
UK	120.0	91.5	91.2	52.4	30.9	29.2
Poland	155.6	153.0	114.5	108.4	86.1	86.7
Russia	155.8	163.7	152.1	106.8	101.5	110.2
US	592.5	646.5	760.4	781.4	840.1	875.6
Australia	29.6	61.6	93.6	111.3	135.0	162.0
China	551.9	768.9	965.1	1 195.0	1 107.3	1 191.2
Japan	11.1	12.5	8.2	6.3	3.0	-
India	81.3	119.1	169.3	233.5	282.8	307.5
South Africa	104.5	162.4	165.5	202.4	222.7	221.7

Source: IEA, *Coal Information,* 2003, tables 1.18

Table 10: Hard Coal Imports – Selected Countries (Mt)

Specification	1960	1970	1980	1985	1990	1995	2000	2002
World	**95.3**	**176.8**	**257.0**	**343.7**	**391.3**	**482.9**	**608.4**	**658.6**
Belgium	3.9	7.6	10.1	9.3	14.8	14.1	11.3	13.9
France	10.1	13.7	29.4	18.8	19.4	13.2	19.0	17.8
Germany	6.7	18.0	16.2	15.5	13.6	15.1	27.9	31.0
Spain	0.3	3.5	5.7	8.4	10.5	13.4	21.6	24.5
UK	-	0.1	7.3	12.7	14.8	15.9	23.4	28.7
Russia	-	-	28.2	60.0	53.2	22.7	25.5	21.0
US	0.2	-	1.1	1.8	2.4	6.5	11.3	14.0
Japan	8.7	50.9	68.6	93.4	103.6	122.7	149.4	158.5
India	-	-	0.6	2.0	4.9	8.8	20.9	24.8

Source: IEA, *Coal Information,* 2003, tables 1.9 and 1.10

Table 11: Coking Coal Imports – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**140.5**	**165.7**	**174.7**	**186.2**	**190.1**	**187.6**
Belgium	4.2	4.7	7.1	5.3	3.8	4.0
France	10.5	7.8	7.8	7.3	6.5	6.0
Germany	3.0	2.2	1.7	1.4	4.6	4.0
Spain	4.1	4.1	4.2	3.2	3.7	3.4
UK	2.4	7.2	8.6	7.8	8.5	6.3
US	-	-	-	-	1.5	2.2
Japan	62.2	69.2	67.6	65.4	65.7	65.8
India	0.6	2.0	4.9	8.6	11.1	12.8

Source: IEA, *Coal Information,* 2003, tables 1.19 and 1.21

Table 12: Steam Coal Imports – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**116.5**	**177.9**	**216.6**	**296.7**	**418.4**	**471.0**
Belgium	6.0	4.7	7.6	8.8	7.5	9.9
France	19.0	11.1	11.5	5.9	12.5	11.8
Germany	13.1	13.3	11.9	13.6	23.3	27.0
Spain	1.6	4.3	6.3	10.2	17.9	21.1
UK	4.9	5.6	6.2	8.1	15.0	22.4
Russia	28.2	60.0	53.2	20.5	25.3	20.8
US	1.1	1.8	2.4	6.5	9.7	11.8
China	2.0	2.1	1.8	1.6	1.8	10.1
Japan	6.3	24.2	36.0	57.2	80.6	92.7
India	-	-	-	0.2	9.9	12.0

Source: IEA, *Coal Information*, 2003, tables 1.20 and 1.22

Table 13: Hard Coal Exports – Selected Countries (Mt)

Specification	1960	1970	1980	1985	1990	1995	2000	2002
World	**113.2**	**167.2**	**263.3**	**345.5**	**400.6**	**493.4**	**599.3**	**640.3**
Germany	17.8	16.2	12.7	9.2	5.5	1.9	0.3	0.1
UK	5.3	3.2	4.0	2.4	2.3	0.9	0.7	0.5
Poland	21.0	32.0	31.1	36.1	28.1	31.9	23.2	22.6
Russia	..	..	..	60.3	56.1	26.3	36.7	45.1
US	34.5	65.7	83.2	84.0	95.9	80.3	53.0	34.6
Australia	1.2	18.0	43.2	83.8	104.0	136.4	177.2	197.9
China	0.5	0.7	6.3	7.8	17.3	28.6	55.0	85.7
South Africa	1.0	1.5	28.2	47.6	49.9	59.7	69.9	68.7
Canada	0.8	4.0	15.3	27.4	31.0	34.0	32.0	26.8
Vietnam	0.6	0.2	0.6	0.6	0.7	2.8	3.4	4.8
Colombia	-	-	0.1	3.2	13.5	18.3	35.6	34.4
Indonesia	-	-	0.1	1.1	4.9	31.3	55.4	73.0

Source: IEA, *Coal Information,* 2003, tables 11.1, 1.12 and 1.12 b

Table 14: Coking Coal Exports – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**138.5**	**157.8**	**175.8**	**186.6**	**180.5**	**189.0**
Germany	8.6	5.7	4.0	0.7	-	-
Poland	7.2	15.6	6.3	12.3	5.3	3.5
Russia	..	..	31.6	8.7	7.3	9.0
US	57.2	54.7	57.6	47.3	29.8	18.3
Australia	36.1	50.5	58.4	73.8	97.0	105.8
China	1.4	2.5	3.5	6.7	6.5	13.8
South Africa	3.4	5.1	3.6	-	-	-

Source: IEA, *Coal Information* 2003, tables 1.23 and 1.25

Table 15: Steam Coal Export – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**124.8**	**187.6**	**224.9**	**306.8**	**418.8**	**451.3**
Belgium	0.3	1.1	0.7	0.8	1.4	2.0
Germany	4.1	3.5	1.5	1.1	0.3	0.1
UK	4.0	2.4	2.3	0.9	0.7	0.5
Poland	23.1	20.5	21.8	19.6	18.0	19.1
Russia	..	60.3	24.5	17.6	29.4	36.1
US	26.0	29.3	38.3	33.1	23.2	16.2
Australia	7.0	33.3	45.6	62.6	80.2	92.0
China	4.9	5.3	13.8	21.8	48.6	72.0
South Africa	24.7	42.5	46.3	59.7	69.9	67.7

Source: IEA, *Coal Information*, 2003, tables 1.24 and 1.26

Table 16: Hard Coal Consumption – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**2 777.9**	**3 200.7**	**3 505.4**	**3 658.2**	**3 743.1**	**3853.3**
Belgium	17.0	15.6	16.2	12.4	11.0	12.7
France	48.1	36.5	28.8	22.6	21.8	18.9
Germany	96.4	93.5	87.0	74.2	67.0	60.2
Spain	16.5	25.2	26.3	27.6	32.8	33.6
UK	123.6	106.0	106.7	75.9	58.7	58.0
Poland	164.0	159.9	119.9	107.8	83.4	80.5
Russia	274.0	254.5	240.0	163.3	142.2	139.5
USA	608.0	682.6	736.9	782.8	893.3	896.2
Australia	34.4	40.0	49.3	51.7	60.8	78.1
China	626.0	803.9	1051.0	1 316.9	1 214.9	1 252.0
Japan	87.7	109.4	113.1	129.2	152.3	158.5
India	107.0	152.8	210.5	279.1	340.2	356.8
South Africa	87.0	125.9	124.9	147.2	154.1	155.8

Source: IEA, *Coal Information*, 2003, tables 1.13 and 1.14

Table 17: Hard Coal Supply and End-Use (Mt)

Specification	1980	1985	1990	1995	2000	2002
World Hard Coal Supply	**2 778**	**3 201**	**3 505**	**3 682**	**3 743**	**3 853**
of which:						
Steel Industry	625	567	577	586	543	536
Power and Heat Stations	1 218	1 453	1 761	2 113	2 454	2 541
Households	165	213	215	196	122	123

Source: IEA, *Coal Information*, 2003, table 1.13 and tables III 4 to III 11.

Table 18: Hard Coal Consumption – Regional Aggregates (Mt)

Specification	1980	1985	1990	1995	2000	2002
Europe	571.6	563.8	509.0	427.7	380.5	365.6
Former USSR	529.1	543.4	516.6	323.6	274.0	284.5
North America	633.3	707.9	758.7	801.4	918.6	918.2
Latin America	16.7	25.1	26.2	28.2	31.8	34.9
Asia	897.9	1 184.4	1 507.5	1 865.1	1 906.9	1 998.5
Australia & New Zealand	36.2	41.8	51.3	53.8	62.7	80.4
Africa	93.1	134.2	136.1	158.5	168.7	171.2
World	**2 777.9**	**3 200.7**	**3 505.4**	**3 658.2**	**3 743.1**	**3 853.3**

Source: IEA, *Coal Information*, 2003, table 1.13

Table 19: Coking Coal Consumption - Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**548.2**	**520.3**	**536.3**	**547.4**	**501.2**	**496.4**
Belgium	8.0	8.1	7.2	4.7	4.0	4.0
France	14.6	11.3	9.7	7.7	6.5	6.0
Germany	50.3	47.8	42.2	34.0	24.5	20.8
Spain	5.4	4.9	4.5	3.3	3.6	3.4
UK	11.6	11.1	10.5	8.5	8.8	6.8
Poland	..	..	..	17.4	13.3	12.3
Russia	90.0	91.1	53.9	50.7	43.9	44.7
US	61.5	37.2	35.3	29.9	26.7	25.0
Australia	7.0	5.5	5.9	5.9	4.8	8.2
China	66.8	62.9	81.0	140.7	119.9	122.7
Japan	70.2	73.5	68.0	65.4	65.7	65.8
India	31.0	33.9	47.9	42.2	41.3	38.9
South Africa	7.2	6.0	5.7	4.2	2.6	1.8

Source: IEA, *Coal Information*, 2003, tables 1.27 and 1.29

Table 20: Steam Coal Consumption – Selected Countries (Mt)

Specification	1980	1985	1990	1995	2000	2002
World	**2 229.7**	**2 680.4**	**2 969.1**	**3 110.8**	**3 241.9**	**3 356.9**
Belgium	9.0	7.5	9.0	7.7	7.0	8.7
France	33.5	25.2	19.1	14.9	15.3	12.9
Germany	46.1	45.6	44.7	40.2	44.5	39.4
Spain	11.1	20.3	21.9	24.3	29.2	30.3
UK	112.0	94.9	96.2	67.4	49.8	51.2
Poland	..	..	..	90.4	70.0	68.2
Russia	184.0	163.4	186.1	112.6	98.3	94.9
US	546.6	645.3	701.7	752.9	866.6	871.2
Australia	27.4	34.5	43.4	45.9	56.0	70.0
China	559.2	741.0	970.0	1 176.2	1 094.9	1 129.3
Japan	17.5	35.9	45.0	63.8	86.7	92.7
India	75.9	118.9	162.6	236.9	298.9	318.0
South Africa	79.8	119.9	119.2	143.0	154.6	154.0

Source: IEA, *Coal Information*, 2003, tables 1.28 and 1.30

Table 21: Brown Coal Production – Selected Countries (Mt)

Specification	1973	1980	1985	1990	1995	2000	2002e
World	**834.8**	**978.5**	**1 171.8**	**1 150.2**	**912.3**	**889.0**	**876.5**
Australia	24.1	32.9	38.4	46.0	50.8	67.4	66.6
Canada	8.1	16.5	26.5	30.7	36.4	35.4	36.8
Czech Rep.	76.0	89.1	94.5	79.0	57.2	50.3	49.4
Germany	366.4	389.7	434.0	357.5	192.8	167.7	181.8
Greece	13.3	23.2	35.9	51.9	57.7	63.9	68.0
Hungary	25.9	25.1	23.5	17.7	14.6	14.0	12.8
Poland	39.2	36.9	57,7	67.6	63.5	59.5	58.2
Spain	3.0	15.5	23.6	21.1	14.8	12.2	12.3
Turkey	7.8	15.0	36.4	44.7	52.8	60.9	51.1
US	12.9	42.8	65.7	79.9	78.5	80.5	74.5
India	3.3	5.1	8.0	14.1	22.1	24.2	22.4
North Korea	7.0	10.0	12.0	10.7	7.6	7.2	7.3
Thailand	0.4	1.5	5.2	12.4	18.4	17.7	19.8
Bulgaria	26.5	29.9	30.7	31.5	30.6	26.3	25.6
Romania	17.7	27.1	37.9	33.7	40.0	29.0	30.4
Former Yugoslavia	31.9	40.9	68.1	75.6	54.3	51.6	53.2
Former USSR	137.8	188.3	184.2	178.3	105.0	105.9	90.0

Source: IEA, *Coal Information,* 2003, table 6.2

Table 22: Brown Coal Demand – Selected Countries (Mt)

Specification	1973	1980	1985	1990	1995	2000	2002e
World	**843.5**	**976.1**	**1 166.3**	**1 164.5**	**919.7**	**903.4**	**888.0**
Australia	24.1	32.9	38.4	46.0	50.8	67.4	66.6
Canada	8.1	15.9	26.7	30.3	36.7	40.5	43.6
Czech Republic	76.0	79.8	83.9	71.8	52.3	50.4	47.6
Germany	372.5	391.8	432.5	364.1	194.8	169.9	183.0
Greece	13.0	22.7	36.2	52.1	57.0	64.6	68.0
Hungary	26.9	25.9	24.6	19.3	15.5	14.5	13.5
Poland	34.3	35.3	57.6	67.4	63.2	59.5	58.5
Spain	3.1	14.7	23.2	20.8	15.1	12.9	12.6
Turkey	7.6	15.8	35.3	46.2	52.5	64.4	51.5
US	12.9	42.1	62.1	79.0	80.8	77.2	74.5
India	3.8	5.1	7.9	15.0	22.3	24.8	22.4
North Korea	7.0	10.0	12.0	10.7	7.6	7.2	7.3
Thailand	0.4	1.5	5.1	12.5	18.5	18.6	19.8
Bulgaria	26.3	29.7	30.7	31.8	30.9	25.8	25.6
Romania	17.7	27.4	38.4	36.9	39.8	29.3	30.4
Former Yugoslavia	31.4	40.5	68.2	75.8	54.9	51.9	53.2
Former USSR	157.1	163.0	157.0	160.0	106.5	107.6	90.1

Source: IEA, *Coal Information,* 2003, table 3.1c

Table 23: Electricity Production from Coal – Selected Countries

Specification	2000 Electricity production TWh			% of total	
	Total	**From Hard Coal**	**From Brown Coal**	**Hard Coal**	**Brown Coal**
World total	**15 453.7**	**5 136.0**	**749.1**	**33.2**	**4.8**
OECD total	9 699.5	3 060.8	570.5	31.6	5.9
Australia	208.4	110.2	50.4	52.9	24.2
Canada	605.3	56.1	61.7	9.3	10.2
Czech Rep.	73.4	5.5	47.0	7.5	64.0
France	540.7	27.0	0.4	5.0	0
Germany	571.3	143.2	148.3	25.1	26.0
Italy	276.6	26.0	0.3	9.4	0
Japan	1 091.5	205.9	-	18.9	-
Korea	294.1	115.9	-	39.4	-
Mexico	204.4	-	18.6	-	9.1
Netherlands	89.6	22.6	-	25.2	-
Poland	145.2	82.3	53.4	56.7	36.8
Spain	225.2	67.6	11.5	30.0	5.1
Sweden	145.9	1.9	-	1.3	-
Turkey	124.9	3.0	34.4	2.4	27.5
UK	374.9	120.0	-	32.0	-
US	4 030.3	2 005.4	97.2	49.8	2.4
Non OECD total	5 754.1	2 075.2	749.1	36.1	13.0
Egypt	75.7	-	-	-	-
South Africa	210.4	193.4	-	91.9	-
Argentina	89.0	1.2	-	1.4	-
Brasil	349.2	7.7	-	2.2	-
Chile	41.3	11.1	-	26.9	-
Colombia	43.9	2.8	-	6.4	-
Paraguay	53.5	-	-	-	-
Venezuela	85.2	-	-	-	-
India	542.4	401.5	18.4	74.0	3.4
Indonesia	92.6	28.8	-	31.1	-
Malaysia	69.2	-	1.8	-	2.4
Pakistan	68.1	0.2	-	0	-
Taiwan	193.0	91.4	-	47.4	-
Thailand	96.0	0.9	16.7	0.9	17.4
China	1 355.6	1 055.6	-	77.9	-
Romania	51.9	0.4	18.5	0.7	35.6
Kazakstan	51.6	36.1	-	70.0	-
Russia	877.8	99.6	68.7	11.3	7.8
Ukraine	171.5	46.0	-	26.8	-
Iran	121.4	-	-	-	-
Saudi Arabia	128.4	-	-	-	-

Source: IEA, *Electricity Information*, 2002, table 6 (pages I 39 to I 42) and table 7 (pages I43 to I 46)

Table 24: Steam Coal Costs Import (Average Unit Value, CIF, US$/t)

Specification	1980	1985	1990	1995	2000
Import to 15 EU countries (all sources)	51.35	48.10	51.27	46.18	34.94
from:					
Australia	55.61	49.70	51.85	45.07	39.20
US	57.76	55.17	54.52	49.75	41.24
South Africa	43.57	41.95	45.13	43.76	33.74
Poland	54.26	51.75	60.52	46.42	35.32
China	59.54	55.19	49.57	45.30	31.45
Colombia	-	44.81	52.40	43.69	34.23
Russia	55.74	41.89	41.65	42.54	33.68
Import to Japan (all sources)	54.60	45.32	50.97	47.85	34.59
from:					
Australia	55.41	44.40	52.23	48.87	35.59
Canada	56.10	43.66	48.26	44.20	34.72
US	70.45	56.74	53.17	52.65	45.49
South Africa	41.46	45.81	47.95	48.27	35.82
Russia	45.59	41.08	46.54	43.45	30.68
China	50.03	49.16	47.59	44.48	33.69

Source: IEA, *Coal Information,* 2001, tables 2.1 and 2.2 (page I67)

Table 25: Coking Coal Costs Import (Average Unit Value, CIF, US$/t)

Specification	1980	1985	1990	1995	2000
Import to 15 EU Countries (all sources)	67.02	60.65	64.09	58.48	47.89
from:					
Australia	62.01	58.78	67.03	57.05	45.47
Canada	75.57	62.00	64.84	57.03	45.99
US	68.80	62.76	63.14	61.19	52.91
South Africa	67.53	44.37	58.77	49.66	39.09
Poland	63.90	60.11	64.47	59.28	50.52
Russia	59.03	43.42	57.44	56.02	42.03
Import to Japan (all sources)	66.40	59.77	60.72	55.03	39.46
from:					
Australia	59.59	54.36	55.27	51.15	39.01
Canada	62.16	67.51	71.27	64.49	45.46
US	81.27	68.67	66.90	61.37	52.69
South Africa	53.14	49.62	50.11	49.54	39.99
Russia	58.10	54.69	57.45	54.81	43.62
China	55.81	51.17	54.38	49.49	37.12

Source: IEA, *Coal Information*, 2001, tables 2.9 and 2.10 (page I74)

Table 26: End-Use Steam Coal Prices for Electricity Generation and Coking Coal Prices for Industry in OECD selected Countries in US$/t (converted using exchange rate)

Country	**Steam Coal Prices for Electricity Generation**		**Coking Coal Prices for Industry**	
	1985	**2000**	**1985**	**2000**
OECD total	42.4	26.0	60.3	..
OECD Europe	56.9	32.4	61.7	..
Belgium	49.9	32.8	60.4	47.2
Finland	49.9	38.6	..	99.8
France	38.7	35.5	52.4	47.3
Germany	81.4	42.4	62.9	..
Ireland	75.1	30.3	..	..
Italy	50.8	..	59.2	50.6
Japan	63.5	..	62.1	42.4
Poland	..	28.2	..	39.0
Portugal	56.9	30.2	68.4	37.1
UK	58.7	44.4	..	..
US	38.1	24.5	59.9	49.0

Sources: IEA Energy Prices and Taxes 1995 Fourth Q., tables 16 and 17 (pages 283 and 284)
IEA Energy Prices and Taxes 2002 Third Q., tables 17 and 18 (pages 360 and 361)

Table 27: Employees in Hard Coal Industries for Selected Countries - Main Producers (thousands)

Country	**1980**	**1985**	**1990**	**1995**	**2000**	**2002e**
Australia	26.5	31.2	28.7	25.5	18.6	21.2..
Canada	11.4	12.1	11.0	9.1	5.9	..
China	4 501.6	4 982.8	5 464.0	3 308.0	4 050.0	..
Colombia	..	..	5.2	3.9	..	48.7
Germany	186.8	166.2	130.3	92.6	58.1	
Poland	338.4	418.8	369.0	275.0	160.0	140.0
Russia	..	..	..	..	197.0	..
South Africa	122.8	121.0	84.3	61.5	42.5	47.1
UK	232.0	171.0	65.0	9.5	7.7	6.9
US	225.1	165.7	119.0	81.0	63.0	71.7

Source: IEA, *Coal Information* 2003, table 6.4

Table 28: Productivity in Hard Coal Industries for Selected Countries (1000 t/man-year)

Specification	1980	1985	1990	1995	2000	2002e
Australia	2.9	4.1	5.7	7.5	13.2	12.9
Canada	3.2	5.0	5.9	8.2	11.7	..
China	0.14	0.17	0.19	0.41	0.30	..
Colombia	..	..	2.6	3.5	..	..
Germany	0.46	0.49	0.54	0.57	0.57	0.54
Poland	0.57	0.46	0.40	0.49	0.63	0.73
Russia	..	..	..	..	1.3	..
South Africa	0.9	1.4	2.1	3.4	5.3	4.7
UK	0.47	0.16	1.15	3.90	2.64	2.83
US	3.2	4.4	7.2	10.6	14.2	12.8

Source: IEA, *Coal Information,* 2003, table 6.4

Table 29: Labour Costs in Hard Coal Industries for Selected Countries (US$/t)

Specification	1980	1985	1990	1995	2000	2002e
Australia	7.9	8.7	9.9	10.1	3.4	3.4
Canada	..	5.5	6.5	4.7	3.6	..
China	..	..	..	..	..	..
Colombia	..	..	5.1	..	..	..
Germany	36.4	39.9	85.0	86.6	..	..
Poland	..	12.0	8.3	19.4	..	..
Russia	..	..	..	..	..	..
South Africa	..	2.7	3.3	3.4	2.4	2.2
UK	32.9	34.2	26.2	..	18.3	17.6
US	7.2	7.3	5.3	4.1	3.1	..

Source: IEA, *Coal Information*, 2003, table 6.4

Units and Abbreviations

Mt	-	million metric tonnes
Mtoe	-	million metric tonnes of oil equivalent
toe	-	tonne of oil equivalent
TPES	-	Total Primary Energy Supply
-	-	zero
..	-	not available
0	-	negligible

Part III:

CASE STUDIES

(Available on CD)

ANNEX A

BIBLIOGRAPHY

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ANNEX B

WEC STUDY GROUP MEMBERSHIP

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ANNEX C

LIST OF ABBREVIATIONS

°C	degree Celsius
AFBC	Atmospheric Fluidised Bed Combustion
AFC	Armoured face conveyor
approx.	Approximately
bcm	Billion cubic metres
BoA	Braunkohlenkraftwerk mit optimierter Anlagentechnik; German optimised plant technology
BOO	Build-Own-Operate
BOOT	Build-Own-Operate-Transfer
BOT	Build-Own-Transfer
CaO	Calcium Oxide
CBM	Coal bed methane
CBP	Coal Beneficiation Plants
CCT	Clean Coal Technologies
CDM	Clean Development Mechanism
CEE	Central and Eastern Europe
CHP	Combined Heat and Power
CIAB	International Energy Agency Coal Industry Advisory Board
Cif	Cost, insurance, freight
CIS	Commonwealth of Independent States
CM	Continuous Miner
CMM	Coal mine methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRC	Australian Cooperative Research Centre
DOE	US Department of Energy
EBRD	European Bank for Reconstruction and Development
EC	European Commission
ECA	Export Credit Agency
ECSC	European Coal and Steel Community
EIB	European Investment Bank
EIT	Economies in transition
ET	Emissions Trading
EU	European Union
FDI	Foreign Direct Investment
FGD	Flue Gas Desulphurisation
FOB	Free on board
FSI	Furnace sorbent injection
FSU	Former Soviet Union
GATT	General Agreement on Tariffs & Trade
GATS	General Agreement on Trade & Services
ex-GDR	Former German Democratic Republic, now part of Germany
GDP	Gross Domestic Product
GEIS	Global Energy Information System (www.worldenergy.org)
GHG	Greenhouse Gas
Gt	gigatonne
GW	gigawatt
IBRD	International Bank for Reconstruction and Development – World Bank Group
IEA	International Energy Agency
IGCC	Integrated Coal Gasification Combined Cycle
IIASA	International Institute for Applied Systems Analysis
ILO	International Labour Organisation
JI	Joint Implementation

kg	kilogram
kj	kilojoule
km	kilometre
kW	kilowatt
kWh	kilowatt hour
m	metre
m^2	square metre
Mst	Million short tons
Mt	million tonnes
MW	megawatt
NCV	Net calorific value
NEDO	Japan New Energy & International Technology Development Organisation
NGO	Non-Governmental Organisation
NO_x	Nitrogen Oxide
OECD	Organisation for Economic Cooperation and Development
OPEC	Organisation of the Petroleum Exporting Countries
p.a	Per annum
PCI	Pulverised Coal Injection
PF	Pressurised Fluidised
PFBC	Pressurised Fluidised Bed Combustion
PPCC	Pressurised Pulverized Coal Combustion
R&D	Research & Development
RFQ	Request for Quotation
ROM	Run-of-mine
SACI	China's State Administration of the Coal Industry
SCR	Secondary control reaction
SETC	China's State Economic and Trade Commission
SNCR	Secondary Nox Control Reaction
SO_2	Sulphur Dioxide
tce	tonne of coal equivalent
toe	tonne of oil equivalent
TVE	China's Township and Village Enterprise
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
US$	United States dollar
WEC	World Energy Council
WESP	Wet electrostatic precipitator
WTO	World Trade Organisation
ZECA	Zero Emission Coal to Hydrogen Alliance

ANNEX D

LIST OF GRAPHS, FIGURES AND TABLES: PART I

GRAPHS

FIGURES

TABLES