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INTERNATIONAL ENERGY TECHNOLOGY COLLABORATION AND CLIMATE CHANGE MITIGATION

CASE STUDY 4: CLEAN COAL TECHNOLOGIES

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FOREWORD

This document was prepared by the OECD and IEA Secretariats in March 2005 at the request of the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy-makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

The Annex I Parties or countries referred to in this document are those listed in Annex I of the UNFCCC (as amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Korea and Mexico, as OECD member countries, also participate in the Annex I Expert Group. Where this document refers to "countries" or "governments", it is also intended to include "regional economic organisations", if appropriate.

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Executive Summary

This case study reviews recent experience in international collaboration in the field of clean coal technologies in order to identify lessons that may be relevant for climate-friendly technology collaboration. It presents information on cleaner and more efficient coal technologies, their current status and development prospects, with a focus on fuel combustion and power generation. The study also focuses on China because of its significant use of coal and the various efforts made for transferring clean coal equipment and technologies to that country. Finally, it draws on lessons learned from international technology collaboration and transfer in China.

The clean coal technologies considered in this paper include both cleaner and more efficient technologies for coal combustion, including supercritical coal plants; more efficient industrial boilers; fluidised bed combustion; coal gasification, and various "end-of-pipe" pollution abatement technologies – including carbon dioxide capture and storage.

Information is presented on six IEA implementing agreements that deal with various aspects of clean coal technologies. These agreements provide for cost-sharing experiments, and research, development and demonstration programmes, and important exchanges of information, including through the production of high-quality information syntheses. Information is also provided on other forms of international collaboration, such as the European Union's programmes and policy forums that directly or indirectly contribute to clean coal technology development and dissemination.

In China, many countries have undertaken bilateral efforts to facilitate access to clean coal technologies. Multilateral institutions, such as development banks and the Global Environment Facility (GEF), have also been active in this field.

The following lessons can be drawn from successes and failures of these various international collaborative efforts on clean coal technology transfer in China:

- *Technology transfer is about more than equipment transfer.* The various successes of bilateral efforts and GEF to bring clean technologies to China suggest that technology transfer is more widespread when manufacturing technology is also transferred to the host country. Beyond the transfer of clean-coal equipment, this implies transferring the technical ability to replicate and manufacture such equipment locally. Enhancing the knowledge of and providing training to manufacturers and users is also critical. More generally, it appears that technology transfer would benefit from policy reform. With a few notable exceptions, transfer of clean coal technology has been witnessed in the context of 'one-off' demonstration projects with limited dissemination. Domestic policy that fosters technology diffusion is likely to be a key factor for successful technology transfer.

- *Intellectual Property Rights (IPR) protection matters for transferors and transferees.* The conventional understanding of the wisdom is that the weak IPR protection in developing countries deters foreign companies from transferring their technology as they see a risk that it may be stolen, once transferred. While this is true, companies in countries that are willing to acquire the technology (via licenses) may also be deterred by inadequate IPR protection: host companies may be reluctant to acquire technology that competitors in their own markets could copy while not having to pay. IPR protection addresses both concerns.

An interesting, paradoxical finding from this case study is that strong growth in power demand is not necessarily conducive to the introduction of advanced technologies. While economic growth provides opportunities to introduce new, more efficient technologies, in the particular case of power generation in China, it creates concerns about power shortages. Generators are therefore discouraged from discarding outdated, inefficient and dirty infrastructure. This suggests that technology transfer on the generation side may benefit from efforts to limit too rapid a growth in electricity demand, and may be crucial for the success of an international effort to encourage the transfer of clean coal technologies.

1. Introduction

1.1 Context and background

Mitigating climate change and achieving stabilisation of greenhouse gas atmospheric concentrations – the objective of the United Nations Framework Convention on Climate Change (UNFCCC) – will require deep reductions in global energy-related carbon dioxide emissions. Developing and disseminating new or improved low-carbon energy technology will thus be needed. Besides R&D efforts, adequate policies, regulations, legislations and economic tools will be required. Two previous AIXG papers have focused on possible drivers for such a profound technological change: *Technology Innovation, Development and Diffusion*, released in June 2003, and *International Energy Technology Collaboration and Climate Change Mitigation*, released in June 2004.

The first of these papers (Philibert 2003) assesses a broad range of technical options for reducing energy-related CO_2 emissions. It examines how technologies evolve and the role of research and development (R&D) efforts, alternative policies, and short-term investment decisions in making long-term options available. It considers various policy tools that may induce technological change, some very specific (e.g. R&D subsidies), and others with broader expected effects (e.g. taxes or cap-and-trade systems). Its overall conclusion is that policies specifically designed to promote technical change, or "technology push", could play a critical role in making available and affordable new energy technologies. However, such policies would not be sufficient to achieve the Convention's objective in the absence of broader policies. First, because there is a large potential for cuts that could be achieved in the short run with existing technologies; and second, the development of new technologies requires a market pull as much as a technology push.

The second paper (Philibert 2004a) considers the potential advantages and disadvantages of international energy technology collaboration and transfer for promoting technological change. The advantages of collaboration may consist of lowering R&D costs and stimulating other countries to invest in R&D; disadvantages may include free-riding and the inefficiency of reaching agreement between many actors. This paper sets the context for further discussion on the role of international collaboration by describing the globalisation of the economy and current efforts of technology collaboration and transfer. Finally it considers various ways to strengthen international energy technology collaboration.

This paper is one of several case-studies that seek to provide practical insights on the role international technology collaboration could play to achieve the objectives of the UNFCCC. They all consider the past achievements of international technology collaboration, and the role it could play in helping to develop and disseminate new technologies in the future: what worked, what did not work and why, and what lessons might be drawn from past experiences.

These case studies consider concentrating solar power technologies (Philibert 2004b), high-yielding crop varieties (Gagnon-Lebrun 2004), energy efficient appliances (Guéret 2005) and wind power grid integration (Justus 2005).

1.2 A case study on clean coal technologies

There are many reasons for performing a case study on coal. First, the current importance of coal in world emissions makes this study more than a mere example of successful or unsuccessful technology collaboration and experiences providing lessons for other areas. Some lessons might have direct implications on coal with large implications for future global CO_2 emissions. This is all the more true as coal is simultaneously the fossil fuel with the highest carbon content per unit of energy and the fossil fuel with the most abundant resources in the world.

Second, clean or cleaner or more efficient coal use is already the subject of numerous forms of international collaboration, aiming either at reducing local polluting emissions or global CO_2 emissions from coal use.

Collaboration on Research, Development and Demonstration (R, D&D) occurs, in particular, through collaborative efforts such as the five technology “implementing agreements” under the auspices of the International Energy Agency that relate entirely or partially to coal technologies. Policy collaboration takes place within various institutions and international bodies, including the recent Carbon Sequestration Leadership Forum. Professional associations also play a role in the internationalisation of clean coal concepts and technologies.

More specific to clean coal are the many efforts undertaken by industrialised countries’ governments and industries, independently or together, to transfer efficient technologies or equipment to developing countries. These efforts include, in particular, bilateral cooperation, and more collective efforts through regional cooperative frameworks such as the Asia Pacific Economic Cooperation (APEC), the regional development banks, the World Bank and the Global Environment Facility (GEF).

Many such efforts – and probably the best documented ones – are in China, which is currently by far the largest and most active market for coal technologies. They include, in particular, numerous bilateral efforts with varying degrees of success, various projects supported by the World Bank and regional development banks, and perhaps the most successful project ever undertaken and financed by the GEF – a project on industrial boilers.

An analysis of recent and on-going international collaboration with China on clean coal highlights lessons learned that are not discussed in other case studies on international technology collaboration and climate change mitigation. This is why it is given an important place in this paper.

Section **2** briefly defines and reviews clean and efficient coal technologies; Section **3** describes the broad landscape of international collaboration on clean coal; Section **4** analyses the successes and failures of collaborative efforts with China undertaken by various industrialised countries, development banks and the GEF; and Section **5** draws some lessons from that analysis.

2. The Technologies and Their Potential

2.1 Coal and the local and global environment

Coal is the least clean fossil fuel with respect to both local and global environment issues. The environmental impacts include those of the mining industry and coal transportation – on the landscape, rivers, water tables and other environmental media. This paper, however, focuses on the impact of coal combustion on air quality and greenhouse gas concentrations.

Coal combustion emits particulates, sulphur oxides, nitrogen oxides, mercury and other metals, including some radioactive materials, in a much higher proportion than oil or natural gas and, therefore, causes local and regional pollution problems (contributing to acid rain and increased ground-level ozone levels), and global climate change. It entails relatively higher emissions of CO_2 than other fossil fuels, as coal's ratio of hydrogen atoms over carbon atoms and power generation efficiency are relatively low compared to other fossil fuels. Coal is also responsible for methane emissions, notably from mining.

While oil accounts for 36% of total primary energy supply (TPES), against 23% for coal, both fuels are responsible for 38% each of global energy-related CO_2 emissions. According to recent IEA projections, based on existing energy policies in both the industrialised and developing world, the share of coal in TPES will fall to 22% and coal will be overtaken by natural gas, but its absolute consumption will continue to increase, at least in the next three decades.

Coal is primarily burnt for electricity generation. Steam coal is also used for process and comfort heat in many industries and in the residential and commercial sectors. Coal is burnt in isolated stoves or industrial boilers for central heating systems. Coking coal is used in the steel industry. Coal plays a small role in transport, either directly in old steam locomotives in various developing countries, or as a source for liquid fuels (mostly in South Africa). It is also a source of gaseous fuels (synthetic gas).

Stronger policies favouring energy efficiency improvements and non-carbon emitting energy sources can modify the picture – but coal will remain an important energy source in the coming decades. Fuel switching in favour of natural gas is occurring world-wide but will be limited by resource availability. In the longer run, while oil and gas will become progressively depleted, coal will remain the largest fossil fuel resource available.

Increased use of coal will exacerbate local, regional and global pollution problems unless cleaner and more efficient coal technologies are used. Ultimately, CO_2 capture and storage could be necessary to reduce global CO_2 emissions. This can be illustrated, for example, by a publication from the US Department of Energy's Energy Information Administration (EIA 2003). In analysing the "Climate Stewardship Act", a proposal sponsored by Senators McCain and Lieberman to bring overall US emissions back to 2000 levels by 2025, the EIA forecasts a decline in US coal-fired generating capacity from 315 GW in 2001 to 147 GW in 2025, the net result of 38 GW of projected new integrated gasification combined cycle coal plants with carbon capture and sequestration equipment, less 206 GW of retirements. Mitigating climate change will not eliminate coal use in any foreseeable future, but GHG abatement combined with air quality issues will make clean coal technologies essential.

2.2 Efficient coal use

Efficient coal use is currently the primary means of reducing coal's GHG impacts as carbon dioxide capture and storage are a long way from being commercially viable. Another possibility is to use coal plants to increase the share of biomass in the electricity mix through co-firing of biomass and coal. A third dimension is the reduction of methane emissions; but will not be considered in this paper.

The average efficiency of coal-fired generation in the OECD is 36% in 2002 compared with 30% in developing countries. As a result, one kilowatt-hour produced from coal in developing countries emits 20% more carbon dioxide than in industrialised countries.

New installations can differ markedly with respect to CO_2 intensity. The latest full-size state of the art plants in industrialised countries rely on supercritical technology with efficiency exceeding 45% with favourable cooling water conditions, while new sub-critical plants can reach an efficiency of 38-39%. Increased working temperatures will further increase the efficiency of supercritical plants, with efficiency of more than 50% being envisaged. Current demonstration plants based on gasification have an efficiency of 42-43%. Further deployment and development indicate that this could exceed 50% in a similar time frame for advanced forms of supercritical pulverised coal firing. Where demand for heat exists, either for some industries or for district heating, combined heat and power (CHP, or cogeneration) can increase the energy efficiency of coal plants to much higher levels – 80% or more.

Coal-fired generating capacity of about 1,000 GW is installed worldwide. Almost two-thirds of the international coal-fired power plants over 20 years old have an average efficiency of 29%, emitting almost 4 gigatonnes (Gt) of CO_2 per year. If they are replaced after 40 years with modern plants of 45% efficiency, total GHG emissions will be reduced by about 1.4 Gt per year (global energy-related emissions are about 24 Gt).

There are many options for improving plant performance and reducing emissions. Low to medium cost improvements can increase fossil-fuelled plant efficiency by 2 to 3.5 percentage points. Current and emerging re-powering technologies can achieve much larger reductions in CO_2 emissions, but are only cost-effective in plants close to the end of their technical life. They include: co-firing and re-powering with biomass; re-powering with super critical boiler; re-powering with CHP or gasification.

According to an APEC (2004) study, re-powering enables large increases in power generation for a similar fuel demand, as well as large CO_2 emission reductions, with the use of existing infrastructure, thus reducing costs and implementation time. Refurbishment of older thermal power stations gives up to a 12% reduction in greenhouse intensity as well as significant increases in power generation (at a significantly lower unit cost than that of a new power plant). Taking into account changes in operating costs and revenue from power generation and the annualised capital cost, refurbishing can often be beneficial and CO_2 emissions reduced at no cost.

2.3 Clean coal use

Environmental control technologies were developed to remove or prevent the formation of SO_2, NO_x and particulates when coal is burned to generate electricity at conventional, coal-fired power stations. These "clean coal" technologies extend from coal washing to combustion to end-of-pipe techniques.

Coal washing reduces the amount of ash in raw coal to facilitate combustion and increase the energy content per tonne. In many cases, it is also possible to reduce the sulphur content in coal in order to decrease the production of sulphur dioxide when burnt. Coal blending and briquetting are also efficient fuel preparation methods.

At the other end of the process, particulate control is generally the first step and often relies on electrostatic precipitators. Flue gas desulphurisation units can remove 90% of the SO_2 or more and are widely adopted. Many NO_x reduction technologies are employed at commercial plants: low-NO_x burners, over-fire air, reburn, non-catalytic reduction techniques and, to meet the most demanding standards, selective catalytic reduction.

Legislative pressures in OECD countries have driven these developments and are expected to continue and push the technologies into ever greater performance. Also, more recently, concern over the emission of heavy metals into the air have become an important issue in the USA where legislation has been enforced. Other OECD countries may follow with their own regulations in due course.

Advanced combustion technologies offer an alternative approach to these conventional emission abatement measures. The two main technologies are Fluidised-Bed Combustion (FBC) and Integrated Gasification Combined Cycle (IGCC).

FBC reduces emissions of SO_2 and NO_x by the controlled combustion of crushed coal in a bed fluidised with jets of air. Sulphur released from coal as SO_2 is absorbed by a sorbent such as limestone, which is injected into the combustion chamber along with the coal. Around 90% of the sulphur can be removed as a solid compound with the ash. FBCs operate at a much lower temperature than conventional pulverised coal boilers, greatly reducing the amount of thermal NO_x formed. The FBC is particularly suited to poorer quality fuels; this relatively low-cost, clean and efficient technology, though complex to operate, could be more widely used in developing countries. There are a number of expressions of FBC technology, but the one gaining most market penetration is known as Circulating Fluidised Bed Combustion (CFBC).

IGCC systems involve gasification of coal, usually by high temperature reaction with oxygen, cleaning the gas produced, and combusting it in a gas turbine to produce electricity. Residual heat in the exhaust gas from the gas turbine is recovered in a heat recovery boiler as steam, which can be used to produce additional electricity in a steam turbine generator. IGCC systems are among the cleanest and most efficient of the emerging clean coal technologies: sulphur, nitrogen compounds, and particulates are removed before the gas is burned in the gas turbine and thermal efficiencies of over 50% are likely in the future.

Another option is that of "polygeneration": gasification of coal, possibly with other fuels (from biomass or petroleum residues) provides heat, power and synthetic fuels. Many more poly-generation plants are found in the oil industry than in the coal industry.

Finally, gasification could also be operated *in situ* with underground coal gasification (UCG). In the UCG process, water/steam and air or oxygen are injected into a coal seam. The injected gases react with coal to form a combustible gas which is brought to the surface and cleaned prior to utilisation. This relatively new technology is being used to exploit coal seams that are otherwise impossible to mine.

While efficiency improvements and advanced combustion technologies tend to reduce all polluting emissions, the opposite may not be true: the removal of local pollutants has an energy cost and thus tends to slightly increase CO_2 emissions.

2.4 CO_2 Capture and storage

Deep emission cuts may require deployment of geological carbon capture and storage technologies. CO_2 capture technologies are not new; a number of proven methods exist to separate CO_2 from gas mixtures. For the past sixty years these technologies have been routinely used on a small scale by the oil, gas and chemical industries. While technically sound, none of today's commercial CO_2 capture technologies were developed for large power plants and scaling them up is expensive and energy intensive.

There are currently three main CO_2 capture approaches. The most conventional approach is to capture the CO_2 from combustion products in power plant flue gas or industrial exhaust. This is known as post-combustion capture. Two other approaches to capturing CO_2 happen before fossil fuel combustion. In the oxygen combustion (usually called oxy-fuel combustion) approach, O_2 and recycled flue gas is used to increase CO_2 concentrations in flue gas prior to capture. In the hydrogen/syngas approach, coal is gasified or natural gas is reformed to produce synthesis gas (syngas) of carbon monoxide (CO) and H_2; a water/CO shift then takes place to produce H_2 and CO_2 for CO_2 capture. Both approaches increase CO_2 concentrations in the exhaust gas stream making CO_2 easier to capture. The capture step incurs most of the cost of carbon capture and storage processes. Hence, the main challenges associated with capturing CO_2 are reducing costs and the amount of energy required for capture.

Carbon in the form of coal, oil and natural gas is stored throughout the earth. There are also naturally occurring CO_2 deposits that supply CO_2 to the oil and chemical industries. The concept of CO_2 capture is linked with CO_2 storage in natural geological formations that may have once held carbon (depleted oil reservoirs and deep coal seams) or in saline formations, which have enormous storage capacity. The main challenge associated with geological storage is the prevention of CO_2 leakage. Furthermore, measurement systems which monitor and verify carbon dioxide storage must be developed. Sufficient proof of storage permanence is essential for any credible carbon dioxide capture and storage strategy (IEA CCC 2004). It is important to match sources of captured CO_2 and storage sites, as much as possible, to reduce CO_2 transportation needs.

IPCC estimates for geological storage capacities range from 1,500 to 14,000 Gt of CO_2; this scale suggests that storage capacity is unlikely to be a major constraint on CO_2 removal, provided current knowledge is improved and long-term storage guaranteed. The concept of injecting CO_2 in plain ocean waters raises serious environmental concerns and is highly controversial.

Besides R&D challenges, prospective deployment of carbon dioxide capture and storage technologies requires appropriate legal and regulatory frameworks and policies. These new policies are needed to create a level-playing field for capture and storage technologies alongside other climate change mitigation measures. Public awareness of CO_2 capture and storage technologies, which is the first step towards gaining public acceptance, is still very limited.

Atmospheric CO_2 concentration stabilisation will be less costly if capture and storage are included in the mitigation options – but leakage rates or even the risk of large-scale leakage from underground reservoirs might be a critical issue. A recent modelling exercise at the IEA (2004b) suggests that at a carbon price of US$50/t CO_2 – translating into an electricity production cost increase of 1 to 2 US cents per kWh – introduction of CO_2 capture and storage amongst all other options would lead to additional emission cuts on a Gigatonne scale (4.9 Gt CO_2 in 2030; 7.9 Gt CO_2 in 2050).

3. International Technology Collaboration

This section describes on-going collaborative efforts on clean coal technologies, including research, development and demonstration (R, D&D) and information exchange, policy collaboration and the role of professional associations. A brief analysis underlines the usefulness of international collaboration.

3.1 R, D&D collaboration and information exchange

Since its creation in 1974, the International Energy Agency has provided a structure for international co-operation in energy technology R, D&D, and for dissemination of related information: the IEA "Implementing Agreements". Six out of the more than forty existing implementing agreements have activities partially or wholly related to coal. The European Union is providing financing for cooperation among its Member States. Carbon dioxide capture and storage has drawn the attention of the international scientific community, governments and industry.

3.1.1 IEA Clean Coal Centre

The IEA Clean Coal Centre (CCC) was formed in 1975 in the wake of the oil crisis. It is the world's foremost provider of information on efficient coal supply and use, in a balanced and objective way without political or commercial bias. It shows, where appropriate, the opportunities for technology transfer worldwide. Based in London with a staff of 23, its annual budget is 2 million[1].

CCC technical review and assessment reports are distributed widely to nominated parties as part of the membership subscription. These are a core product and about 15 are produced each year. Topics include mining, transport, combustion, the disposal of residues and emission control. Market studies have remained in demand and the emphasis in recent years has focused on power generation and the environmental consequences of coal use.

The CCC is in the process of producing the Clean Coal Compendium which will soon be available on the Centre's website. This will be an encyclopaedia on topics related to coal use. There is also a Coal Abstracts database and eight databases which make up CoalPower5. Coal Abstracts is a searchable database of the world's literature on coal containing about 200,000 abstracts of coal literature. CoalPower5 contains details of the world's coal-fired power plants, their individual units, emission control equipment, as well as emission standards applicable to these plants. Website: www.iea-coal.org.uk.

3.1.2 Greenhouse Gas R&D Programme

IEA GHG was set up as an international collaborative activity in 1991. The initial focus was on capture and storage of CO_2 produced in power stations fired on both coal and natural gas. Since then, activities have expanded to cover a wide range of technologies aimed at reducing the emissions of greenhouse gases. It is highly recognised as a source of impartial information in this area.

IEA GHG is a cost sharing IA in which participants contribute to a common fund to finance the activities. Operational management of the IA is assigned to an Operating Agent who is accountable to the Executive

[1] There are currently 16 members. At country level there are Austria, Canada, Italy, Japan, Sweden, the UK, the USA and the European Union. Sponsors include the South African Anglo Coal and Eskom, the Australian Coal Industry Consortium, the Beijing Research Institute of Coal Chemistry (BRICC), the Indian BHEL, the Coal Association of New Zealand, the Danish Power Group, and Netherlands Industry Group.

Committee. The Operating Agent for the IEA GHG is IEA Environment Projects Ltd., a UK registered company[2].

The main activities are the production of technology and market information; confidence building by promotion of technology development and the organisation of research networks (e.g. a network of researchers on solvent capture of CO_2, and one on monitoring of underground CO_2 storage); and information dissemination, to governmental and other policy makers, industry leaders, technology developers, and public audiences such as environmental NGOs. Website: www.ieagreen.org.uk.

3.1.3 Clean Coal Sciences

The focus of the Implementing Agreement on Clean Coal Science is the basic science of coal combustion[3]. The specific objectives are to encourage, support and promote research and development that will lead to improved understanding and characterisation of conventional combustion processes; develop techniques that control and reduce solid, liquid and gaseous emissions associated with combustion processes; improve operating efficiency, and identify methods for the effective utilisation of combustion by-products.

This Agreement has led to numerous commercial applications, including the development of a new generation of low-NO_x burners which has already achieved sales of over $400 million in one participating country. Current work includes modelling and diagnostic methods to co-firing with other fuels and bio-coprocessing.

The work programme is conducted using both task sharing and cost sharing. The cost shared component involves a common fund which is used to support coal research studies at the International Flame Research Foundation in the Netherlands. Website: www.iea-ccs.fossil.energy.gov.

3.1.4 Energy Conservation and Emission Reduction in Combustion

The Implementing Agreement on Energy Conservation and Emissions Reduction in Combustion aims at accelerating the development of combustion technologies for use by industry that demonstrate reduced fuel consumption and have lower pollutant emissions. The focus on emissions is primarily concerned with toxic or noxious emissions, rather than greenhouse gases[4].

The work programme is conducted through task-sharing and information exchange between participants. Participants also undertake collaborative work at each others' facilities. Website: www.im.na.cnr.it/IEA/.

3.1.5 Fluidised Bed Conversion

Burning in a fluidised bed allows combustion of a wide range of low-grade and difficult fuels, e.g. waste and biomass, as well as mixed fuels. Utility-scale units operating with supercritical steam conditions offer the potential for power generation efficiencies as high as 45 % with low polluting emissions[5].

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[2] The current participants are Australia, Canada, the Commission of the European Communities, Denmark, Finland, France, India, Japan, Korea, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the UK, the USA, and Venezuela. The current sponsors are ALSTOM Power, BP, ChevronTexaco, EniTechnologie SpA, EPRI, ExxonMobil, Repsol YPF, RWE A.G., Shell International B.V., and Total.

[3] Current membership includes Australia, Canada, Denmark, Finland, Germany, Italy, Japan, Mexico, Netherlands, South Africa, Sweeden, United Kingdom and United States.

[4] The list of member countries includes: Belgium, Canada, Finland, Germany, Italy, Japan, Norway, Sweden, Switzerland, United Kingdom and United States

[5] Member countries are Austria, Canada, France, Finland, Italy, Japan, Korea, Portugal, Spain, Sweden and United Kingdom.

Circulating Fluidised Bed (CFB) boilers, introduced at utility scale in 1985 are now progressing steadily, with large coal-fired units in the 250-300 MWe range being installed worldwide. Italy, Mexico, Turkey, Puerto Rico, Australia, Poland, Finland, the Czech Republic, India, China and USA have recently installed CFB boilers burning coal, coal washing residues, brown coal, petroleum coke or other fuels.

The Implementing Agreement Fluidised Bed Conversion brings together experts to exchange technical information exchange on research conducted in support of commercial FBC units. Website: www.iea.org/tech/fbc/index.html.

3.1.6 Multiphase Flow Sciences

Multiphase flow is a mixture of two or more solids, liquids or gasses (generally solid-liquid, solid-gas and liquid-gas)[6]. As these mixtures behave in a different way to flows of ordinary liquids or gasses, they are more difficult to predict and control. Multiphase flow has many applications in the fossil fuel sector. Improving knowledge and control of multiphase flow helps to achieve more efficient and cost-effective energy production, and fuel transport and use technologies (IEA 2005).

The implementing Agreement for Multiphase Flow Sciences operates at both national and international levels to encourage collaboration amongst technology researchers and developers and to promote co-ordination of information exchange through annual meetings and teleconferences. Website address: http://www.etsu.com/ieampf.

3.1.7 R, D & D cooperation within the EU

Clean Fossil Fuels have been a subject of the 5th (1999-2002) and 6th (2003-2006) Framework Programmes supported by the Commission of the European Communities. In the 5th Programme, key actions 5 and 6 concerned energy R&D and were respectively “cleaner energy systems, including renewables” and “economic and efficient energy for a competitive Europe”. A list of actions included, among others: “large scale generation of electricity and/or heat with reduced CO2 emissions from coal, biomass and other fuels, including combined heat and power” (financing received: 160 million), and “cost effective environmental abatement technologies for power production” (financing received: 40 million). Many of these projects concerned clean coal technologies.

In the 6th Framework Programme, the Energy Research Area includes longer term actions aimed at "Capture and Sequestration of CO2 associated with cleaner fossil fuel plants" and is the only fossil fuel-related research priority in this Programme. Several already approved projects receive funding of around 36 million. Third call in the 6th FP included funds of around 30 Million available for CO2 capture and storage projects including clean hydrogen production from fossil fuels.

3.1.8 International R, D&D projects

The relatively new area of carbon capture and storage has international R&D projects on clean coal, for a global value above $100 million (IEA 2004b). R&D on the permanence of CO2 storage, necessary to gain confidence and public acceptance of this option, is an area of special interest for international collaboration. Scientific monitoring of the CO2 storage in oil fields at Weyburn (Canada) and in saline aquifer deep below sea floor at Sleipner (Norway) are the flagships of this international collaboration.

Another form of international scientific collaboration is the on-going assessment of carbon dioxide capture and storage technologies undertaken under the auspices of the Intergovernmental Panel on Climate Change (IPCC). A special report will be published in 2005.

[6] Member countries are Australia, Canada, Mexico, Norway, United Kingdom and United States.

3.2 Policy collaboration

The Carbon Sequestration Leadership Forum (CSLF) is an international climate change initiative of the US Government focusing on development of improved cost-effective technologies for the separation and capture of carbon dioxide. The purpose of the CSLF is to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage. This could include promoting the appropriate technical, political, and regulatory environments for the development of such technology.

The CSLF charter was signed on June 25, 2003 in Washington, DC by representatives of 13 countries and the European Commission. Since then, Germany, South Africa, and France have joined, bringing the total number of members to 17. The charter will stay in effect for 10 years. While there are several large scale international CO2 sequestration projects underway, this first-ever ministerial-level sequestration forum underscores the new importance given to international cooperation.

The activities of the CSLF are conducted by a Policy Group, which governs the overall framework and policies of the CSLF, and a Technical Group, which reviews the progress of collaborative projects and makes recommendations to the Policy Group on any required action. Collaborative projects may be undertaken by the CSLF as authorised by the Policy Group at the recommendation of the Technical Group. This specifically includes projects involving the following: information exchange and networking; planning and road-mapping; facilitation of collaboration; research and development; demonstrations; public perception and outreach; economic and market studies; institutional, regulatory, and legal constraints and issues; support to policy formulation; and others as authorised by the Policy Group (website: www.cslforum.org).

Several multilateral environmental agreements dealing in particular with various forms of air pollution have also had an enormous impact on clean coal technologies. An example is the 1979 Geneva Convention on Long-range Transboundary Air Pollution and its seven protocols currently in force, which initially focused on mitigating acid rains in Europe, and had tremendous implications for clean coal technologies. The UN Framework Convention on Climate Change and its Kyoto Protocol as well as other possible future approaches for international co-operation on mitigating climate change – some of which directly target clean coal technology dissemination – may also have important implications.

3.3 Professional associations

3.3.1 The World Coal Institute.

The World Coal Institute (WCI) is a global non-profit, non-governmental association of coal enterprises, working worldwide on behalf of coal producers and coal consumers.

The objectives of the World Coal Institute are to:

- Provide a voice for coal in international policy debates on energy and the environment;
- Improve public awareness of the merits and importance of coal as the single largest source of fuel for electricity generation;
- Ensure that decision makers - and public opinion generally - are fully informed of advances in modern Clean Coal Technologies that steadily improve the efficient use of coal and greatly reduce the impact of coal on the environment;
- Broaden understanding of the vital role that metallurgical coal fulfils in the worldwide production of the steel on which all industry depends;
- Support other sectors of the worldwide coal industry in emphasising the importance of coal and its qualities as a plentiful, clean, safe and economical energy resource;

- Promote the merits of coal and upgrade the image of coal as a clean, efficient fuel, essential to worldwide generation of electricity and steel manufacture.

Membership is open to coal enterprises worldwide. Present membership is drawn from six continents, with member companies represented at Chief Executive level. The WCI has numerous publications, conferences and workshops and a website: www.wci-coal.com

3.3.2 The Coal Industry Advisory Board

The Coal Industry Advisory Board (CIAB) is a group of high level executives from coal-related industrial enterprises advising the IEA on measures to encourage investment in coal production, transport and power generation. Current members are from 17 countries accounting for about 75% of world coal production.

In recent years, the CIAB has focused attention on clean-coal technologies for power generation. The current work programme continues with work on near-zero emission technologies for coal-fired power generation and on sustainable development and coal, thereby acknowledging that coal security is as important as the effects on the environment.

Numerous books, brochures, and an annual market report are published by the CIAB, as well as some papers made available on their website: http://spider.iea.org/ciab/index.html.

3.3.3 The EURACOAL

The European Association for Coal and Lignite (EURACOAL) integrates associations and companies representing the coal industries of Austria, Belgium, France, Germany, Great Britain, Greece and Spain, and the relevant organisations of the New Member States: Poland, the Czech Republic and Hungary, as well as Romania, Bulgaria, Slovenia and Serbia.

EURACOAL is the voice of the coal industry in Brussels. Its task is to promote coal's contribution to security of energy supply within the enlarged EU and to price stability. EURACOAL provides a meeting platform for its members and represents their interests in Europe by dealing with European institutions and political organizations and distributes coal information. Website address: http://euracoal.be/.

3.4 The role of technology collaboration

Wide technology deployment usually needs to be preceded by major R&D efforts, demonstration phase and market introduction. Clean and efficient coal technologies show various levels of maturity in this respect. Direct treatment of coal and flue gases encompasses well established, proven, and commercialised technologies – but carbon dioxide capture and storage is in its infancy for large scale applications. Regarding efficient power generation technologies, the situation varies. Supercritical steam and CFBC plants are commercial, while Pressurised FBD and IGCC are subsidised demonstration projects.

The clean coal case suggests that the form of international collaboration depends heavily on the degree of maturity of a particular technology: open international collaboration is possible only for the very new and risky technologies, such as carbon dioxide capture and storage.

Public-private partnership arrangements, also at international level, are being created for the proven but not yet competitive technologies and for demonstration purposes; for the mature technologies, more competitive framework is created. In this latter case international information exchange is still possible, although joint collaborative projects face major constraints resulting from property rights and confidentiality agreements.

International collaboration may have played an important role in keeping some renewable energy technologies alive during times of weak or inexistent policy support in most countries (e.g. concentrating power solar technologies, Philibert 2004b). The role it plays with clean coal technologies is of a different nature. Cost-shared RD&D programmes naturally save money. Exchanging, processing and synthesising abundant information may play an even more important role by accelerating diffusion of knowledge and understanding on technologies and their environmental, economic, social and policy implications. Arguably, with respect to engineering, this role can be played by multinational industries and consulting companies. The more political aspects may be better dealt with under the various forms of international technology collaboration considered here.

In accelerating economic growth, current globalisation simultaneously increases the pressures on the environment, accelerate learning-by-doing processes and economies of scale that reduce the costs of new technologies, and provides more opportunities for cleaner technology diffusion and transfer (Philibert 2004a). It is important that governments develop both domestic and international environmental policies so that these conflicting trends result in an overall improvement in the environment.

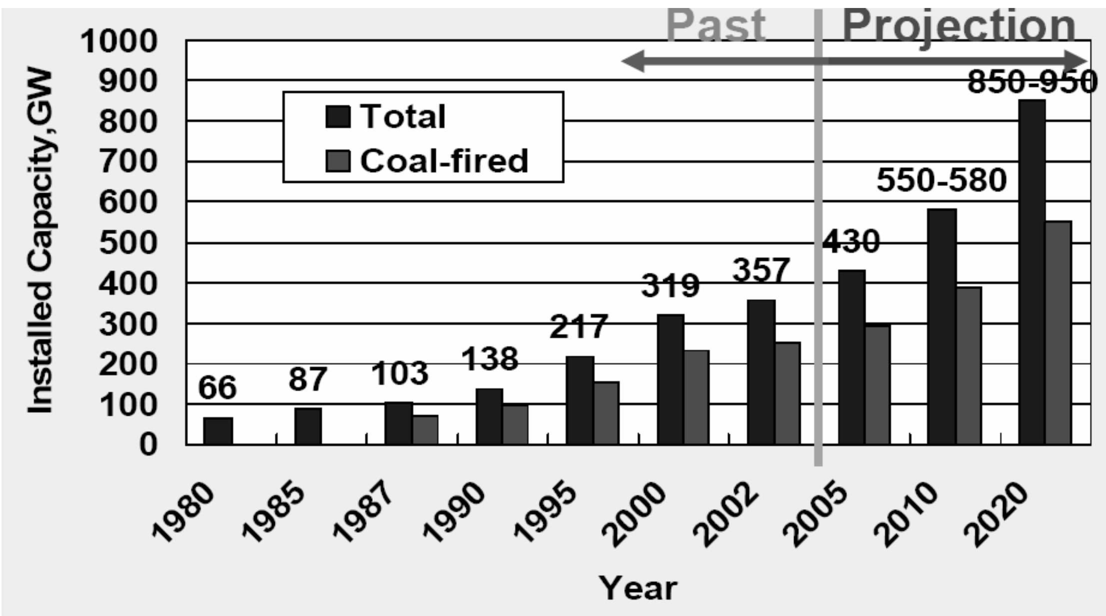
4. Collaboration with Developing China

China provides an important case study for collaboration with developing countries as it attracted many international clean coal technology projects. From 2001 to 2003, the proportion of global orders of new coal-fired power plants placed in China has been higher than 80%. In this section, we describe the Chinese coal situation, including environmental aspects; we then assess Chinese efforts to acquire technology through patents, bilateral collaborative efforts, development banks programmes and finally the GEF project on efficient industrial boilers.

4.1 Coal use in China

China expects its power generation to at least triple in the next twenty years, and coal, which currently provides three quarters of power generation, is expected to show the biggest increase. The IEA (2004a) projects a total capacity of 1187 GW in 2030 against 360 GW (in 2002). Coal-fired plants would total 776 GW – a decrease due to rapid growth of gas-fired generation and renewables. Another comparable projection is shown in Figure 2.

Figure 1: China's Power Industry Development



Source: Zhao 2004

More than three quarters of electricity generated in China is from coal combustion. Power plants, however, represent only half of Chinese coal consumption – a much lower share than the world average of about 69%. Various direct and indirect usages in industry and energy sectors account for another 42%, while end-use consumption in the residential and commercial sectors account for the remainder. About 40% of Chinese coal is burnt in half million "industrial boilers" in industry and in district heating systems. Conversely, over 95 % of industrial boilers in China burn coal.

The two most important sources of demand for industrial boilers are light industry and the textile industry, which require process heat and power; and space heating for individual apartment buildings, district residential areas and commercial buildings, particularly in northern Chinese cities.

Industrial boilers in China have small unit sizes by international standards. Over half of them in the mid 1990s produced only 1 to 4 tonnes of steam per hour. Chinese industrial boiler designs and production methods were based on pre-1950 design principles. Typical efficiency levels for Chinese boilers are in the range of 60-65%, compared to at least 80% in developed countries.

4.2 Environmental consequences of coal use

Major cities in China are some of the most polluted cities in the world, largely due to high rates of coal use. More than 500 Chinese cities are said to have air quality standards below the World Health Organisation's (WHO) criteria. Particulate and sulphur levels exceed WHO and Chinese standards by a factor of two to five. Chronic obstructive pulmonary disease is the leading cause of death in China, partly because of ambient outdoor and indoor pollution levels. The latter, mostly from burning coal or biomass for cooking and heating, is estimated to cause 110,000 premature deaths each year. The expected increase in coal use would, however, raise sulphur dioxide emissions from power plants from 8.5 million tonnes in 1995 to 21 million tonnes in 2015.

An investigation based on data for 50 million people in 26 cities showed that the average PM10 pollution in urban districts and in control districts were 460 μg/m3 and 220 μg/m3, respectively, and the corresponding average mortality from lung cancer was 14 per cent and 7 per cent, respectively. Every 100 μg/m3 increase in total suspended particulate concentrations also led to a 6.75 per cent increase in the incidence of chronic broncho-pneumonia in coal-burning areas (WHO, 2000).

With respect to energy-related CO2 emissions, China is comparable with the European Union at about 15% of world emissions – behind the largest emitter, the US. However, coal is responsible for 80% of China's emissions against 26.3% in Europe. Increased coal consumption in China has also important price consequences for other consumers.

4.3 Clean coal

Primarily for domestic environmental motives, the interest of the Chinese government in clean coal technologies is beyond any doubt. As in other countries, advanced clean coal technologies have substantial potential to improve the efficiency of coal-based power generation and to reduce the harmful impacts of power generation. The average cost of power generation from clean coal technologies is declining and might make them eventually competitive with conventional pulverized coal (PC) steam plants.

The dominant installed technology is pulverised coal combustion with a subcritical steam cycle. Units range widely in sizes from less than 25 to 660 MW. There are still a large number of these subcritical units under construction. Ten supercritical units were in operation in 2003 and twenty more units were approved for construction. There will likely be a surge towards 1000 MW power plants with ultra-supercritical steam conditions (Minchener 2004). The National Development and Reform Commission (NRDC) has recommended advanced supercritical plants for large scale power generation and most recent orders have been for supercritical units. IEA experts indicate that supercritical plants totalling more than 60 GW of capacity were recently ordered.

Since the 1960s, Chinese engineers have developed their own designs of small fluidised bed combustion equipment independently of early efforts in other countries (Watson & Oldham 1999). Over 1000 commercial circulating fluidised bed (CFB) boilers have been put into operation since 1989 and fifteen 300 MWe CFB boilers are in the planning or construction stage (Minchener 2004). More than 30 GW of cogeneration plants are currently in operation, notably in the coldest parts of China.

IGCC is not yet a fully mature technology, even in developed countries, where it delivers electricity at a higher cost of about 20%. The main risk factors include capital cost over-run, construction delay, and shortfalls in plant availability and performance. The cost and the risk disadvantages are substantially higher in China, where the average cost of power generation from an IGCC plant would be 32% higher than power from a PC plant; the overall risk factor would be 23% greater, according to the Nautilus Institute (1999). Consequently, there is only 1 IGCC prospect currently in China, for a demonstration plant at Yantai.

There is however, considerable knowledge of coal gasification with many examples in the chemical industry for production of fertiliser chemicals. This explains why polygeneration has been suggested as a more realistic alternative for China (Zheng et alii 2003; TFEST 2003). Based on coal gasification ("syngas"), polygeneration systems can produce a variety of energy products: clean synthesis gas and electricity, high-value-added chemicals, high-value-added fuels for vehicles, residential and industrial uses, and other possible energy products. Gasification enables conversion of coal – including high-sulphur coal resources - with very low levels of air pollution compared to most existing coal combustion technologies in China. A recommendation of the China Council for International Cooperation on Environment and Developed made in 2003 to the Chinese Government essentially equates coal modernisation with polygeneration through gasification.

An extensive review of the norms and standards for existing and new plants of different types in various parts of China, and other instruments such as effluent charges, are beyond the scope of this paper. They are usually less stringent than equivalent norms and standards in OECD countries, but are frequently revised and tightened. However, they might have little impact given the widespread absence of monitoring equipment, which leads to poor enforcement (Watson & Oldham 1999).

The Chinese government wishes to see large power stations equipped with FGD burn high sulphur coal and leave low sulphur coal for smaller boilers without FGD. Current practice, however, is exactly the opposite: to fulfil the more severe standards on large boilers low sulphur coal is burnt in large power plants while smaller boilers only have access to high sulphur coals.

Despite the government policy emphasising the construction of larger, more efficient units of 300 to 600 MW power plants, the main increase in generating capacities consisted of hundreds of smaller units just a few years ago. In 2000, units smaller than 200 MW still represented 65% of a total capacity 237 GW, emitting 60% more CO2 per kWh than larger units (Novem, 2003). In 1999 the Nautilus Institute (1999) expressed concern that "many of the new plants being built by the local governments are in unit sizes of 50 MW or less. The main reason is that these small units are easier to finance."

Recently, however, some small units have been shut down and replaced with larger and more efficient units. Moreover, 25~30 GW generation units with unit size equal to or smaller than 50 MW were to be shut down before 2005, and all remaining units were to be shut down before 2010, while retirement of units of a size equal to 100 MW will start before 2010. (Guo & Zhou 2004).

China's main concern is a power shortage according to IEA experts. By the end of 2003, 21 provinces were reported to have a shortage of electricity (Cheng 2004), with a growth in production of 15% per year. Emphasis may be put on shortening siting, permitting and construction delays in such a context. This emergency situation may turn out to be a primary obstacle to technical improvements.

Minchener (2004) suggests a similar reason for the failure to introduce emissions trading schemes in China – in about 10 cities: "It has not proved possible to implement a meaningful scheme because of the overall shortage of power and the need to operate each power plant at maximum availability. (…) In the near term the overwhelming need to generate power, with demand exceeding supply, will mean that such schemes cannot be effective."

More efficient designs can be fully competitive, as lower fuel costs compensate for higher initial capital costs; however, the lack of up-front capital can still be a barrier. End-of-pipe techniques, such as FGD, always entail positive costs, and can only be disseminated thanks to environmental regulations. Other techniques, however, such as CFB or polygeneration, can use a great variety of coal quality and help use other fuels (such as biomass), as well as reduce emissions. This might explain why these technique are easier to implement in China.

4.4 Technology transfer through patent acquisitions

Jin & Liu (1999) listed patent acquisitions of various clean coal technologies by Chinese enterprises: for coal extraction & preparation equipment; for power equipment design and manufacture technology; for industry boiler design and manufacture technology and for desulphurization and dust-removal technology for coal-boilers. The acquired technology mainly includes dust-removal devices. There is only one project for desulphurisation. All were fully mature technologies in developed economies.

Analysing these patent acquisitions, Jin & Liu note that the acquiring entities of technologies are mainly large or super-large enterprises. By contrast, most of medium or small enterprises are the major producers of thermal-energy equipment with high energy consumption and high GHG emission. But few of them have taken part in the transfer process of industry boilers. There are three reasons for this: their limited capital and weak technology strength, the lack of necessary information and technology transfer experience, and the government's approval procedure and policies for technology transfer. They note, however, that the pace of patent acquisition has slowed after 1992 while the number of direct imports grew, which they attribute to the economy reforms and the breaking off of the mechanisms for technology transfer previously dominated by the government. This was, however, before the GEF project on industrial boilers took place (see below 4.5).

Jin & Liu compare various methods for China to acquire clean coal technologies. They warn that direct imports of clean coal technologies are profitable for importing companies but do not entail real technology transfer: *"As buyers are usually the direct end-users of imported equipment rather than manufacturers, and imported equipment will be used entirely as capital goods, it will unlikely enhance imported technology. Buyers of the imported technology will not acquire any knowledge of the design and manufacturing of the equipment."*

By contrast, patent acquisition allows effective technology transfer but it is a risky strategy. *"Since the system of intellectual property right protection is still in the process of strengthening, violations of intellectual property rights often take place. Because the enterprise's intellectual property rights can not be effectively protected, the risk of introducing technology will be very high.*" Their preference, however, goes to absorbing technologies through foreign direct investments (FDI): *"FDI can bring capital, technology and management skills which are necessary for China to develop its clean coal technology. And what is more, it can also have demonstration effects, stimulate competition and indirectly accelerate technology transfer."* Amongst the limits of that method is the frequent tight control of the investors over the technology; therefore host-enterprises can hardly obtain the core elements of the technology.

Overall, several factors limiting clean coal technology transfers to China can be found in the country, from weaknesses of the domestic industry to low energy prices and emission charges. Others may be found in the strategy of the multinationals, according to Jin & Liu (1999): *"Their actual strategies are the following: to export only equipment, not technology; to transfer only outdated technology once new technology has been developed; and to make transfer conditions extremely hard to meet, so that Chinese enterprises find them hard to accept."*

As a result, the Chinese are keen to establish a position whereby much of the equipment for clean coal and other technologies are subsequently manufactured in China in order to ensure that costs can be kept competitive. International technology/equipment is not transferred to power plants directly. Rather, foreign technology is transferred to selected power equipment manufacturers under a royalty licence arrangement. To date, this approach has been used for the complete design and manufacture technology of 600 MWe boilers, turbines and generators, 100 MW and 300 MW CFB boilers, and some components such as burners, FGD systems and others. (Minchener 2004)

4.5 Bilateral collaboration

In 2001, China emphasised its desire to explore measures to accelerate the deployment of clean coal technologies and requested the IEA to look into this and help develop recommendations on how to accelerate the clean coal technology deployment in China. A study (Novem 2003) was made considering collaboration with the World Bank, the Asian Development Bank and the United Nations Development Programme, as well as with the EU, Australia, Germany, Japan, the Netherlands, the United Kingdom and the United States. All the programmes considered aimed at assisting China in improving the environment.

Most bilateral programmes aimed also to generate economic gains for Western companies through trade or technology transfer – traditionally in such programmes, governments tend to promote their own industries. The German programme was different in that economic gain was less an objective than poverty alleviation in China. Industrialised countries adopted different approaches in this cooperation:

- Australia focused on the coal trade position and blended coal combustion;
- Germany focused on mature technologies, towards easy adoption in China;
- Japan worked on almost all possible technologies and made a great number of demonstration projects;
- The Netherlands focused on their own technologies;
- The UK focused on the technologies that China might need and appreciate;
- The US made great efforts on IGCC and advanced combustion technologies.

Meanwhile, the World Bank, up to 2000, and the Asian Development Bank have participated in the financing of various large coal-fired plants and related projects (see below), while the UNDP has focused on other energy sources and the EU has focused on management, training and knowledge transfer.

The results of these efforts are somewhat mixed. Most demonstration projects have worked, such as those of Japan (circulating fluidised bed boilers, simplified flue gas desulphurisation, coal briquetting plants, coal preparation technologies, etc.) but most have not led to dissemination of these technologies beyond the demonstration projects (Oshita & Ortolano 2002, 2003). One possible exception is that of coal washing, which appears widespread in China and may be due to early collaboration with Japan. A number of German efforts, especially power plant performance optimisation, are said to have contributed to significant emission reductions (Novem 2003), but the report gives very little detail. One project deals with performance optimisation with fifteen measuring vehicles financed with a 10M loan from Germany's development bank KfW, which travel to power plants across China.

The Australian collaboration on two 125 MW existing units at the Banshan Power plant showed that increasing efficiency from 35% to 40% was possible and affordable using blended coals (Boyd 2004).

In 1995 the US DOE proposed an initiative for US government support for the promotion of CCTs in developing countries, requesting a $75 million budget necessary to support a small number of operations in China and Eastern Europe. The US Congress did not approve this additional allocation of financial resources to the Program. This refusal, according to the Nautilus Institute (1999) "emphasised the need for coordination of existing channels rather than adding a new mechanism for the financial support of CCTs in developing countries". The US DOE's effort, thereafter, shifted. It has, since then, focused on low-cost initiatives in the areas of information dissemination and training.

Amongst other collaborative efforts from the UK, one project aims at developing clean underground coal gasification (UCG) in China. However, as fully acknowledged on the British side, "*Whilst Chinese experts recognise the potential benefits of deep UCG technology, they have reservations regarding the high technology guided drilling, the cost of oxygen generation and the fact that deep UCG is unproven in large scale and sustained operation.*"

Meanwhile, several large new plants were built in China by Western companies, including the first supercritical pressure steam plants in Shanghai (1200 MW) build by a consortium led by Alstom and Sargent&Lundy.

After the study mentioned earlier (Novem 2003) another collaborative efforts with China was undertaken under the auspices of IEA, "*Best Practices in Chinese Power Plants*". A team of experts from IEA member countries undertook a detailed audit of two typical Chinese power plants and formulated recommendations of cost-effective efficiency and environmental improvements. Their report was presented to a wide audience from the Chinese power sector.

4.6 Development banks

In the power sector, the World Bank helped build 20 percent of the transmission lines and 20 GW of generating capacity, including the first 300-megawatt, 600-megawatt, and 900-megawatt generating plants in China.

Apart from its direct contribution to supply expansion, the Bank leveraged its influence in two ways. First, Bank analytical and advisory activities (AAA) contributed significantly to sector policy reform and institutional development, especially in the power sector. Over the course of the decade, and especially in the past five years, China introduced extensive policy and institutional changes that were first outlined in a 1994 Bank report on power sector reform and further developed in other AAA and through pilot projects. These changes include price reform, separation of management and regulation, corporatisation of government energy production units, introduction of competitive power markets, and improvements in the policy framework for private participation in infrastructure. The energy sector is perhaps the most successful example of the Bank's dual track approach to lending and policy reform.

Although China remains one of the most inefficient major economies in terms of primary energy use per unit of GDP (3.3 times higher than the United States in 2001 and 40 percent higher than India), unit energy use improved by 30 percent between 1995 and 2001. In a period of increasing industrial production, industrial pollution loads have fallen drastically since the late 1990s.

The environmental performance of Bank-funded coal-fired power plants has been very good when compared with non-Bank plants. Not only are emissions much lower, but also China's power authorities themselves have taken responsibility for environmental management and supervision.

The Bank has financed several large hydro and multi-purpose dams that substitute for thermal coal-powered plants. The Bank has also maintained a dialogue with the government on clean coal technologies over the past five years through technical and policy studies, awareness workshops - the last one in September 2004. (World Bank 2004)

One difficulty for World Bank clean coal technology financing is the need for project sponsors to demonstrate that the project is economically and financially viable (Nautilus Institute 1999).

The Asian Development Bank (ADB) is very active in the power sector of China. It provides support to power plant rehabilitation and efficiency improvement projects. The ADB is a bit ahead of the World Bank Group in terms of its involvement and support of CCTs. In 1988, it financed a 2 X 600 MW supercritical coal-fired power plant in Anhui Fuyang that promises to have higher efficiency than a subcritical conventional plant. It also financed a study on the Yantai prospect for an IGCC plant.

4.7 The GEF

China has been the host of the largest-ever GEF project, launched in 1996 to introduce efficient industrial boilers in the country. As noted by the designers of the original GEF project: "*if the thermal efficiency of the current stock of industrial boilers in China could be raised to those of similar sizes in the developed countries, coal consumption by small boilers could be reduced by 60 million tons per year-a saving of about 17 percent*" (GEF 1996).

One must note, however, that efficient industrial boilers had been imported into China in previous years, mainly from Germany, the US and Japan (Jin & Liu 1999).

Retrofitting existing boilers had been deemed insufficient for sustaining efficiency improvements in the sector, as the demand for new boiler technology in China grew, making existing boilers an ever-smaller percentage of the total market; the lifespan of a typical boiler in China was only about 15 years; and improved boiler production techniques was considered crucial for raising thermal efficiency by minimizing exit gas temperature and excess air in the boiler. There are good examples, however, of 10% increases of thermal efficiencies with existing industrial boilers, in particular as a result of an earlier UK-China technical assistance project (Minchener 2004).

A more ambitious project was envisioned by GEF: *"Upgrading existing Chinese boiler models through the introduction from abroad of advanced combustion systems and auxiliary equipment, especially the application of simple automatic controls; adoption of new high efficiency boiler models through the introduction of modem manufacturing techniques and boiler designs suitable for burning Chinese coals; and technical assistance and training for boiler producers and consumers"*, for a total cost of $100M with GEF contributing a third of this amount.

Investment funding was provided to nine Chinese boiler manufacturing enterprises in two phases. Under Phase 1, GEF funds were used to acquire advanced international technologies for new and existing Chinese industrial boilers models and produce the model industrial boiler units. At the end of Phase 1, the model units were evaluated against agreed technical, environmental and safety performance indicators, while project enterprises were required to show viable production, marketing and financing plans for Phase 2. Under Phase 2, GEF grant funds were used to acquire advanced production equipment from abroad to upgrade their production lines to allow mass production of the successful models.

Emission reductions from this project have been estimated over the total lifetime of the investments to 637 Mt representing a third of the total 1.7 Gt for all 104 active climate-related GEF projects (GEF 2004). This resulted in a cost per avoided tonne of CO_2 of about 3 US cents. However, Minchener (2004) note that the new boilers have achieved efficiency levels in the range 80-85% *"under the artificial conditions of a verification test"*. Under normal conditions of operation, with typical boiler-house operating staff and typical supplies of raw coal, the benefits can be much lower. Minchener (2004) concludes that coal quality remains a critical issue.

The GEF has drawn lessons from its successes and failures. *"Projects are more successful when they have a clear concept of which market they wish to transform, and which market barriers have to be overcome and have a well-defined and narrow target group. Examples of focused projects are the HEECP, which targets the financial market through banks as the primary target group; China's Energy Conservation project focusing on industrial boilers; and projects targeting EE products for specific market segments or aiming to develop a submarket—the ESCO industry or the municipal market—or projects that target key manufacturers with a dominant market share. Projects that target different and varied groups tend not to be as effective.* (GEF 2004)

The Climate Change Task Force has discussed the possibility that there may be little justification for GEF energy efficiency interventions in industry because many of these investments are financially viable and have short paybacks. The task force believes there are at least two factors that can justify GEF interventions in this area. *"One is that industry accounts for 40 percent of global energy use; in China it accounts for nearly 70 percent of national energy use. The potential for major GHG reduction in this sector cannot be ignored. The second reason is that many industries in developing countries are simply not aware of the potential to reduce costs through EE improvements. These countries also face significant barriers in terms of the favourable policy frameworks, the availability of finance, undeveloped ESCO markets, and lack of capacity."*

A number of GEF projects have attempted to tackle a range of these barriers through multiple strategies (for example, Malaysia and Kenya, both by UNDP). However, these projects often progress no further than undertaking a number of energy audits, raising awareness, building capacity, and piloting a few projects. According to the Climate Change Task Force (GEF 2004), "*sustainable market transformation seems much more likely if specific market segments are tackled in a systematic and sustained manner. The China Boiler project is an excellent example of what can be achieved*."

The Scientific and Technical Advisory Panel to the GEF has also drawn its own lessons from GEF's China Efficient Industrial Boiler Project. They are as follows:

- "*The domestic adoption capacity in the target country is crucial for technology selection and transfer. Country drivenness and local involvement are prerequisites for such projects.*

- *"Capacity building should be emphasized in the technology transfer projects. Knowledge transfer is a key component of technology transfer. Success of technology transfer depends on the adoption by local manufacturers of the transferred knowledge, in addition to the hardware and software components of technology transfer.*

- *"The technology transfer, in general, occurs between business entities. The technology procurement will follow the market rules even under GEF and government intervention. The project design and implementation schedule should avoid being too drawn out and complex, hindering the active involvement of the private sector.*

- *" Market barrier removal for technology transfer is an important element to technology transfer projects. Without grant resources for the market barrier removal, otherwise the adoption and replication of new technology will be difficult.*" (STAP 2001)

These lessons draw mostly from comparing the successful industrial boiler project in China with other GEF projects. Comparing this project with other less successful bilateral technology transfer projects provides additional insights.

The industrial boilers project did not seek simply to market and sell more efficient boilers to China. It transferred instead the knowledge, the intellectual property rights and the tools – including a few foundry lines – allowing the Chinese boiler industry to produce its own efficient boilers, i.e., a combination of knowledge and hardware transfer. The risk of having Chinese manufacturers sell hardware back to industrialised countries was low and did not constitute a barrier. Another important dimension was the collaborative nature of the effort, because of the need to adapt the technology to the local market conditions, e.g., to local coal resource characteristics.

This lesson is well illustrated by the Nautilus Institute (1999) "*The literature offers different perspectives of technology transfer by viewing it as a commodity, or knowledge, or a socio-economic process. In classical economics, technology transfer is viewed as a commodity, e.g. obtaining a design document, or purchasing new vintage equipment. More recent studies propose that technology transfer is knowledge and is brought about through a learning process; purchase of machines and blueprints by itself does not constitute technology transfer. The contemporary advocates of international transfer of technology view the concept to encompass a combination of hardware, services, and knowledge. They also propose the term "technology cooperation" as a replacement for technology transfer, because the latter does not satisfactorily represent the two-way relationships involved in the matter. This contemporary view adds many dimensions to the phenomenon, most of which are not well understood."*

5. Lessons Learned

5.1 Context: Strong demand growth may slow supply-side progress

The study has highlighted an interesting point, although it does not directly relate to international technology collaboration. It is however an important element in considering how to best foster technological transfer. While government policies, international collaboration and technology transfers of various forms promote clean coal technologies in China, the rate of improvements in this country seems to be slowed by the strong electricity demand growth. Companies may be so concerned by the risk of electricity shortage that they often choose the fastest solution which is often a small-scale plant based on local technology. Moreover, the building of new plants of a more efficient design does not always induce the closure of older, smaller and less-efficient ones.

This is somewhat paradoxical. In a country with a slow economic growth there would be slower capital stock replacement and therefore fewer opportunities for introducing new and efficient technologies. The dynamism of the Chinese economy does contribute to technology improvements, as shown by the recent surge of large supercritical power plants. However, if electricity demand growth is too rapid, it might dampen the effects of technology improvements.

One way of solving this problem might be to combine improved international collaboration and domestic policies towards end-use energy efficient technologies slowing the growth of energy demand, with collaboration on supply-side technologies.

5.2 Lesson 1: Technology transfer is more than equipment transfer

The mixed successes of bilateral efforts to bring clean coal technologies to China, and the impressive success of the GEF project on industrial boilers in China suggest that co-ordinated, sustained and systematic efforts are needed, and that they must be driven by host countries' needs and take into account diverse national circumstances.

Moreover, technology transfer extends beyond the mere transfer of equipments to "end-users" (utilities in this case) but includes the transfer of the ability to replicate and manufacture locally similar equipments, as well as knowledge and training of fabricants and users.

While the lack of capital certainly remains a barrier to technology transfer, it may be that the financial contribution from the GEF played a more important role in making GEF experts worth listening to than in adding to local financial resources. The transfer of western efficient industrial boiler technology, including manufacturing, to Chinese boilermakers was certainly the most important factor for this success.

While decentralised economic instruments for the transfer of equipments, such as the Kyoto or other mechanisms involving the private sector, could help address financial barriers, it remains to be seen if they can be efficient as well for full transfer of technologies.

5.3 Lesson 2: IPR protection matters for transferees as well

Weak protection of intellectual property rights in developing countries is often mentioned as a barrier to technology transfers as technology owners fear that they their technology may be "stolen" – especially if they sell equipment or undertake an investment without any license agreement. This risk may be seen as especially important in a country that seeks actively to acquire technology, i.e. the capability to locally replicate and manufacture the imported equipments.

Arguably, however, after the technology has been sold it belongs to the acquirer, not to the sellers. What western companies fear most may be the risk of facing more intense competition on their own domestic markets from developing country exporters when they are not any weaker on technology – and this is why they are often reluctant to sell the most advanced technologies.

However this perception may be biased. Developing countries need clean and efficient technologies that are proven – they are not necessarily interested in experiencing the difficulties of the very latest inventions, even if they are more effective on paper. Many other circumstances – from staff capacities to coal qualities – may increase the risk of importing not yet fully-proven technologies. So the reluctance for transferring such technologies might be shared on both sides.

Thus, the most important problem with weak protection of IPR may be for developing country acquirers themselves, as is suggested in China's case study. Host-enterprises might be reluctant to acquire the technology that their own competitors on their own markets could copy while not having to pay, note Jin & Liu (1999).

Developing country governments may often perceive that the problem of IPR protection is for foreign investors only. As they do not have much experience with market institutions, they may not perceive that domestic investors also suffer from weak IPR protection. This may not only impede foreign direct investment or acquisition of clean and efficient equipments, it may also deter developing country companies from taking the necessary measures to acquire new technologies.

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