WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE

Carbon Capture and Storage:
a WEC "Interim Balance"

Le Captage et Stockage du Carbone:
un Bilan Intérimaire du CME

World Energy Council 2007

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

World Energy Council (WEC) Cleaner Fossil Fuels Systems Committee (CFFS)

Contents

The WEC Cleaner Fossil Fuels Systems Committee

Preface by the Chairman, Barbara N. McKee:

The Committee

In 1999 the World Energy Council created the Cleaner Fossil Fuels Systems (CFFS) Committee to discuss and promote knowledge worldwide about the research, development, demonstration and deployment of cleaner fossil fuels systems to meet global energy needs. Global energy use is projected to increase by 53% during 2004 – 2030. Fossil fuels are critical to meeting global economic development and energy security needs. Their share of global energy use is even expected to increase from 81% in 2004 to 82% in 2030. Production and consumption of every form of fossil fuel will increase to meet needs (IEA 2006).

Use of fossil fuels could have major local, regional and global environmental impacts, and the environmental challenge is great. Cleaner systems mitigate and even neutralize the adverse consequences of the use of fossil fuels and permit their positive qualities to be enjoyed for economic and social development. The technology for these systems is advancing rapidly.

The mandate

Stakeholders need to fully understand the high value of clean systems to ensure that cleaner fossil energy systems will be used and to enable fossil fuel systems to be sustainable. Hence, the aim of the Committee is to ensure that a broad range of stakeholders appreciate the great potential of these systems to ensure the sustainable use of fossil fuels. To achieve this mission, the Committee:

- provides a forum for energy experts, decision makers and consumers to discuss the role of cleaner fossil fuel technologies;
- exchanges information, creates networks, elaborates proposals and introduces recommendations for the worldwide deployment of such technologies, including to developing countries;
- addresses barriers and critical issues that may hamper the advancement of cleaner fossil fuel systems and encourages governments, investors and financial institutions to proactively deploy clean and innovative fossil fuel technologies.

The activities

The Committee endeavors to achieve these goals mainly by presenting seminars and roundtables organized throughout the world in: Ankara, Turkey-1999; Krakow, Poland-1999; Dakar, Senegal-2000; Rio de Janeiro, Brazil-2001; Buenos Aires, Argentina-2001; Washington, DC, United States-2002; Warsaw, Poland-2002; Cairo, Egypt-2002; Kiev, Ukraine-2003; Sydney, Australia-2004; Erice, Italy-2005; Colombo, Sri Lanka-2005; Neptun, Romania-2006; Tallinn, Estonia-2006; Moscow, Russia-2006; and Amman, Jordan-2007. We also research and publish informational documents.

Focus on carbon capture and storage

From 2004 to 2007, the Committee focused on carbon capture and storage.

The Discussion Session on "Cleaner Fossil Fuels – The Cornerstone for Human Development and Energy Security," held in **Sydney**, Australia, on 8 September 2004 at the occasion of the 19th World Energy Congress placed carbon capture and storage in the general context of sustainable development and mitigation of energy poverty.

The Workshop held in **Erice**, Sicily, on 24 August 2005 focused on "Carbon Capture and Storage – A Way Forward for Cleaner Fossil Fuels Systems." It was a unique event because it was organized at the invitation of the World Federation of Scientists (WFS) and was held in the prestigious International Centre for Scientific Culture in Erice. Prof. Richard Wilson, Chairman of WFS-Energy PMP (Permanent Monitoring Panel), and I jointly chaired the workshop.

On 7 September 2005, the CFFS Committee organized a dialogue on "Cleaner Fossil Fuel Systems with Carbon Capture and Storage – What's In It for the Developing World?" in **Colombo**, Sri Lanka, at the occasion of the Executive Assembly of the World Energy Council.

"Cleaner Fossil Fuels for Sustainable Development" was the topic of a workshop organized jointly by the CFFS Committee and the Craiova Power Energy Complex on 13 June 2006, at the occasion of the WEC Regional Forum FOREN06 in **Neptun**, Romania.

"Focused lectures on global and regional efforts toward carbon capture and storage" were given at a workshop organized by the CFFS Committee in **Tallinn**, Estonia, on 4 September 2006, at the occasion of the Executive Assembly of the WEC.

"Cleaner Fossil Fuels for Power Generation" were discussed at a workshop organized jointly by the CFFS Committee and the All-Russian Thermal Engineering Institute (VTI) in **Moscow**, Russia, on 3 September 2006.

On 25 April 2007, the CFFS Committee and the Arab Union of Electricity Producers, Transmitters and Distributors held a workshop on "Mitigating the Growing Contributions of West Asia in Global Emissions" in **Amman**, Jordan.

At the occasion of the 20th World Energy Congress in Rome, a forum on "Fossil Fuels Leading the Clean Energy Revolution" will be held on 12 November 2007.

For 2008, a workshop in **Africa** on "Facilitating CCS Project Preparation and Management" is under consideration.

Outreach

All the above-mentioned events created a wealth of information that called for its broad dissemination. Hence, this brochure aims at informing a broader audience about the Committee's assessment of the present status of carbon dioxide capture and storage. The assessment is gauged against the dual need to control climate change and to advance on the road of economic development to eliminate poverty. As carbon capture and storage develops, "interim balances" rather than final conclusions are in order. Hence this 2007 Edition is the second in a series on the subject.

The Committee naturally concentrates on the papers generated under its auspices and listed in Annex A. Main references appear at the end of each chapter. Interested readers may wish to access papers with the help of the Annex.

Acknowledgments

I thank the members of the Committee, the authors, Barry Worthington, USEA and the editor Klaus Brendow for their valuable contributions to this document.

Barbara N. McKee
Chairman, CFFS Committee, WEC

Carbon Capture and Storage: A WEC Interim Balance – 2007 Edition

1. Needs

The development of carbon capture and storage (CCS) technologies is driven by the need to mitigate climate change resulting from economic development.[1]

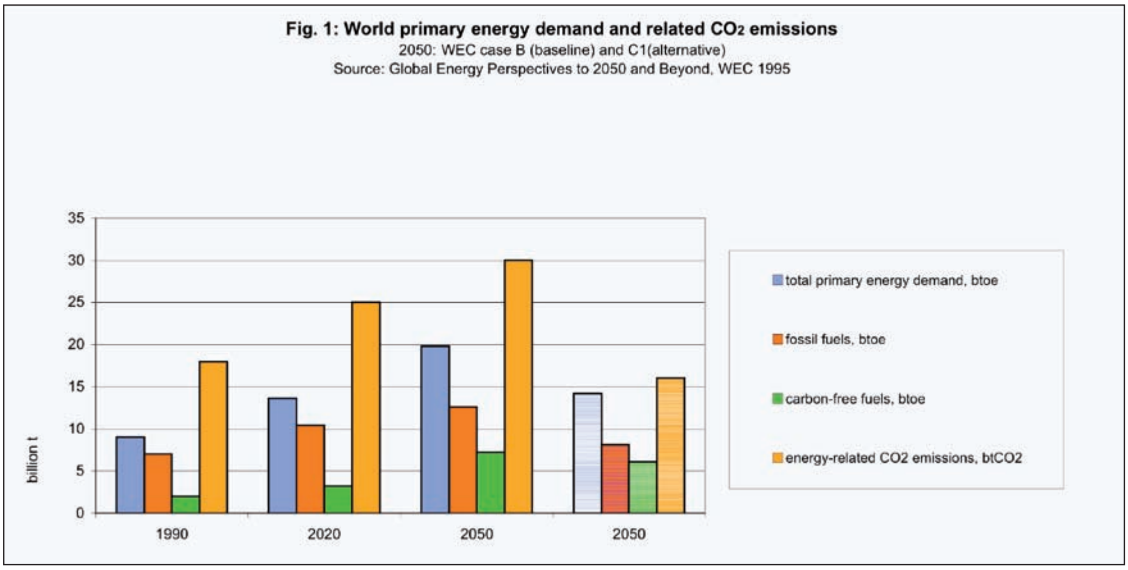
World energy demand: Fossil fuels have supplied nearly all of the world's commercial energy supply between 1900 and 1970, and still provide about 85% in 2007. They are predicted to continue to supply 82% in 2030 and 64% in 2050. In absolute terms, this expectation implies a significant increase in generation and use. Figure 1 demonstrates that under present policies fossil fuel demand will increase by 80% between 1990 and 2050 (Fig. 1, first column 2050). However, under alternative policies, increased efficiencies, substitution of coal by natural gas, promotion of non-carbon emitting sources or new technologies could constrain fossil fuel demand and related carbon dioxide emissions. In such a scenario, fossil fuel demand growth during 1990 – 2050 could be curbed (from 80% to 60%) and CO_2 emissions reduced (by 12%) (Fig. 1, last column 2050).

The world's energy system is huge. The introduction of new technology and systems on an annual basis can only incrementally change the entire system. Changes in energy sources and utilization technology take 25 to 50 years of penetration to change the entire system.

This is due to the extraordinary capital needs and the long lifetime of facilities and equipment, i.e. a low capital turnover. This is in part compensated for by rising efficiencies in energy production, conversion and transportation/transmission. However, today, there appears to be no feasible and viable alternative to fossil fuels to meet the twin developmental and environmental aspirations of nations, at least up to 2050. A faster decline of fossil fuel use would, in fact, absorb resources, which most, if not all, countries are unable to mobilize.

Related CO_2 emissions: Over the past 250 years, fossil fuels contributed 75% - 80% to the build-up of global CO_2 concentrations. From an average 23.5 Gt in the 1990s, annual CO_2 emissions from fossil fuel use rose to 26.1 Gt during 2000 – 2005 (IPCC 2007). Given that the carbon intensity of energy use (2.3 tCO_2/toe) is projected to fall only slightly, energy-related CO_2 emissions would increase to 40.4 Gt by 2030 under present policies (including implementation of the Kyoto Protocol) or to 34.1 Gt under alternative, more stringent policies (IEA 2006). Thus the Kyoto Protocol is not likely to have a significant impact on energy use and carbon dioxide emissions. One reason is that in the 2020s, emissions from developing countries (which are not subject to Kyoto reduction requirements) will overtake emissions from OECD countries and reach a share of 60% - 70% in 2050. Thus, it is important in the post- Kyoto process to find ways and means to involve these countries in the process of climate control, while safeguarding their progress on the road to development. Carbon capture and storage

[1] IPCC WG I, Climate Change 2007: The Physical Science Basis, Summary for Policy Makers, February 2007, p. 2 and 5: "The global increases of carbon dioxide concentrations are due primarily to fossil fuel use and land-use change … The understanding of anthropogenic warming and cooling… has improved…, leading to a very high confidence [>90 %] that the globally averaged net effect of human activities since 1750 has been one of warming."



will be an important option for many developing countries with fossil fuel sources (see Chapter 5).

Enabling development while mitigating climate change: Unabated increases in CO_2 emissions would obviously severely undermine any policy to mitigate climate change. This reality illustrates the need for at least precautionary measures, where feasible and cost-effective. In particular, mitigating impacts of fossil fuels can be accomplished first by improving combustion and end-use efficiency and replacing the direct use of fuels by potentially more efficient and less polluting electricity, and then by deploying CCS technologies.

Carbon capture and storage technology systems have the potential to achieve substantial reductions in global energy-related CO_2 emissions, if deployed at a significant scale, in a timely manner and at competitive costs needed to attract investments. The relevance of CCS in emissions reduction will increase over time, since the growth rates of global CO_2 emissions will likely exceed those of global energy demand due to projected declining shares of nuclear and hydropower. However, the currently high cost of CCS is seen as a serious impediment to its deployment and must be reduced.

FURTHER READING: Workshop in Erice: Hisham Al-Khatib; Workshop in Tallinn: Barbara N. McKee; other sources: IEA World Energy Outlook 2004 and 2006; IPCC Climate Change 2007, Summary report for policy makers

2. Technology

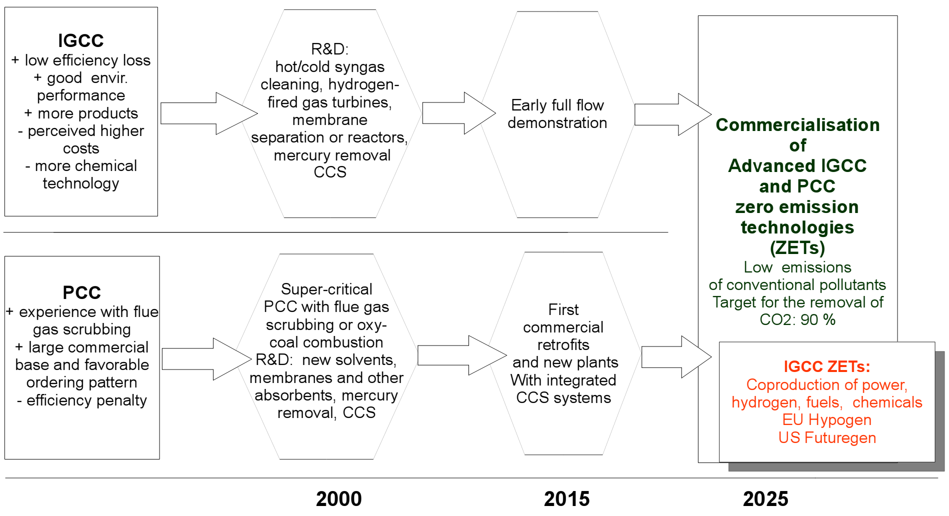
Carbon capture and storage technology captures carbon dioxide, then compresses and liquefies it, and finally transports it by pipeline or in tankers to safe and permanent storage in geologic formations. Some of this technology is proven and has been utilized by the oil industry for enhanced oil recovery. However, it has not been adequately demonstrated on large-scale coal-fired power plants as components of integrated clean energy systems. CCS technology for utilization at new, large power plants offers the greatest potential for CCS. CCS can also be used to mitigate CO_2 emissions from other large, stationary source industrial applications.

It should be noted that, in addition to geologic storage, research is also being conducted on terrestrial storage, mineral carbonation and options to convert CO_2 to beneficial products.

Carbon - Capture: Technology utilized with new large coal plants can reduce emissions by 80% – 85%. However, capture technologies require additional energy, which reduces overall efficiency. Earlier conversion loss estimates of up to 13% have been revised (IEA 2004) down to eight percentage points in existing coal-fired power plants, and to four percentage points in future integrated coal gasification combined cycle (IGCC) designs.

- Pre-combustion technologies convert coal or natural gas into hydrogen and/or ultra-clean diesel fuels while removing the CO_2. Inte-

Fig. 2: Coal-based power generation: main technology routes to carbon capture
source: adapted from John Topper, Colin Henderson, I EA Clean Coal Centre (2005)



grated coal gasification combined cycle (IGCC) technology is a promising approach because of the potential coproduction of electricity, fuels and chemicals (Fig. 2).

- Post-combustion technologies capture CO_2 from flue gases by chemical processes. Another option is oxyfueling, which modifies the combustion process by using pure oxygen instead of air to obtain highly pure CO_2. An attractive example is the oxygen-fired super-critical steam cycle (SCSC) in pulverized coal combustion (PCC).

Transportation: The transportation of CO_2 from the source point to the storage site is comparatively inexpensive but substantial infrastructure needs to be built. The mode of transportation (pipeline, tanker, truck, ship) of the CO_2 in gaseous, liquid or supercritical state depends on the pressures and volumes to be shipped, and on the distance to the storage site. A network linking various source points to a storage site would be an asset in regions where storage sites are not proximate to the sources. It remains to be determined how such networks can be sited, financed and operated. At present, 3,000 km of dedicated, land-based CO_2 pipelines are in routine operation (IEA 2004).

Storage: Potential underground depositories for CO_2 are plentiful. Global capacities in saline formations are estimated at 1,000 to 10,000 $GtCO_2$ and in depleted oil and gas fields at 1,100 $GtCO_2$. This corresponds to 90 – 480 years of current world emissions at 23 – 24 $GtCO_2$/year. Moreover, CO_2 can also be stored in abandoned or unminable coal beds or glacial clathrates. At present, more than 33 million tons of CO_2 are being captured and stored in over 70 projects (IEA 2004). Most are experimental, but there are large-scale commercial projects in operation in In Salah (Algeria), Weyburn (Canada), the North Sea (Sleipner), and forthcoming in the Barents Sea, Gorgon (Australia), Gassi Touil (Algeria) and other fields. As noted earlier, CO_2 is injected commercially into oil reservoirs for enhanced oil recovery (EOR) in many parts of the world.

Storage-related issues include a reliable assessment of storage capacity; an increased understanding of CO_2 trapping, migration and impact on ground water; and prevention, monitoring and remediation of leaks. Public concern about the risk of leaks needs to be addressed at an early stage by pointing to the present safe storage of millions of tons of CO_2 and the elaboration of designated regulatory regimes. Additionally, issues of short and long-term liability need to be discussed and settled.

Mineralization/adsorption of CO_2 in porous and thermally stable structures (silicates, shale, and salt) is still speculative and at the conceptual stage; however, this storage method may have great promise.

Research, development and demonstration (RD&D): The most pressing aims for RD&D are to reduce the present cost of 50 – 100 US$/$tCO_2$

(Figure 3) by at least 50%, enhance the integration of CCS in power plant designs, increase capture efficiency, upsize installations to demonstration and commercial scales, and achieve technical feasibility, operational reliability, safety, leak prevention, commercial viability and public acceptance. In view of the increase in emissions, RD&D must be accelerated. At this stage, different approaches are being developed, and prioritizing one approach over another is neither possible nor desirable. Rather, the near-term objective is to achieve a diversified portfolio of advanced technologies. The long-term vision is to operate near-zero emission multi-product power/chemical plants.

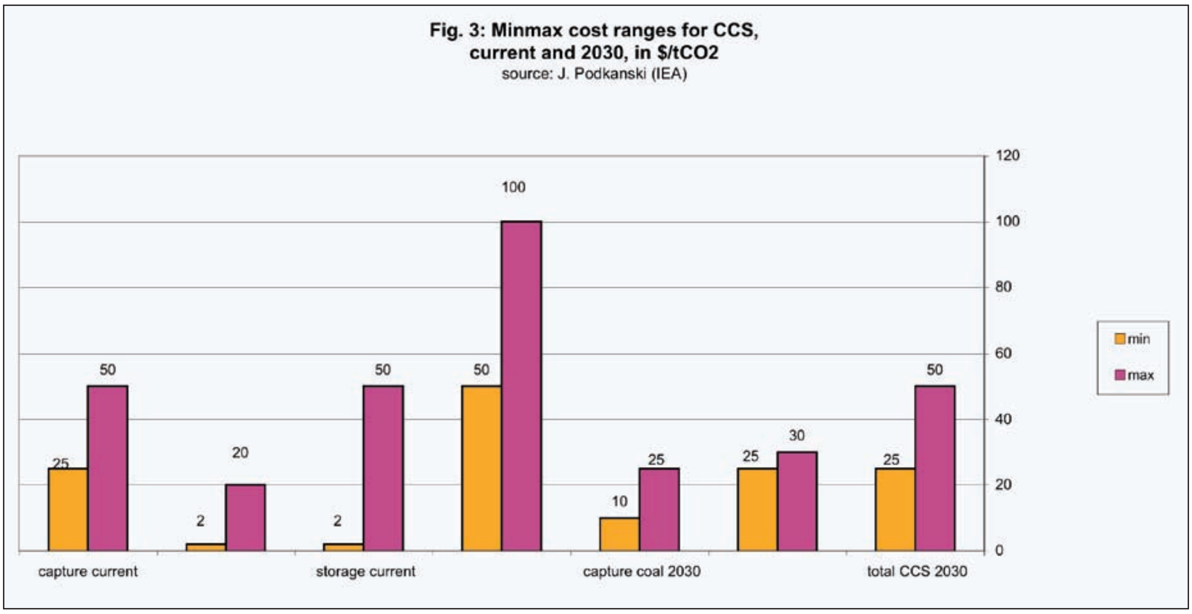
At present, some 110 RD&D projects are underway worldwide. They include the U.S. FutureGen and EU-Hypogen projects (both also producing hydrogen as a chemical feedstock or transportation fuel), the Canada-Clean Power Coalition and programs in Australia, Germany (Cooretec), United Kingdom, Norway, France, Italy, Japan and others (see Annex B).

International cooperation aims at information exchange and coordination through the Carbon Sequestration Leadership Forum, IEA Working Party on Fossil Fuels, EU Framework Programmes for Research and Technological Development, Intergovernmental Panel on Climate Change (IPCC), WEC Cleaner Fossil Fuel Systems Committee and others. Industry involvement in these efforts is essential. In the United States, industry funds about one-third of the cost of sixty research projects, which supplements US$200 million expenditure by the federal government.

The completion of several larger-scale demonstration plants (250 MW or larger) by 2015 is critical in order for CCS to gain market share and become widely deployed in the 2020 – 2030 timeframe.

FURTHER READING: Workshop in Erice: James Ekmann; Jacek Podkanski; David Sevier; Olav Kaarstad; Klaus Lackner; Suzanne Hurter; Workshop in Neptun: Ionel Illie; Henrik Noppenau; Robert Gentile; Gurgen Olkhovsky; Workshop in Tallinn: M. Uus; Workshop in Moscow: A. Tumanovsky, A. Silin, J. Topper, R. Gentile, P. Casero, A. Nakanishi; further sources: IEA Prospects of carbon capture and storage, Paris 2004, p. 13 – 21, 55; John Topper, Colin Henderson – IEA Clean Coal Centre: Advanced technologies towards zero emissions from coal-fired plant and their introduction in EU member States; lecture given at the International Conference on Policy and strategy of sustainable energy development for central and eastern European countries until 2030, Warsaw, 22/23 November 2005; for storage risks and remedies, see: Wolfgang Heidug, Geologische CO_2-Speicherung als Beitrag zum Klimaschutz: Potenzial, Sicherheit, Wirtschaftlichkeit, in Erdöl Erdgas Kohle 123 Jahrgang, Heft 1 (for English: www.dgmk.de)

The U.S. Department of Energy (USDOE) has set a goal to develop by 2012 fossil fuel conversion systems that offer 90% CO_2 capture with 99% storage at less than a 10% increase in the cost of energy services.



3. Comparative Economics

Costs: Electricity produced by generating plants equipped with carbon capture and storage technology is certain to be more expensive than electricity produced from coal-fired power plants today. This reality applies regardless of whether existing or new build plants are outfitted with these technologies. At present, IEA (2004) estimates the costs of CCS to range from US$50 to US$100/tCO_2. CCS increases capital cost for power plants by 30% - 100%, and electricity production cost by 25% – 100%. By 2030, costs might fall to US $25 –$50/tCO_2 (Fig. 3). Some experts expect this to represent an increase to consumers of one to two cents (US) per kilowatt hour, which represents a cost increase of approximately 10% to 20%. This may be much less in an IGCC plant (EC) (IEA 2009).

Competitiveness: The range of uncertainty regarding the cost of deploying CCS technologies makes comparison of competitiveness relative to other CO_2 emission reduction options speculative. This reality is a factor not only of the uncertainty of CCS costs, but the uncertainty of costs of other options.

Figure 3, from the IEA, illustrates the costs of CCS deployment today and in 2030, which assumes dramatic cost reductions. The current range of costs as well as the range in 2030 is significant.

Costs of CCS deployment are often compared to costs of new renewable or nuclear generation. Wide ranges of the expected costs of all these options have been developed by experts (see Table 1). Not surprisingly, at the low end of the range for CCS costs and the middle to high end of the range for the alternatives, CCS looks very competitive. However, at the high end of the CCS cost range and the low end of the alternative range, CCS looks very expensive.

Efforts to drive down the costs of all of these technologies are underway, and the success of these efforts will determine which technologies are most quickly and widely deployed. The reality is that the world will need to utilize all available technologies to their maximum economic potential to reduce emissions and, ultimately, concentrations of CO_2 in the atmosphere to levels scientists predict to be sustainable.

CCS competitiveness will be influenced by the proximity of sources to sinks and other local circumstances. Additionally, policy choices that favor one technology over others will have a huge bearing on the economics of CCS. Currently CCS is not afforded the benefits that renewables receive under some international agreements.

Perhaps most important, as noted earlier, the most economic and competitive options to improve energy efficiency are to reduce CO_2 emissions from power generation, petroleum production, refining, automobiles and industrial application.

TABLE 1: Comparison of CO_2 abatement costs for a range of renewables, fossil fuel and nuclear generation technologies in 2010

Technology	Abatement cost relative to coal (US$/tC), low to high	Abatement cost relative to natural gas (US$/tC), low to high
onshore wind	-63 to 125	-61 to 291
offshore wind	11 to 287	265 to 592
energy crops	108 to 200	240 to 447
nuclear	44 to 80	89 to 164
wave	277 to 597	572 to 1168
CCS retrofit on IGCC	24 to 45	101 to 188
CCS on new IGCC	54 to 101	151 to 282
CCS retrofit on coal	66 to 122	195 to 362
CCS on new coal	92 to 221	243 to 566

Source: World Coal Institute, ECOAL, July 2005, p. 6, similar: Euracoal, Coal industry across Europe 2005, p. 7.

Revenues: Most prospective CCS applications, for example deployment of technologies for utilization with a large coal fired power plant, represent costs to the plant owner - both capital costs and operating and maintenance costs. However, some circumstances represent revenue opportunities that may reduce net expenditures or perhaps in select circumstances cover the total cost of CCS deployment. For example, if the coal plant location is in proximity to oil fields, CO_2 could be sold to the oil field operator for use in enhanced oil recovery. Some estimates of the value of CO_2 in this application are US $55/+ CO_2 (IEA), while others range higher, US $40-200/+ CO_2 (Z. Khatib).

Other industrial uses of CO_2 exist and future applications are likely to develop. Future business opportunities may include managing CCS applications for others, such as hydrogen production, fuel cell/battery applications, emission trading and CO_2 storage.

In deploying technologies to reduce sulfur and nitrogen emissions, researchers and technology developers found ways to make useful products by capturing these pollutants at coal plants rather than placing these wastes in landfills. It is highly likely that the world's scientists will develop uses for carbon not currently envisioned, including storage as a solid.

Externalities: Similar to most advanced technologies, CCS will offer society benefits not easily quantifiable. Perhaps the most significant is the contribution to the global economy by maintaining the viability of coal as an option for power generation and industrial applications. Coal's viability represents not only a low-cost fuel supply, but also a corresponding number of generally high-income jobs (although this is not universal). For countries with coal resources and those importing from stable suppliers, coal utilization offers energy security value as well. In some circumstances CCS will reduce atmospheric pollutants such as NO_x, SO_2 and mercury. Resulting improvements are thus achieved in air quality, reduced negative health effects, improved soil fertility, and so on. By preserving the coal option, CCS deployment contributes directly to the three primary WEC goals of accessibility, affordability and acceptability.

Investments: Investment needs for the first generation of new highly efficient coal-fired power plants of about 250 MW with CCS (based on super-critical steam cycles or IGCC) are estimated at between US $500 million and $1 billion each. At least ten demonstration plants will be needed by 2015 to develop the technology and bring down costs to achieve a significant market penetration by 2030 (IEA 2004). Equipping 250 GW of new IGCC plants in the OECD region during the next thirty years with CCS would increase investments by 20% - 25% or US $350 - $440 billion. For 500 GW of combined cycle gas turbine (CCGT) plants, the incremental cost would be US $200 - $250 billion. This would increase investments in power generation in the OECD area by 20% - 25% (IEA WEIO 2003, p. 417).

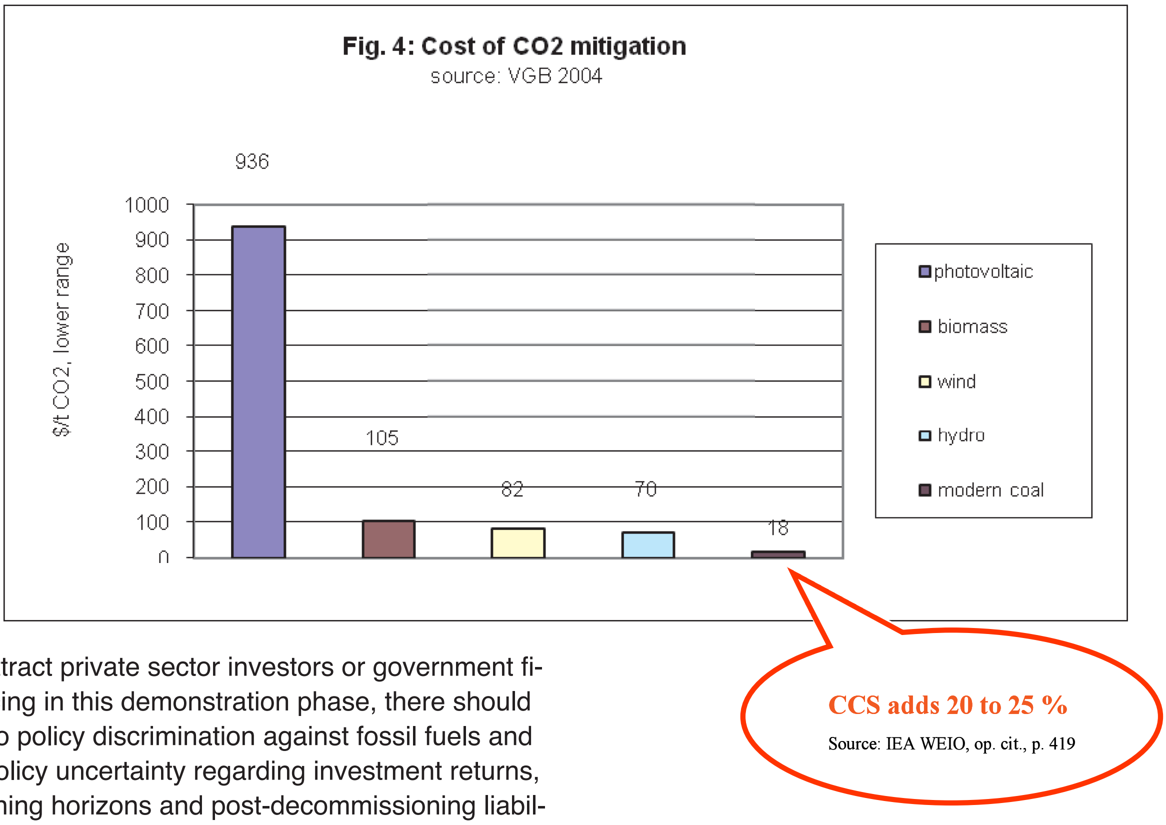


Fig. 4: Cost of CO2 mitigation
source: VGB 2004

To attract private sector investors or government financing in this demonstration phase, there should be no policy discrimination against fossil fuels and no policy uncertainty regarding investment returns, planning horizons and post-decommissioning liabilities. Market drivers and incentives for CCS deployment need to be in place. Today, these prerequisites are largely not present and there are a number of commercial, technical, legal and political uncertainties related to future deployment of CCS. While there may already be a number of demonstration plants by 2015 or so, the real commercial take-off depends on the commercial value of CCS – and eventually on incentives, if that market value is too low.

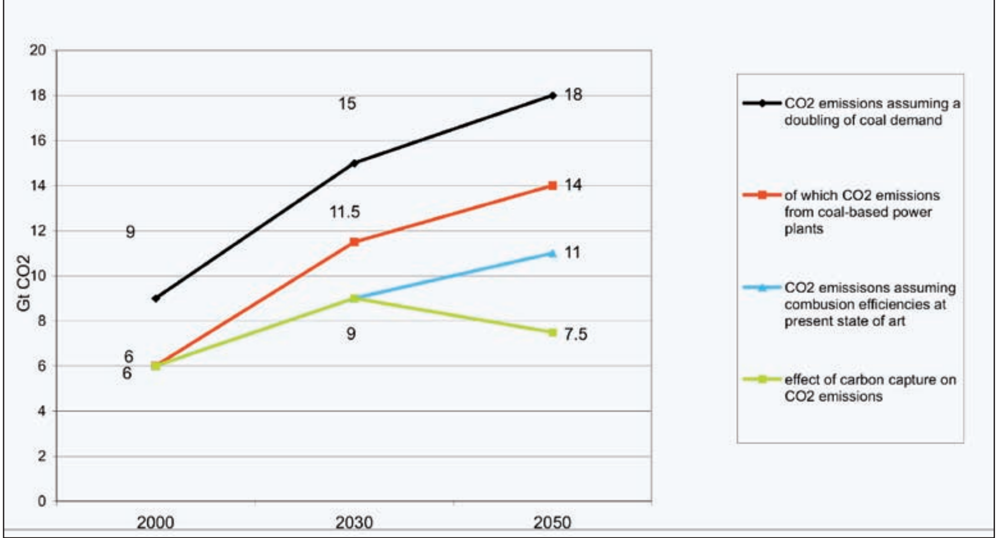
FURTHER READING: Workshop in Erice: Jacek Podkanski; Elena Nekhaev; Michel Lokolo; Workshop in Neptun: Michael Moore; Zara Khatib; further sources: IEA, Prospects for CO2 capture and storage, Paris 2004, p. 20; IEA, World Energy Outlook 2006, p. 75; Euracoal: Coal industry across Europe 2005, p. 6, 7; Barry Worthington: Funding for clean coal technologies (www.usea.org); for costs of storage, see also Wolfgang Heidug, op. cit.; on costs and health benefits: European Commission Staff working document on Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020, SEC(2006) 1722, p. 39-42; IPCC, Special Report on Carbon Dioxide Capture and Storage, 2005, p. 358; IEA World Energy Investment Outlook 2003, fig. 8.1

4. DEPLOYMENT

The drivers: The deployment of CCS depends on demonstrating the technology on a large scale, its competitiveness with other mitigation options, the policy and legal/regulatory framework (see Chapters 7 and 8), executive and board level management support, and adequate time to demonstrate integrated systems. Applicable in principle to all major fossil fuel-consuming sectors and emitters, CCS is most likely to be first deployed in coal- and natural gas-based power generation with high CO_2 concentration in the waste or flue gas in developed countries and in new facilities. Model calculations suggest that CCS systems will begin to be deployed significantly when the price for CO_2 reaches approximately US$25 to 30/t$CO_2$ (IPPC), provided CCS costs have been brought down to at least this level. Nonmarket-based policies also could accelerate CCS deployments as noted in Chapter 2.

The potential: The potential for CCS deployment could be significant. For entire energy systems, CCS deployment may be less significant, limited by system replacement cycle and possibly competition between mitigation options. The IEA (2004) suggests that by 2050, and assuming a carbon penalty or carbon price of $50/t$CO_2$, CCS could reduce total global energy-related CO_2 emissions by half

Fig. 5: Global CO2 emissions from coal-based power plants assuming higher efficiencies and carbon capture



compared to a scenario without such a penalty (Chapter 6). If one looked only at coal-related emissions instead of total emissions, the percentage reduction could be much higher. Unless deployment is accelerated, it will take decades to achieve widespread deployment of CCS. The good news is that most energy facilities operating in 2000 will be retired or subject to major modification by 2050. In the short term, there is the risk that out of the 1,391 GW new coal plants forecast worldwide by 2020, almost 86% will likely be built with conventional technology (Hawkins). These units will likely still be operating in 2050.

Coal-based power generation: Figure 5 illustrates the combined effect of CCS and efficiency improvements on CO_2 emissions from global coal-based power plants. These generate about 80% of the 18 $GtCO_2$ of all energy-related CO_2 emissions in 2050. In this scenario, net efficiency gains (22%) and CCS deployment (30%) would reduce CO_2 emissions from coal-based power generation in 2050 from about 14.4 $GtCO_2$ to 7.5 $GtCO_2$. However, emissions remain significantly above present levels.

There is an additional potential for reducing CO_2 emissions from further advances in combustion efficiency, faster CCS technology development, earlier international deployment, aggressive plant modernization, improved CCS conversion efficiency, faster market penetration, and co-combustion of biomass and coal. By contrast, CO_2 abatement would be less if the relative cost reductions of coal combustion and CCS fall below expectations, which might result from delays in RD&D. Indeed, more may need to be done. Depending on the international consensus of what is "sustainable," the amount of unabated CO_2 emissions in this scenario (7.5 $GtCO_2$) or parts thereof could be considered unacceptable from a climate change mitigation policy point of view.

Natural gas-based power generation: Natural gas has a competitive advantage over coal in regard to CO_2 emissions. However, reliance on imported natural gas increases energy security concerns and only partially reduces climate change concerns, including the following:

- CO_2 emissions during combustion are lower (but there are potential methane emissions upstream).
- Combustion efficiencies are higher, even taking into account efficiency losses during capture.
- CCS is already used for natural gas production: CO_2 is separated from produced natural gas streams and reinjected in underground formations for permanent storage. Presently a significant CO_2 storage operation takes place in the Norwegian natural gas field Sleipner.

Switching from coal to natural gas fuel, regardless of size, would continue to contribute to the global mitigation of energy-related emissions. Local ex-

Figure 5 assumes a doubling of global coal demand through 2050. This corresponds to an annual growth rate of 1.4%, compared with the historical rate of 2%. Coal use in power generation and related emissions between 2000 and 2050 are estimated to grow faster, by 1.8%/year. Average world combustion efficiency for coal plants is assumed to rise from 32% at present to the present state of the art in 2050: 43%. CCS conversion losses are assumed to decline to 4 percentage points, which limits efficiency growth to 39% in 2050 (IEA 2004). The market penetration of CCS by 2050 is estimated at 30% (IEA 2004).

periences in the United Kingdom, where liberalization of electricity markets has resulted in a considerable expansion of natural gas use in power generation, show a correspondingly significant reduction in CO_2 emissions. However, in the United States, climate policy must be linked with increased access to domestic reserves that are currently off limit to production.

This trend, even if attenuated by rising gas prices and a growing price competitiveness of coal, will be an important driver for a cleaner fossil energy system globally, especially before CCS is widely available for deployment. IEA projects that global natural gas consumption will increase by 68% during 2004 - 2030 (coal: 60%) (2006). This translates into a projected faster growth of gas-based power generation (3.2%/year) compared with coal-based plants (2.9%/year). However, coal would remain first in terms of capacity (33%) compared with gas (31%) and oil (5%). This scenario does not see CCS playing a notable role before 2030 (IEA). By contrast, a US$50/t CO_2 penalty or carbon price would stimulate CCS penetration and thus coal combustion. In this case, by 2050, 69% of the capacity of all power plants equipped with CCS would be on coal units, 23% on gas units and 8% on dedicated biomass (IEA 2004).

Oil-based power generation: In 2004, oil generated 7% of world electricity generation and is expected to generate 3% in 2030 (IEA 2006). In absolute terms, the decline is less impressive – from 1161 mtoe in 2004 to 940 mtoe in 2030. There are, however, many countries where oil use is still important. For example in Mexico oil still accounts for 40% of fossil fuel power generation, down from 90% some time ago. Generally speaking, in most countries oil power plants are the oldest and least efficient. Their main competitor is natural gas. Some natural gas units have dual-fuel capability. Also, some small generators use gasoline, diesel or kerosene. These offer no CCS options and the only climate mitigation strategy is to not use them.

Management issues: Experience from companies leading in emission control suggests that CSS must be an integrated part of medium- and long-term GHG emission control strategies. Some companies see CCS as a step on the road toward a hydrogen economy. Such an approach requires strong involvement at the central management level and the integration of CCS into corporate business plans.

Cooperation with other stakeholders, through national and international partnerships and conventions, is another facet of management involvement to educate the public and clarify issues that are potential barriers for widespread CCS deployment. Relations with authorities and policy makers are important to carry the message that CCS policies should take into account the project-specific nature of CCS installations, be predictable, transparent and cost-effective; promote RD&D; and reduce uncertainties such as the regulation of decommissioning of installations (post-closure liability).

Management should also consider business opportunities associated with its CCS action plans (EOR, emission trading, hydrogen, fuel cells, and storage services). Results in terms of reduced CO_2 emissions and reinjections into depositories should be recorded in standardized GHG emission accounting systems to enhance comparability and credibility. All strategies to reduce greenhouse gas emissions are likely to eventually be subject to third-party audits.

FURTHER READING: Workshop in Erice: Elena Nekhaev; David D. Hawkins; Arthur Lee; Jacek Podkanski; Workshop in Neptun: Dumitru Manea; further sources: IEA: Prospects for CO_2 capture and storage, Paris 2004; IEA: World Energy Outlook 2006, p. 258, 492, 493); IPPC Special Report on carbon dioxide capture and storage, p. 11: K. Brendow: Sustainable World coal mining and use: perspectives to 2030, lecture given at the International Conference on Policy and strategy of sustainable energy development for central and eastern European countries until 2030, Warsaw, 22/23 November 2005; on coal CCS, see: European Commission Staff working document on Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020, SEC(2006) 1722

5. Developing Countries and Transition Economies

Today, 1.6 billion of the world's 6.2 billion population have no access to electricity. No availability of commercial energy results in lower life expectancy, lower school enrollment, reduced education opportunities, poorer health - particularly in children, and dirtier drinking water. "Lack of energy in developing countries and regions is a planetary emergency" (Wilson).

The dilemma: Enforcing a strong carbon discipline and developing alternative energy systems presupposes a broad public awareness of the risk of climate change and support for mitigation policies. It also requires a capacity at the government and industry levels to comprehend issues, elaborate solutions and shoulder a considerable cost. These are high hurdles for developing countries (see Box) and transition economies. While developing countries have not committed themselves to CO_2 reduction targets, the transitional economies did, but their emissions will remain below the agreed upper limit for a number of years, depending on their rate of economic growth.

For the world as a whole, the problem is compounded by the fact that most of the future increases in CO_2 emissions will come from developing countries. Their share in global CO_2 emissions will rise from 39% in 2004 to 52% in 2030. As of 2012, their emissions will exceed those of the industrialized world.

Financing the deployment of CCS to developing countries

From a global perspective of mitigating climate change, financing the deployment of CCS to developing countries is a priority, due to the growing contributions of these countries to global CO2 emissions. How can the deployment of CCS in developing countries be financed?

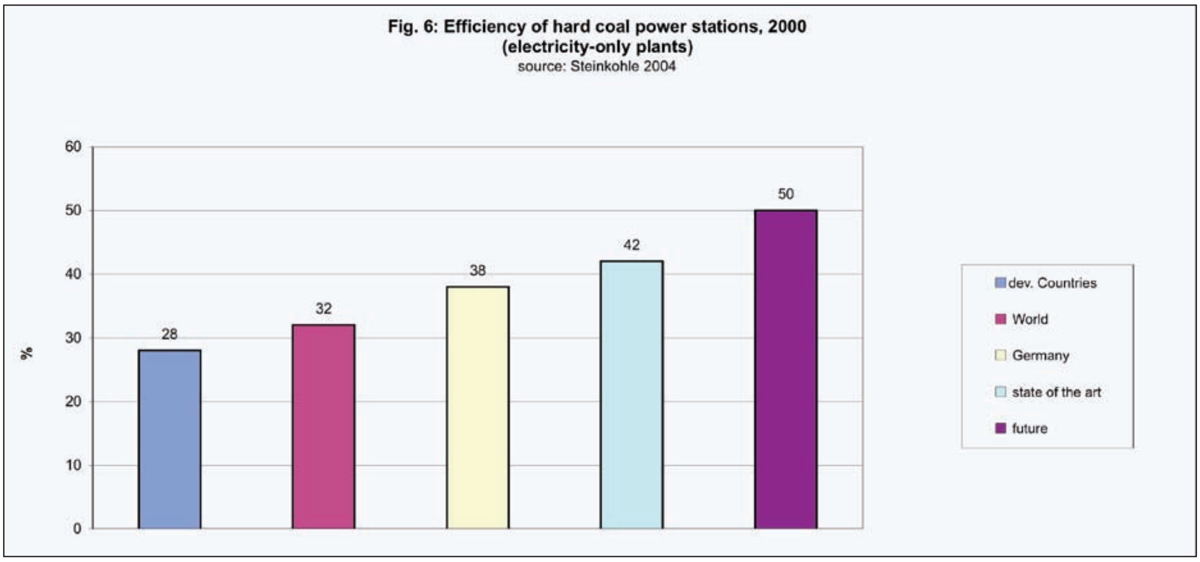
How much? During 2015-2030, fossil fuel power generation capacity in the developing countries may increase by 592 GW, according to the IEA (WEO 2006) alternative scenario. These plants would produce an additional 1.4 Gt of CO2, which corresponds to 56% of the increase of world energy-related CO2 emissions (2.48 Gt)!

Assuming that deploying CCS in fossil-fuel power generation in the developing countries will, as of 2015, cost 20 to 30 US$/tCO2, the total additional cost of deploying CCS to mitigate the above mentioned 1.4 Gt CO2 would be US$28 to $42 billion during 15 years. As a result, world CO2 emissions would rise much less: from 31.6 Gt in 2015 to only 32.7 Gt in 2030, instead of 34.1 Gt. There is no other single technological option that would cut the growth of global emissions by more than half, while enabling development and energy security.

How? Can the world community afford to inject on average US$2 to $3 billion per year into technology transfer? The consensus of opinion is yes - the more so, if national and regional carbon trading schemes were encouraged and compatible, creating a significant carbon price signal worldwide, [1] and if in the extended EU emission trading system and in the post-Kyoto process, CCS projects were eligible for CDM and JI projects, which is presently not the case. In this case, the above-mentioned public funding needs could be reduced.

For their part, the developing countries "must develop legal policies on copyright, intellectual property and dispute settlement and provide new incentives for private investment" (WEC Statement 2007: The Energy Industry Unveils Its Blueprint for Tackling Climate Change, London, 2007).

[1] Stern Review, The impact of climate change, Executive summary, London 2007, estimates the cost of "no action" with regard to climate change over the next two centuries at an average reduction of global per capita consumption of at least 5 to 20%, particularly in developing countries. This compares with a cost of emission reduction consistent with stabilization at 550 ppm of on average 1% of GDP (p. xiii). (http://www.hm-treasury.gov.uk/media/8AC/F7/Executive_Summary.pdf)



This trend is driven by high economic and population growth, rising per capita energy consumption and a high carbon-intensity of the fuel mix. This emphasizes the fact that a global carbon constraining policy, without the involvement of developing countries, will miss the goal of mitigating climate change. However, developing countries could utilize CCS once these technologies are mature and viable. There would be a time lag in adopting CCS in developing countries, but by 2050 almost half of the capture activity could be in these countries, particularly China and India (IEA 2004).

Enhanced recovery of oil and gas: The utilization of CCS to mitigate climate change will be easier for oil and gas producing countries. They can reduce part of their rising CO_2 emissions by capturing CO_2 and injecting it into some oil and gas fields. This raises both well productivity and profitability, as the value of CO_2-EOR can be as high as US$40 to 200 t/$CO_2$. Moreover, CO_2 injections could liberate gas from enhanced gas recovery (EGR) operations for residential use, LNG (liquefied natural gas) or gas-to-liquids production. However, at present, EOR contributes only 4% or 160 million tons of oil equivalent to world oil production, of which 7% or 11 million tons of oil equivalent is via CO_2 injection (but more in the United States) (Z. Khatib).

The Middle East could see a favorable development as gas flaring can be significantly reduced. And while unrelated to CCS, it reduces greenhouse gas emissions of methane. Moreover, fossil fuel-based electricity generation during 2004 - 2030 is expected to increase by 150%, while CO_2 emissions would rise by only 108%. This difference reflects the expectation that CO_2 injections will play a growing role. Several feasibility studies on CO_2-EOR are underway in Dubai, Abu Dhabi, Qatar and Libya, with first demonstration plants expected toward 2015. A regional CO_2 grid covering Qatar, the United Arab Emirates, Saudi Arabia and Bahrain is on the drawing boards for operation around 2020.

CO_2-EOR or EGR are not primarily driven by concerns about climate change but by resource constraints. This should not demean their role in attenuating the growth of CO_2 emissions. Moreover, EOR/EGR can help build a CCS capacity in terms of skills and infrastructure to ultimately address the issue of capturing CO_2 from fossil fuel plants in large quantities and storing it on a long-term basis. Evolving from EOR/EGR to CCS with long-term storage requires developing countries and economies in transition to design an approach based first on raising the efficiency of power generation and, second, preparing for CCS deployment. It is in the interest of electric utilities and hydrocarbon producers to take a lead in deploying CCS.

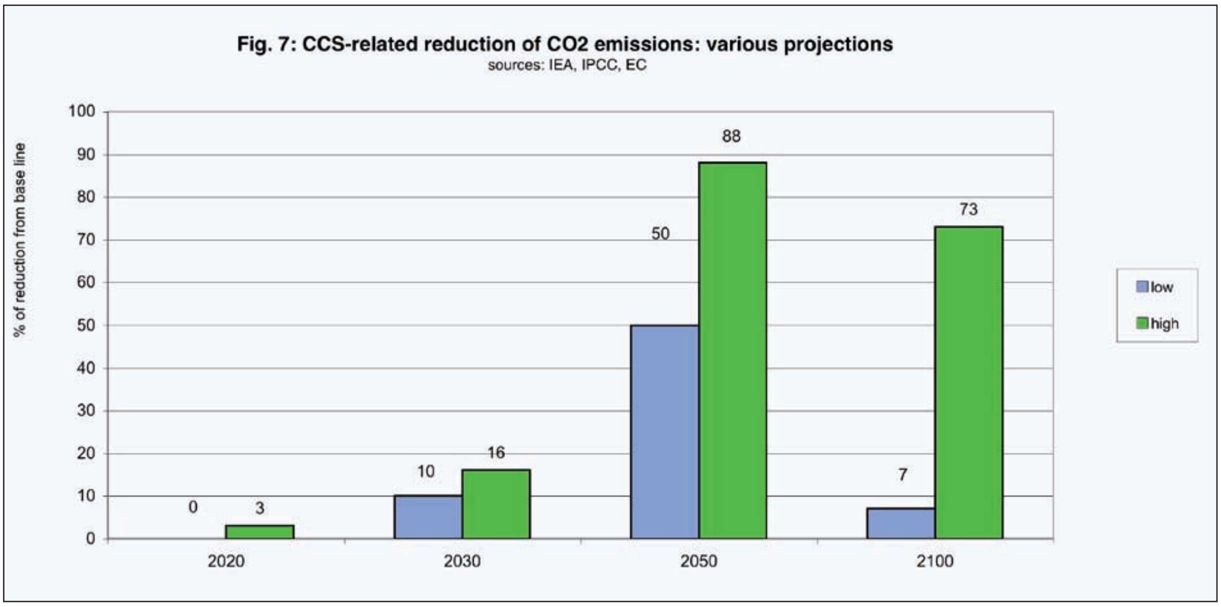
Efficiency first: Raising the combustion and plant efficiency of thermal power generation offers a significant potential for savings of fuel, emissions and cost. This is true the world over, but particularly with regard to coal-based power generation in developing countries, where coal is 36%, oil 15% and natural gas 21% of installed generating capacities (2004).

At present, average coal-based power generation efficiency in developing countries is perhaps at best 28% (lower rates are quoted), while state-of-the-art generating efficiencies are 42% to 45% (Fig. 6). Raising the efficiency in developing countries to present state of the art during the next two or three decades would imply a reduction of specific CO_2 emissions from coal-based power stations by perhaps 40% – 45% (taking into account CCS conversion losses). This would be a significant contribution to mitigating climate change and, in fact, the single most cost-effective supply-side mitigation option.

CCS next steps: At the same time, and with the strong support of developed nations and the international CCS community,[2] developing countries and transitional economies could and should prepare themselves for the CCS option, by:

- Developing a knowledge and technology base as a foundation for technology transfer;
- Joining international CCS networks and partnerships;
- Promoting a new international clean technology fund;
- Creating regional alliances and energy research and investment funds;
- Seeking financial assistance for
  - Energy and CCS RD&D; –
  - Studying the concept of "applied" CCS for developing countries;
  - Bringing down the cost of clean electricity for the poorest of the poor in order to make "less clean resources," e.g. animal dung, less attractive;
- Designing power systems and new plants so as to facilitate the later retrofit with CCS ("capture-ready");
- Mapping underground storage capacities;
- Participating in the licensing and manufacture of low-cost components for CCS equipment;
- Considering joint ventures in CCS;
- Promoting CDM (clean development mechanisms), IBRD and GEF (Global Environmental Facility) funding for CCS investments and emission trading;
- Protecting intellectual property and trade secrets, in particular through nondisclosure agreements;
- Undertaking studies of public attitudes toward CCS and addressing concerns referring to different technologies of sequestration, alternative use of underground storage (storage of natural gas, etc.), the risk of CO_2 leakage from underground storage, and the availability of laws and regulations to secure health and safety;

[2] It will be recalled (see Preface) that the WEC CFFS Committee held workshops in Colombo and Jordan and is considering an event in Africa.



- Stressing the potential of CCS as an important option along with others for economic development and reduced energy poverty. The message: what is needed is a "low carbon world" or even better, a "low emissions world," and not a "low fossil fuel world."

FURTHER READING: Workshop in Erice: Barbara McKee; Hisham Al-Khatib; F. Zancan; Hilal Raza; Richard Wilson; Elena Nekhaev; Workshop in Tallinn: Anita Kvesko; K. Brendow; further sources: WEC: Sustainable global energy development – the case of coal, London 2004, p. 8; IEA, World Energy Outlook 2006, p. 81; Zara Khatib: Opportunities for CCS in the MENA region; role of WEC in accelerating its development and implementation; lecture given at the CFFS meeting held in London on 12. 12. 2006; Georg Rosenbauer, in WEC: The World Energy Book, issue 3; IEA, World Energy Outlook 2006, p. 513

6. Perspectives

Synthesis: Projections of present (and alternative scenarios) policies suggest that CCS will play a significant global, climate-relevant role after 2020. Its market penetration depends on adequate technology demonstration, on the price for carbon (or incentives) exceeding the cost of CCS systems, and on the cost of other mitigation options. The benchmark is presently estimated at around US$25 to 30/t$CO_2$ (€ /t19 – 23). This implies that present CCS costs must be brought down by half. The greater the difference between CCS cost and carbon prices, the more significant the role of CCS becomes. Its maximum effect by 2050 is estimated at around 50% of world energy-related CO_2 emissions (IEA 2004). This is the minimum goal of the EU. More could be attained for coal-based CCS (92% in the European Union) (Fig. 7). A 50% reduction would stabilize global energy-related CO_2 emissions and later, concentrations, while allowing a 2° C increase in global temperatures. However important such a reduction of CO_2 emissions may be, climate mitigation measures should also cover the other greenhouse gases, particularly methane and should be portfolios of various mitigation measures, of which CCS would be an important – but not alone sufficient – component.

Intergovernmental Panel on Climate Change: Model calculations estimate the economic cumulative reduction potential of CCS during 2000 - 2100 at between 220 and 2200 GtCO_2 compared to cumulative emissions of 3000 Gt. The range of reduction (7% to 73%) reflects the differing stringency of the assumed mitigation policies, with 50% being the long-term goal for 2050. The higher estimate implies stabilization of CO_2 concentrations at around 450 ppm. IPCC suggests that CCS systems will begin to deploy significantly when the price for CO_2 reaches approximately US$25 to 30/t$CO_2$. In most of its scenarios, the role of CCS increases over time.

CCS would be a low-cost reduction option accounting for 15% - 85% of a least-cost mitigation strategy; CCS is expected to reduce the costs of stabilizing CO_2 concentrations by 30% or more (see also Fig. 3 and Table 1).

Fig. 7: Explanations and sources: 2020: refers to OECD region = world, IPCC Special Report on carbon dioxide capture and storage, 2005, p. 358; 2030 and 2050, low: reduction of global energy-related emissions compared with a base line without CCS (IEA WEO 2006, p. 258 and IEA 2004, p. 101); 2030 and 2050, high: reduction of emissions from EU coal power plants compared with 2005 (EC Sustainable power generation from fossil fuels, SEC (2006) 1722, p. 71); 2100: average 2000-2100 reduction of global energy-related emissions compared with a baseline without CCS (IPPC 2005, op. cit., p. 350, 354)

International Energy Agency: IEA foresees no notable contribution of CCS in its reference and alternative scenarios for 2030. However, in its more stringent "Beyond the Alternative Policy Scenario" (BAPS), IEA explores the conditions for CCS to bring global energy-related CO_2 emissions in 2030 (26.1 Gt) down to the 2004 level. In this case, IEA attributes to CCS proper (excluding efficiency gains) a savings potential in power generation of 2 $GtCO_2$ or 11% of global emissions from power and heat plants (IEA 2006). However, this excludes gains of 1 Gt due to efficiency improvements in power plants. For industry, BAPS projects a reduction of 1 Gt due to CCS and efficiency gains. As CCS would be introduced only in highly efficient facilities, the combined effects of efficiency gains and CCS in power generation and industry could be estimated at about 4 Gt in 2030, or 10% of global energy-related emissions compared to the alternative and reference scenarios (IEA 2006).

The reduction in 2030 could be 4.6 Gt or 18% of the BAPS scenario in case of a CO_2 emission penalty or market price of \$50/tCO_2. With this latter assumption and in comparison with a scenario without such penalty, CCS could reduce emissions in 2050 by about 27 to 33 $GtCO_2$ or 50%, down roughly to the level of 2000, thereby stabilizing emissions and concentrations (at 550 ppm). This is deemed to be the maximum obtainable from CCS for global energy-related emissions (IEA 2004). The percent reduction would be higher for coal-based CCS (EC) (Fig. 7).

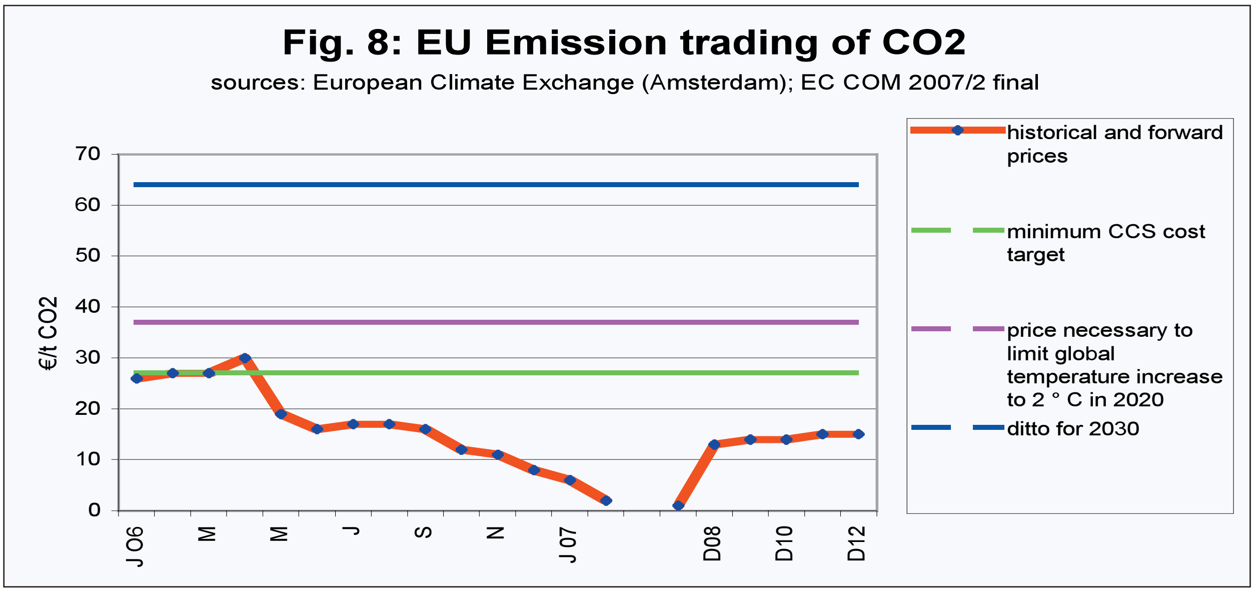
European Commission: If CCS-supported policies were introduced in the European Union (EU), CCS could be used systematically in new coal plants and retrofits by 2020; by 2030, 25% of coal-fueled power generation capacity could be based on CCS, with a resulting reduction of CO_2 emissions from coal plants by 16% in comparison with 2005. By 2050, 100% of coal-based capacity would be CCS-supported and CO_2 emissions 88% lower. The objective of the EU is to limit global temperature increase to a maximum of 2°C, which implies a reduction of global greenhouse gases in 2050 by 60 – 80% in developed countries, compared with 1990 (EC).

FURTHER READING: IPPC, Special Report, already quoted, p. 354 (www.ipcc.ch); World Coal Institute, Newsletter ECOAL, October 2005; IEA, World Energy Outlook 2006, p. 258 and Annex, p. 493; IEA: Prospects for carbon capture and storage, Paris 2004, p. 101, 108, 120; further sources: EURACOAL: Third Coal Dialogue, Brussels, 18 October 2006, paper presented by Ioannis Galanis (EC DG for Energy and Transport) on: Communication on sustainable coal: impact assessment and communication outline, p. 12 and 71; on EU emission trading: http://ec.europa.eu/environment/climat/emission.htm

7. Policies

The deployment of CCS can be greatly supported by nondiscriminatory and affirmative policies.

Climate policies: Implementation of CCS will ultimately depend on the consensus regarding the urgency of climate protection policies. While there is



some agreement on the principles of remedial action (enhanced energy efficiency, promotion of non-carbon energy sources, fuel substitution), views differ on timeframes, institutional processes and means (incentives, penalties).

These uncertainties about the scope, urgency, timing and institutional support of climate control policies are reflected in the recent decrease of the price for a ton of CO_2 at EU emission trading exchanges (Fig. 8). These uncertainties need to be reduced to encourage investors.
At this early stage of CCS development, policies should focus on technical progress, rather than on intervention in markets and customer choice.

Present climate policies are inadequately balanced on two accounts. There is first the sharp focus on CO_2. In reality, during 1980-1990, carbon dioxide contributed only 55% to the increase in radiative forcing. Secondly there is the focus on power generation. However, only 29% of global CO_2 emissions and 41% of energy-related global CO_2 emissions stem from power generation (20% from transport, 18% from industry, 13% from the residential sector and services, 8% from others). This imbalance needs to be replaced by considering all greenhouse gases and all sectors of energy consumption so as to avoid inter-fuel and inter-sectoral distortions.

Moreover, the focus on emissions at the electricity generation stage takes into account only part of total emissions, omitting emissions prior and subsequent to that stage. A full life cycle analysis of emissions is required to determine the global impact of individual energy projects. If life cycle analysis is used and other greenhouse gases (GHG) are also taken into account, electricity generation from coal, gas or oil would show similar levels of GHG emissions. The projected increase in annual GHG emissions from coal between 2001 and 2025 of 1.1 billion tons of carbon equivalent is less than that projected for natural gas (1.3 billion tons) and oil (1.5 billion tons).

- The CCS option should be integrated into energy policies, emission trading schemes, energy balances, scenarios and models in order to avoid discrimination against clean fossil fuel use. CCS should be part of a portfolio of technology and strategies. It is acknowledged that the quantification of its market penetration and emission reduction potential is difficult at this stage – as is the quantification of the contribution of other mitigation options.
- Institutionalized cooperation between all stakeholders - government, industry and the public at large – creates mutual understanding and confidence, hence promotes solutions.
- Developing and transitional economies should exploit the enormous potential of improved combustion and increased plant efficiency as a first option. Internationally, they should be part of networks established for developing

CCS and promote the eligibility of CCS projects as clean development mechanisms (CDMs) and for GEF funding. Nationally, they should build human and technical capacity to deal with CCS and consider interim measures such as plant designs, which allow the later retrofit with CCS (see Chapter 5).

Public trust and support must be achieved and retained. Public concerns over issues such as leakages from CO_2 storage must be addressed. The benefits of CCS in terms of mitigating climate change and allowing fossil fuels to facilitate further economic development and reduction of energy poverty must be recognized. A EU inquiry into the public acceptance of CCS showed that so far less than 10% of the European population had heard of CCS; of those, only 13% felt positive about it right away – this increased to 55% following an explanation of the concept (Euracoal, op. cit.).

Energy policies: In a balanced all-energy perspective, fossil fuels need to be recognized as the major driver of economic development for decades to come. The potential of cleaner fossil fuel systems must also be recognized. No source of energy should be idolized or demonized. All will be needed. CCS should be treated on an equal footing with other mitigation options (as noted earlier, in CDM, emission trading, GEF funding).

CCS policies: The lag time inherent in deploying new technologies as components of energy systems calls for an early definition of the role of CCS. Plans concerning CCS should cover the entire system, from emissions to sinks and trading. CCS policies should balance public and private interest in safety, health, the considered use of natural resources and the profitability of CCS operations.

- CCS policies should offer investment certainty for CCS projects. They should be predictable, transparent and low-cost, enabling market forces to unfold. Flexibility within a given framework is essential, as CCS projects are site-specific.
- CCS technology policy should be open-ended, avoid the early selection of "winners" and be long-term oriented, including toward the development of the hydrogen economy.
- Policies and regulations should take into account the entire life cycle of CCS investments, including:
  - Assessment and approval of CCS projects
  - Access and property rights (CO_2 ownership)
  - Operation of CCS facilities
  - Transportation issues, including across borders
  - Monitoring and verification of storage
  - Decommissioning
  - Sharing of post-decommissioning liabilities

- Best practices should be shared internationally.
- The applicability of maritime conventions to CO_2 storage and other legal aspects need to be reviewed.
- Expenditure in public energy RD&D**,** which had been cut by half in OECD countries over the last few years, should be reconsidered in the light of the changes that are taking place. Given the importance of fossil fuels for development and the environment, RD&D in cleaner fossil fuels systems, and in particular in CCS, should be accelerated and internationally coordinated.
- The roles of the Carbon Sequestration Leadership Forum (CSLF), the IEA and WEC are recognized.
- Pilot studies should explore the "capture-ready" design of conventional plants.
- If in the early deployment phase, the carbon value and, hence, the commercial value of CCS projects or components is insufficient, incentives should be considered (such as early mover incentives, faster depreciation allowances, etc.).
- The fair comparison of CCS technology in Greenhouse Gas Emission inventories requires standardized statistics.

FURTHER READING: Workshop in Erice: Steve Tantala; Arthur Lee; Jacek Podkanski; David Hawkins; Elena Nekhaev; Klaus Lackner; Workshop in Neptun: Peter Mak; further sources: IEA Legal aspects of storing CO2; Paris 2005; IPPC: Climate change – the IPCC scientific assessment, 1990, figures 7; IEA World Energy Outlook 2004, table 2.3; IEA, World Energy Outlook 2006; Euracoal, op. cit.; EC Limiting global climate change to 2°, COM (2007) 2 final; Nicholas Stern, The Stern review on the economics of climate change (www.hm-treasury.gov.uk)

8. LAWS AND REGULATIONS

The timely deployment of CCS technologies worldwide is preconditioned on affirmative national legal and regulatory frameworks, an update of international conventions and treaties, reliable (private) contractual arrangements and an equal playing field for CCS.

Solutions, however partial and inconsistent they may be, are emerging in developed and hydrocarbon-producing countries. They seek a balance among private and societal objectives, market mechanisms and policy interventions, risk avoidance and risk management, and national sovereignty and international convergence. Emphasis at present is on enabling the uptake of CCS projects, particularly those enjoying an enhanced hydrocarbon recovery bonus.

Current discussions:

- Recognize the role of CCS and consider adapting national and international legal frameworks and conventions (removal of technological and cost barriers, pro-active actions);
- Address longer-term concerns (storage, post-operational ownership of sites and CO_2 and related liability for leakage);
- Address the protection of intellectual property;
- Consider equivalence of treatment between CCS projects and other mitigation options regarding emission trading, clean development mechanisms, joint implementation and GEF funding;
- Encourage conditions for the (later) deployment of CCS in developing countries; and
- Build social acceptance of CCS.

By 2008, matters should have been greatly clarified, since the G8 Summit of Gleneagles in 2005 had mandated the IEA and CSLF to submit recommendations to the G8 Summit in Japan in 2008. Broadly, this timing and focus of efforts seems to fit the longer term calendar of launching CCS power plants with long-term storage. In any case, technical progress in CCS and regulatory advancement need to be correlated.

Adapting national legal and regulatory frameworks: Some countries likely to use CCS in the near term have well-established legal and regulatory regimes for the hydrocarbon and mineral industries, and for environmental protection and waste disposal. These countries may not have to substantially change those regimes to apply to CCS projects. Other countries that do not have such legal and regulatory regimes could benefit from experience acquired elsewhere.

Any such regimes have two objectives: protecting the public with regard to health, safety, financial and environmental risks associated with CCS, while enabling the development of CCS as part of a climate change mitigation portfolio. The issues include the following:

- The definition of CO_2 as an industrial commodity (used for enhanced recovery) or as a substance to be stored permanently. This determines the type and jurisdiction of regulations governing CO_2 injections;
- Criteria for site selection and use, in particular assessing the risk of leakage and related risk management. Data collection, monitoring and verification must be sufficiently accurate to meet international inventory standards.
- Licensing of activities and sites;
- Ownership of, and access to, CCS injection sites and storage space; arbitration of conflicting rights between the CCS and hydrocarbon and mineral industries;

- Legal and financial liabilities during the lifetime of the project and after decommissioning; post-closure ownership of the CO_2 and storage sites and liability; and
- Regulation of CO_2 transportation and storage across international or subnational borders, or offshore.

Consistent national frameworks are emerging, for example, in Australia, Canada, the Netherlands, Norway, the United Kingdom and the United States, in addressing the immediately relevant issues. The next priority, also from the point of view of public acceptance, appears to be the monitoring of CO_2 streams and the definition of responsibilities after closure of a storage site. Models applied to other materials injected into geological formations may serve as examples. In the long-term, governments may need to assume liability for long-term storage.

Reviewing international treaties and conventions: CCS projects are subject to international law when they cross borders or take place in international waters. International law requires CCS projects to avoid transboundary environmental damage and to protect the marine environment. These obligations had been specified in a number of legally binding global and regional international instruments, established before CCS became an environmental and climate mitigation option:

- The UN Convention on the Law of the Sea, 1982, which does not specifically regulate or prohibit CCS activities, but calls on States to protect the marine environment from human activity such as dumping;
- The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, prohibits the dumping of "waste" into the sea;
- The London Protocol to the above Convention, 1996, allows as of 10 February 2007 the injection of CO_2 streams from CO_2 capture processes and incidental associated substances in sub-seabed geological formations;
- The Basel Convention on the Control of Transboundary Movements of Hazardous Waste, 1989, which might be applicable if CO_2 contained toxic substances;
- The UN Framework Convention on Climate Change, 1994, under which CCS could be considered as an option to mitigate climate change;
- The Kyoto Protocol, 2005, excludes CCS from the Clean Development Mechanism; and
- Regional treaties and conventions for the protection of the marine environment of the North-East Atlantic (OSPAR Convention), 1992; Baltic Sea, 1992; Black Sea, 1994; wider Caribbean region, 1983; Mediterranean, 1976; Gulf, 1978; west and central African re-

Table 2: Protection of intellectual property rights (Index: 0 = weakest, 10 = strongest performance)	
World	5.3
North America	6.4
Latin America	4.0
Africa	4.2
Middle East/Northern Africa	5.0
Western Europe	7.4
CEE and Russia	4.2
Australia, New Zealand, Japan	9.7
India, China, Philippines	6.0
Pakistan, Kenya, Ethiopia	3.7
Source: IPRI International Property Rights Index 2007 (http://internationalpropertyrightsindex.org)	

gion, 1981; South Pacific, 1981, 1986; Bamako Convention on the Ban of the Import to Africa and the Control of Transboundary Movement and Management of Hazardous Waste within Africa, 1991.

At present, the above major conventions are being reconsidered to distinguish CO_2 injections from dumping. On 2 November 2006, the Parties to the London Protocol defined the conditions under which CO_2 can be stored in sub-seabed geological formations (see above). Parties recognized that ocean acidification caused by rising CO_2 emissions calls for a portfolio of mitigation options, including placement of CO_2 in sub-seabed formations. These amendments may prompt reconsideration of other treaties.

Sharing or protecting intellectual property (IP): Some CCS investors (such as Statoil for Sleipner and Snovit) are willing to release their knowledge to the public domain. However generally, CCS investors cannot be expected to commit themselves unless their IP rights (particularly patents and trade secrets) are protected. IP protection aims to:

- Secure the property of, and access to, land, plants, equipment, storage sites and stored CO_2 , with capture technology being particularly sensitive, and
- Enable the transfer of knowledge and technology to receiving countries, and related capacity building.

The preferred route for dealing with these issues is through enforceable, private contracts rather than through laws and regulations, which do not fit specific circumstances. But IP law needs to support such contractual provisions. IP protection of CCS plants and processes can benefit from well-established protocols in the chemical, engineering and petroleum industries. By contrast, service providers will need to develop specific means of IP protection, probably through trade secrets rather than patents. In both cases, law must enable the protection of IP.

The role of governments consists primarily in securing a robust national regime of IP protection as a precondition for private investments. This is particularly true for developing and transition economies, where, at present, the absence of stringent regulatory frameworks in terms of enforcement and sanctions inhibits the deployment of CCS (see Table 2). Continued efforts at international harmonization of patent and other IP protection regimes (WTO, WIPO) would be beneficial for CCS deployment, but progress may be faster in terms of soft law than of hard law, and at the regional level (Convention on the Grant of European Patents). Public involvement in CCS funding or projects may reduce risks for investors but also render ownership and enforcement more complicated. Predictability of licensing conditions or standards would be an asset. However, on the whole, "the issue of IP is not expected to compromise or inhibit the deployment of the CCS industry" (IEA/CSLF).

Securing a level playing field for CCS: As a latecomer among climate change mitigation options, CCS does not benefit from incentives offered to other low-carbon technologies, such as emission trading (EU), the clean development and joint implementation mechanisms (Kyoto Protocol) or funding from the Global Environment Facility (GEF).

The resulting competitive bias to the detriment of CCS projects has been recognized, and efforts have been initiated in the above conventions, within GEF and the Intergovernmental Panel on Climate Change (IPCC), on whether and how to apply the mentioned instruments to CCS. The difficulty is that CCS projects, unlike other mitigation options, do not remove all the CO_2. Accounting schemes have to be developed to measure the net emission reduction from a CCS project compared to emissions that would occur in the absence of such a project (the baseline). Emissions resulting from the higher energy use during carbon capture will have to be taken into account. International guidelines should ensure equivalence of treatment between CCS and other mitigation options, in order to reduce investor uncertainty toward CCS projects.

Alternatively, governments could level the playing field CCS deployment by other means, such as tax incentives, grants, RD&D funding, sovereign guarantees or by assuming long-term liability for leakage after decommissioning. Financing of CCS deployment is in any case a difficult and as yet unresolved issue, even anticipating future cost reductions of CCS technology. Financing is particularly difficult if emission trading credits are below the higher cost of advanced technologies and if long-term mitigation policies and incentives remain uncertain.

FURTHER READING: IEA/CSLF Second Workshop on Legal Aspects of Carbon Capture and Storage, Paris, 17 October 2006; Harry Audus, An Update on CCS: Recent Developments; Lecture Given at the IEA/CSLF Second Workshop, op. cit.; Barry Worthington, Funding for Clean Coal Technologies (www.usea.org)

CONCLUSION

The CFFS Workshops in Erice, Colombo, Neptun, Tallinn, Moscow and Jordan allow an interim appreciation of the prospects of CCS.

Current status: At present, more than 33 million tons of CO_2 are captured every year worldwide. They are stored in at least 70 projects, with Sleipner alone accounting for more than 6 million tons. There are 3000 km of land-based dedicated CO_2 pipelines. In contrast to enhanced oil and gas recovery, CCS is not yet a commercial reality in electricity generation because of its costs and ongoing strive for technological maturity. There will be a number of demonstration projects by 2015 or earlier, with as yet limited impact on global CO_2 emissions.

Potential: By about 2020, CCS can develop into a significant and competitive option to simultaneously slow the growth of CO_2 emissions and promote economic development, energy security and air quality in many countries for decades to come. Commercial deployment depends on the commercial value of carbon exceeding the cost of CCS systems, and eventually on incentives, if that condition is not met initially.

On the assumption that CCS would reach its full potential in the next 30 to 40 years, CCS could reduce energy-related global CO_2 emissions by up to half by 2050 compared to a business-as-usual case. If coal-based power plants are utilized together with improved combustion and higher plant efficiencies, CCS would have an even greater mitigation effect. During 2000-2100, CCS could economically reduce estimated global CO_2 emissions by 220 – 2200 $GtCO_2$, which corresponds to 15% - 55% of a worldwide least-cost mitigation effort. Hence, CCS, together with other mitigation options, could serve as a bridge to a future sustainable energy economy and to better air quality.

Caveats: A significant role for CCS depends upon its cost being reduced by half to about US$25 to 30/$tCO_2$. But even in this case, CCS – while a low-cost option - is not a universal remedy. It is initially limited to new, highly efficient, high-capacity power and industrial plants in developed countries. CCS projects are site-specific, driven by local conditions and opportunities, and are hence unlikely to be precisely replicable. CCS should be seen as an important part of a portfolio of measures, including enhanced efficiency of energy production and use, renewables and new nuclear technologies.

CCS deployment would slow the growth of and ultimately reduce CO_2 emissions. However, the stabilization of emissions and concentrations at acceptable levels will require advances in combustion efficiency, faster CCS technology development, earlier international deployment, aggressive plant renewal, improved CCS conversion efficiency, faster market penetration and co-combustion of biomass and coal. These measures depend on policies whose stringency would still need to be determined. In transportation, the (likely) mismatch between the location of the emitter and the sink may be a limiting factor for small volumes and very long distances.

The prospects of CCS are also determined by the need to safely store billions of tons of CO_2 for centuries. Failure to prevent, control or remedy leakage (and reassure the general public on this issue) would severely reduce the prospects of CCS. Note, though, that IPCC considers that appropriately selected and managed reservoirs are "very likely" (a probability of 90 to 99%) to retain 99% of the stored CO_2 for over one hundred years and are "likely" (probability of 66 to 90%) to retain 99% for over one thousand years.

Action: Successful deployment of CCS depends on the following:

The message: **"Carbon Capture and Storage is an Essential Bridge to a Sustainable and Secure Energy Future"**

- The recognition of CCS as a climate mitigation option in national policies and international conventions and agreements;
- The formulation of affirmative, predictable, nondiscriminatory and cost-effective CCS and energy policies;
- The integration of the CCS option into these policies, as part of a portfolio of mitigation measures;
- The adoption of investor-conscious national frameworks and laws and regulations on CCS licensing, decommissioning, safety and liabilities;
- Interaction between government, industry and research institutes on the tenor and sequencing of CCS development;
- The eligibility of CCS projects in clean development mechanisms, joint implementation, emission trading systems, IBRD and Global Environment Facility funding;
- Financial mechanisms to set a value for carbon at the global level and incentives, if initial carbon prices are too low;
- The adaptation of international treaties and conventions on the marine environment and cross-border transportation;
- The acceleration of national and international cooperation in CCS RD&D, in particular on cost reduction, the permanence of storage and "capture-ready" capacity expansion;
- The building of several cost-effective large-scale demonstration plants;
- The involvement of all stakeholders;
- Given their growing role as emitters: the integration of developing countries in CCS networks (capacity building), emission trading and project funding; and
- An early proactive and participatory outreach effort. The message: **"Carbon Capture and Storage is an Essential Bridge to a Sustainable and Secure Energy Future"**

Annexes

A. Papers Presented at CFFS Seminars

1. WEC CFFS Committee Discussion Session during the 19th World Energy Congress on: **Cleaner Fossil Fuels – The Cornerstone for Human Development and Energy Security,** Sydney (Australia), 8 September 2004
Website:
http://www.worldenergy.org/news__events/world_energy_congress/sydney_2004/default.asp

- *Introduction*

  Barbara N. McKee, Director, Office of Clean Energy Collaboration, U.S. Department of Energy; Chairman, WEC Cleaner Fossil Fuels Systems (CFFS) Committee

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- *Energy Security and Cleaner Fossil Fuels Systems*

  Ahmad Waqar, Secretary, Ministry of Petroleum and Natural Resources, Pakistan

  Email: hdip@apollo.net.pk

- *Investment in Cleaner Fossil Fuels Systems*

  Fernando Zancan, Executive Manager, SIECESC, Brazil

  Email: zancan@siecesc.com.br

- *Energy Technology Transitions*

  Robert Gentile, President, Leonardo Technologies, Inc., United States

  Email: RHGentile@aol.com

- *Human Development and Cleaner Fossil Fuels Systems*

  Joanne DiSano, Director, CSD Secretariat and Division for Sustainable Development, Department of Economic and Social Affairs, United Nations, New York

2. World Federation of Scientists and WEC Cleaner Fossil Fuels Systems (CFFS) Committee Joint Workshop on: **Carbon Capture and Storage – A Way Forward for Cleaner Fossil Fuels,** Erice (Sicily), 24 August 2005
Website:
http://www.usea.org/CFFS/CFFSErice.htm;
http://energypmp.org;
http://www.worldenergy.org/focus/ccs/default.asp;
also available on CD-ROM

- *Opening Remarks and Welcome*

  Richard Wilson, Department of Physics, Harvard University, Chairman of the World Federation of Scientists PMP, United States

  Email: wilson5@fas.harvard.edu

- *Introduction and Overview*

  Barbara N. McKee, Director, Office of Clean Energy Collaboration, U.S. Department of Energy; Chairman, WEC Cleaner Fossil Fuels Systems (CFFS) Committee

  Email: Barbara.mckee@hq.doe.gov

- *The Need*

  Hisham Al-Khatib, Honorary Vice Chairman WEC, Jordan

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- *The Technologies*

  James Ekmann, Associate Director, National Energy Technology Laboratory (NETL), US Department of Energy, United States

  Email: James.Ekmann@netl.doe.gov

- *The Economics*

  Jacek Podkanski, Senior Energy Technology Specialist, Energy Technology Collaboration Division, International Energy Agency (IEA), France

  Email: jacek.podkanski@iea.org

- *Environmental Issues*

  David Hawkins, Director, Climate Center, Natural Resources Defense Council (NRDC), United States

  Email: dhawkins@nrdc.org

- *Funding Needs and Opportunity*

  Elena Nekhaev, Director of Programmes, World Energy Council (WEC), United Kingdom,

  Email: Nekhaev@worldenergy.org

- *Industry Perspectives*

  Arthur Lee, Principal Advisor, Global Policy and Strategy, Corporate Health Environment Safety, Chevron Corporation, United States

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- *Deployment*

  Fernando Zancan, Executive Manager, SIECESC, Brazil

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- *Regulatory and Legal Issues*

  Steve Tantala, Manager, Resources Environment and Carbon Capture and Storage Policy, Department of Industry, Tourism and Resources, Australia

  Email: Steve.Tantala@industry.gov.au

- *New and Innovative Approaches for CO_2 Capture and Storage*

  Klaus Lackner, Professor of Geophysics and Environmental Engineering, Columbia University, United States

  Email: Kl2010@columbia.edu

  Suzanne Hurter, Shell International Exploration and Production B.V., the Netherlands

  Olav Kårstad, Carbon Dioxide Management, Statoil, Norway

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  David Sevier, Managing Director, Aqueous Logic, United Kingdom

  E-mail: David.s@aqueouslogic.co.uk

- *Discussion and Dialogue*

  Robert Gentile, Managing Partners, Atlantic Partners, United States

  Email: RHGentile@aol.com

3. WEC Cleaner Fossil Fuels Systems (CFFS) Committee Dialogue on: **Cleaner Fossil Fuels Systems with Carbon Capture and Storage: What's in It for the Developing World?** Colombo (Sri Lanka), 6 September 2005

- *Introduction and Session Overview*

  Barbara N. McKee, Director, Office of Clean Energy Collaboration, U.S. Department of Energy; Chairman, WEC Cleaner Fossil Fuels Systems (CFFS) Committee

  Email: Barbara.mckee@hq.doe.gov

- *The Need and Technologies*

  Hisham Al-Khatib, Honorary Vice Chairman, WEC, Jordan

  Email: Khatib@nets.com.jo

- *The Economics*

  Michel Lokolo, Deputy Director of Petroleum Products, Ministry of Mines, Water and Energy, Cameroon

  Email: mclokolo@yahoo.com

- *Energy Situation and the Role of Fossil Fuels in South Asia*

  Hilal Raza, Director General and Chief Executive Hydrocarbon Development Institute of Pakistan, Islamabad, Pakistan

  Email: hilalraza2007@gmail.com

4. WEC Cleaner Fossil Fuels Systems (CFFS) Committee and Craiova Power Energy Complex Joint Workshop on: **Cleaner Fossil Fuels for Sustainable Development**
Neptun (Romania), 13 June 2006
Website : http://www.usea.org/CFFS/CFFSNeptun.htm

- *Opening Remarks, Welcome and Overview*

  Constantin Balasoiu, General Manager, Craiova Power Energy Complex, Romania

  Email: cen@termo.oltenia.ro

- *Session 1: Current Cleaner Fossil Fuels Systems*

  Pollution Controls Systems

  Dumitru Manea, Customer Manager, Alstom Global Power Sales, Romania

  E-mail: dumitru.manea@power.alstom.com

  Improving Efficiencies

  Ionel Ilie, Craiova Power Energy Complex, Romania

  E-mail: ilie@termo.oltenia.ro

  Co-firing of Coal and Biomass

  Henrik Noppenau, Vice President, Product Systems Development, Energi E2, Denmark

  E-mail: hno@e2.dk

  RWE's Strategy on Clean Coal Power in the European Network

  Henning Joswig, RWE Power, Germany,

- *Session 2: Future Cleaner Fossil Fuels Systems*

  Moderator

  Barbara N. McKee, Director, Office of Clean Energy Collaboration, U.S. Department of Energy; Chairman, WEC CFFS Committee

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  New Multi-Generation Systems (Power, Hydrogen, CCS and Systems Integration)

  Robert Gentile, Managing Partners, Atlantic Partners, United States

  Email: RHGentile@aol.com

  Deployment and Dissemination (Financing, Partnerships, Corporate Social Responsibility)

  Zara Khatib, Technology Manager, Shell EP International Limited, United Arab Emirates

  Email: Zara.z.khatib@shell.com

  Market Drivers for Carbon Capture and Storage (Commercial and Environmental Aspects, Emission Trading, and Standards)

  Michael Moore, Director of Marketing, Eastern Region Falcon Gas Storage Company, Inc., United States

  E-mail: mmoore@falcongasstorage.com

  R&D Prerequisites

  Gurgen Olkhovsky, General Director, All-Russian Thermal Engineering Institute, Russia

  Email: vti@cnt.ru

  CSD Policy on Global Fossil Fuel's Future

  Peter Mak, Chief, Energy and Transport Branch, Department of Economic & Social Affairs, United Nations, New York

  Email: makk@un.org

5. WEC Cleaner Fossil Fuels Systems (CFFS) Committee Focused Lectures on: **Global and Regional Efforts Toward Carbon Capture and Storage**
Tallinn (Estonia), 4 September 2006
Website:
http://www.usea.org/CFFS/CFFSTallinn.htm

- *Opening Remarks*

  Barbara N. McKee, Director, Office of Clean Energy Collaboration, U.S. Department of Energy; Chairman, WEC CFFS Committee

  Email: Barbara.mckee@hq.doe.gov

- *Carbon Capture and Storage: a WEC Interim Balance – What Message for the Baltic States?*

  Klaus Brendow, Senior Advisor, WEC, Switzerland

  Email: Kbrendow@compuserve.com

- *Practical Aspects of Oil Shale Energy in Estonia*

  Mati Uus, Development Director, Narva Power Plants Ltd.

- *What Are the Options for Europe and the Baltic States to Mitigate CO_2 Emissions?*

  Anita Kvesko, Senior Environmental Specialist, Latvenergo

6. WEC Cleaner Fossil Fuels Systems (CFFS) Committee and the All-Russian Thermal Engineering Institute (VTI) Workshop on: **Cleaner Fossil Fuels for Power Generation**
Moscow (Russia) 8 September 2006
Website: http://www.usea.org/CFFS/CFFS-Moscow.htm

- *Opening Remarks*

  Sergey Mazurenko, Federal Agency for Science and Innovations, Russia; V. P. Voronin, Open Joint Stock Company RAO "UES of Russia," Russia

  E-mail:

  Barbara McKee, Chairman, WEC Cleaner Fossil Fuels Systems (CFFS) Committee, Email: Barbara.mckee@hq.doe.gov

  Gurgen Olkhovsky, Director General, All-Russian Thermal Engineering Institute, Russia

  Email: vti@cnt.ru

- *Fossil Fuels for Power Generation*

  Elena Nekhaev, Director of Programmes, World Energy Council, United Kingdom

  Email: Nekhaev@worldenergy.org

- *The Use of Fossil Fuels in the Power Industry of Russia*

  Anatoly Tumanovsky, All-Russian Thermal Engineering Institute, Russia

  Email: vti@cnt.ru

- *Natural Gas Combined Cycle Plants*

  Alexander Silin, GE, United States

- *Environmental Protection Systems for Fossil Power Plants*

  John Topper, International Energy Agency Clean Coal Centre (IEA CCC)

  Email: John.Topper@iea-coal.org.uk

- *Results of Implementation of IGCC Demonstration Plants in the USA and Further Development of This Technology*

  Robert Gentile, Leonardo Technologies Inc, United States

  Email: RHGentile@aol.com

- *Application Experience with the Operation of the IGCC Plants in Portalamo and the Prospects of this Technology*

  Pedro Casero, ELCOGAS, Spain

- *Application Experience with the Operation of Pressurized Fluidized-bed Combined Cycle Plants and the Prospects of the Use of this Technology for Power Generation*

  Akio Nakanishi, Japan

- *Power Unit Generated CO_2 Capture and Sequestration – Ideas and Achievements*

  John Topper, International Energy Agency, Clean Coal Center (IEA CCC)

  Email: John.Topper@iea-coal.org.uk

7. WEC Cleaner Fossil Fuels Systems (CFFS) Committee Dialogue on: **Mitigating the growing contributions of West Asia in global emissions**
Dead Sea (Jordan), 25 April 2007
Website: http://www.usea.org/CFFS/CFFSAm-man.htm

- *Opening Remarks, Welcome and Overview*

  Hisham Al-Khatib, Honorary Vice Chairman, WEC, Jordan

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- *Carbon Capture and Storage (CCS) – Global Overview*

  Barbara McKee, Chairman, WEC Cleaner Fossil Fuels Systems (CFFS) Committee, Email: Barbara.mckee@hq.doe.gov

- *Energy Situation in Jordan*

  Ghaleb Ma-abrah, Commissioner, Electricity Regulatory Commission, Jordan

  E-mail: gmaabreh@erc.gov.jo

- *The Clean Development Mechanism*

  Mustafa Attili, Quality Environment & Safety Department Manager, Development & Planning Division, Central Electricity Generating Co., Jordan

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- *Power Sector Perspective*

  Rasheed Sulaiman, Sales Application Engineering, GE Energy, Middle East & Africa

  E-mail: rasheed.sulaiman@ge.com

- *Oil and Gas Sector Perspective*

  Zara Khatib, Technology Manager, Shell EP International Limited, United Arab Emirates

  Email: Zara.z.khatib@shell.com

- *Gas Flaring Reduction*

  François Mouton, Advisor, Global Gas Flaring Reduction, The World Bank

  Email: fmouton@worldbank.org

- *Effect of Firing Heavy Fuel Oil for Electricity Generation on the Environment*

  Fouad M. Alsaeedi, Generation Engineer, General Technical Department, Saudi Arabia

  Email: falsaeedi@se.com.sa

- *Technology for Sustainable Development*

  Milton Catelin, Chief Executive, World Coal Institute, United Kingdom

  E-mail: mcatelin@wci-coal.com

- *Regulatory Perspective on Mitigating Global Emissions*

  Sergio Garribba, Former Director General, Ministry of Productive Activities, Italy

  E-mail: s.garribba@hotmail.it

- *Carbon Capture and Storage: Opportunities and Challenges*

  Klaus Brendow, Senior Advisor, World Energy Council, Switzerland

  E-mail: KBrendow@compuserve.com

8. WEC Cleaner Fossil Fuels Systems (CFFS) Committee Session during the 20th World Energy Congress on: **Fossil Fuels Leading the Clean Energy Revolution?**
Rome (Italy) 12. November 2007

- *Opening Statement & Why Fossil Fuels Must Lead the Clean Energy Revolution*

  Barbara McKee, Chairman, WEC Cleaner Fossil Fuels Systems (CFFS) Committee, Email: Barbara.mckee@hq.doe.gov

- *Opportunities and Challenges for New Technologies and Deployment Including CCS*

  Victor Der, Deputy Assistant Secretary for Clean Coal, US Department of Energy

  E-mail: Victor.Der@hq.doe.gov

- *Fossil Energy and Environment in an Interdependent World*

  Peter Garrucho, Managing Director, First Philippines Holding Corporation; Chairman, WEC Philippines Member Committee

  E-mail: pdgarrucho@fphc.com

- *Market Drivers for Clean Fossil Fuels Systems*

  Michael Moore, Director of Marketing, Eastern Region Falcon Storage Company, Inc., United States

  E-mail: mmoore@falcongasstorage.com

- *The Global Stake in Technology Transfer*

  Preston Chiaro, Chief Executive Energy, Rio Tinto PLC; Chairman, World Coal Institute (WCI), United Kingdom

  Email: preston.chiaro@riotinto.com

- *Open Discussion*

  Moderator:
  Hisham Al-Khatib, Chairman, Electricity Regulatory Commission, Jordan

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B. List of International CCS Initiatives

a) Formulation of policies

- The G8 (Group of 8), at Gleneagles (Scotland) in 2005 (www.g8.gov.uk), agreed in its Plan of Action *inter alia* to accelerate the development and commercialization of CCS. It mandated the IEA and CSLF to hold a workshop on short-term opportunities. It will consider a report on Climate Change, Clean Energy and Sustainable Development at its session in Japan in 2008.
- The International Energy Agency (IEA) (www.iea.org) expanded its long-standing involvement in clean fossil fuel technologies into CCS.
- The Carbon Sequestration Leadership Forum (CSLF) (www.cslforum.org) endeavors to make CCS technologies broadly available. It fosters collaborative RD&D and, in response to the above-mentioned G8 request, examines near-term CCS opportunities, together with IEA, at workshops (San Francisco 2006, Oslo 2007, Canada 2007).
- The UN Framework Convention on Climate Change (UNFCCC) (http://unfccc.org) and the Kyoto Protocol (http:unfccc.int/kyoto) aim at the mitigation of climate change They consider present eligibility of CCS projects for clean development mechanism and joint implementation.
- The European Union emission trading scheme (http://ec.europa.eu/environment/climat/emission.htm) does not, at present, support CCS; however, the 6th (http://ec.europa.eu/research/fp6/index.html) and 7th Framework Programmes for Research and Technological Development (http://ec.europa.eu/resear ch/fp7/index.html) call for CCS-related projects.

b) Data collection and analysis

- IEA publications (www.iea.org):
  - Prospects for CO_2 capture and storage, 2004;
  - Legal aspects of storing CO_2, 2005;
  - Legal aspects of carbon capture and storage, 2006;
- IEA bodies:
  - Greenhouse Gas R&D Programme (www.ieagreen.org);
  - IEA Clean Coal Centre (www.iea-coal.org);
  - IEA Working Party on Fossil Fuels (zero emissions, legal aspects);
  - IEA Coal Industry Advisory Board (www.iea.org/ciab);
- European Commission: European Climate Change Program Working Group on Carbon Capture and Geological Storage (http://europa.eu.int/comm./environment/climat/stake_wg.htm);
- WMO/UNEP Intergovernmental Panel on Climate Change Working Group I on The physical science basis, Working Group II on Climate change impacts, adaptation and vulnerability, and Working Group III on Mitigation

of climate change (www.ipcc.ch); Special report on carbon dioxide capture and storage (2005)

- World Energy Council (www.worldenergy.org):
  - Committee on Cleaner Fossil Fuels Systems (CFFS): pamphlet on Carbon Capture and Storage – a WEC interim Balance, London 2006 and 2007;
  - Committee on the Performance of Generating Plants: Study on energy and climate change;
  - Pilot programme on greenhouse gas (GHG) emissions reduction (concluded);
  - CCS pilot projects in Brazil, China, South Africa (initiated).

c) Collaborative development of technologies

- The IEA Implementing Agreements also address CCS; the IEA Coal Research - Clean Coal Centre (www.iea-coal.org) undertakes an extensive programme on clean coal technologies, surveys progress in CCS;
- The CSLF supports 17 CCS collaborative projects (www.cslforum.org/projects.htm);
- The EU 6th (http://ec.europa.eu/research/fp6/index.html) and 7th Framework Programmes for Research and Technological Development (http://ec.europa.eu/resear ch/fp7/index.html) call for CCS-related projects.

d) International legal and regulatory frameworks

- The UN Convention on the Law of the Sea (UNCLOS) (www.unclos.com), 1982, does not specifically regulate or prohibit CCS activities, but calls on States to protect the marine environment from human activity such as dumping.
- The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (www.londonconvention.org) prohibits the dumping of "waste" into the sea;
- The London Protocol to the above Convention, 1996, allows as of 10 February 2007 the dumping of CO_2 streams from CO_2 capture processes and incidental associated substances in sub-seabed geological formations;
- The Basel Convention on the Control of Transboundary Movements of Hazardous Waste, 1989 (www.basel.int), does not consider CO_2 as a hazardous waste, but may do so if containing toxic substances.
- Regional treaties and conventions for the protection of the marine environment may have implications for CCS: in the North-East Atlantic (OSPAR), 1992; Baltic Sea, 1992; Black Sea, 1994; wider Caribbean region, 1983; Mediterranean, 1976; Gulf, 1978; west and central African region, 1981; South Pacific, 1981, 1986; as well as the Bamako Convention on the Ban of the Import to Africa and the Control of Transboundary Movement and Management of Hazardous Waste within Africa, 1991.

e) Selected RD&D projects

Some 110 RD&D projects on CCS have been undertaken worldwide and described in the database of the IEA Greenhouse Gas R&D Programme (http://www.co2captureandstorage.info/search.php4). Major CCS projects addressing new combustion and storage technologies (excluding EOR) include:

i. Storage

- Sleipner (Norwegian North Sea) (www.statoil.com/) – first industrial-scale storage of CO_2 from gas processing since 1996, ongoing
- CO_2 Store (www.co2store.org) – a follow-up to the Sleipner project on storing and monitoring CO_2 in aquifers
- In Salah (Algeria) (www.bp.com) – an industrial scale demonstration of CO_2 geological storage commenced in 2004
- Gassi Touil (Algeria) – an integrated gas project between Repsol (Spain) and Sonatrach

(Algeria), including CCS, contracted 2004, operational in 2010

- Weyburn II (Canada) (www.ptrc.ca/) – CO_2 storage in conjunction with commercial scale enhanced oil recovery since 2001
- Gorgon (Australia) (www.co2crc.com.au) – injecting CO_2 from natural gas processing in an offshore saline formation as of 2011, with an intended capacity of 120 million tons
- CO_2 Sink (www.cosink2.org) – testing capture and storage of 60 kt in a saline aquifer, in Ketzin near Berlin
- CASTOR (www.co2castor.com) – pilot plant capturing and storing CO_2 from the Elsam coal power station in Denmark
- Halten (mid-Norway) – capturing 2.5 million tons CO_2 from natural gas exploration and power generation for EOR and permanent storage in the Draugen and Heidrun deposits
- Stanwell (Australia) – a 1800 t/day coal-based IGCC demonstration plant (2007-2010) with carbon sequestration (4100 t/day) and storage (net efficiency without/with carbon capture: 40%, 34.3%)
- GeoNet (www.co2geonet.com) – a European project on geological storage of CO_2

ii. Power generation with CCS

- FutureGen (www.futuregenalliance.org) - a U.S.-led international full-scale CCS demonstration coal-fired plant based on IGCC and pre-combustion capture
- The Zero Emission Fossil Fuel Power Plant Technology Platform – a European Union initiative build on the EC Hypogen-Dynamis and other projects; the Platforms emphasizes the need for about 10 CCS projects covering the entire chain (http://ec.europa.eu/research/energy/pdf/zero_emission_ffpp_en.pdf)
- Vattenfall Oxyfuel pilot plant Schwarze Pumpe (www.vattenfall.de) (Germany)
- GREENGEN – a Chinese Government project for a 400 MW zero-emission power plant by 2020
- TOTAL Oxyfuel boiler pilot scale at Lacq (France)
- COORETEC – COORIVA (www.cooretec.de) - innovative IGCC combustion technologies with CO_2 reduction and storage (Germany)
- CANMET (www.nrcan.gc.ca) - a Technology Centre pilot project on CCS (Canada)
- ENCAP (www.encapco2.org) - an integrated project on new precombustion technologies sponsored by 33 legal entities, including the EU
- COMTES 700 (www.comtes700.org) – testing components to enable CO_2 reduction for a new 400 MW 700° C power plant (Germany)
- CO_2 Capture Project (www.co2captureproject.org) - an initiative of major energy companies to reduce emissions via post-combustion scrubbing, pre-combustion decarbonization, Oxy-combustion and geological sequestration
- ZeroGen (www.zerogen.com.au) – an IGCC power plant with CCS in saline aquifer (Australia)
- Progressive Energy (www.dti.gov.uk/files/file30865pdf) – an IGCC power plant with CO_2 capture for enhanced oil recovery (United Kingdom)
- Sask Power (www.saskpower.com) – low sulphur lignite power plant with Oxyfuel technology for enhanced oil recovery (Canada)
- Powerfuel – a IGCC coal-based power plant with CCS (United Kingdom)
- E.ON (www.eon-uk.com/883.aspx) – an IGCC project with a gas-fired power plant, with CCS at a later stage (United Kingdom)
- RWE (www.rwe.com/generator.aspx) – IGCC technology to separate hydrogen for synthetic fuel production (Germany) (see ENCAP above)

- RWE nPower (www.npower.co. uk) – super-critical technology with post-combustion CCS (United Kingdom)

iii. Enhanced coal bed methane recovery

- RECOPOL (http//recopol.nitg.tno.nl) – a EU co-financed R&D project on storing CO_2 in an underground coal bed (adsorption), whereby simultaneously methane is released for sale (Silesia, Poland)
- COAL SEQ II CONSORTIUM (www.coal-seq.com) - a US-led collaborative research project into the storage of CO_2 in unminable coal seams, and related methane displacement and capture
- The Alberta Research Council (Canada) (ARC) Enhanced Coalbed Methane Recovery Project via the injection of CO_2 (www.arc.ab.ca), with a collaborative outreach to the China Coalbed Methane Technology / CO_2 Sequestration Project, Shanxi (China) (www.arc.ab.ca/Index.aspx/ARC/4517)
- a research project on underground coal gasification with local CCS storage (with or without enhanced coalbed methane recovery) presently promoted (www.ucgp.com).

C. Abbreviations

C	carbon
CCS	carbon capture and storage
CCGT	combined cycle gas turbine
CDM	clean development mechanism (Kyoto Protocol)
CFFS	WEC Cleaner Fossil Fuels Systems Committee
CO_2	carbon dioxide
CSLF	Carbon Sequestration Leadership Forum
EOR	enhanced oil recovery
EGR	enhanced gas recovery
GEF	Global Environmental Facility
GHG	greenhouse gas
Gt	gigaton (1 ton x 10^9)
GW	gigawatt (1 Watt x 10^9)
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
JI	joint implementation (Kyoto Protocol)
LNG	liquefied natural gas
MW	megawatt (1 Watt x 10^6)
PCC	pulverized coal combustion
ppm	parts per million (ratio of the number of CO_2 molecules in the total number of molecules of dry air)
RD&D	research, development and demonstration
SCSC	super-critical steam cycle
WEC	World Energy Council
WIPO	World Intellectual Property Organization
WTO	World Trade Organization
ZET	zero emission technology

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