Developments in China's coal-fired power sector

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Abstract

China's power generation capacity has increased rapidly to support the growth of the Chinese economy, and by end of 2008 it had reached 792 GWe, which comprised some 170 GWe of hydropower, 601 GWe of thermal power (nearly 75% of the total), almost all of which is coal fired, nearly 12 GWe wind power and 9 GWe nuclear. The expectation is that the overall capacity will grow to some 1500 GWe by 2020, but with a significant introduction of zero carbon and low carbon power generation technologies, such as nuclear, wind and solar power, together with further growth in hydropower and perhaps some additional natural gas fired plants. Coal fired power generation, although it will represent a smaller proportion of the total capacity in the future, will still grow in absolute terms in China. The average efficiency of the coal fired capacity will continue to rise significantly as the Government continues to introduce very large supercritical and ultra-supercritical pulverised coal units with good environmental controls, and large state of the art circulating fluidised bed combustion units, while closing small, old and low efficiency units.

This coal power plant modernisation programme has involved cooperation and extensive technology transfer via licences and joint ventures with international equipment suppliers. Chinese manufacturers are now in a position where they have advanced the technical quality of their products such that they can gain significant export opportunities, especially as their products are very cost competitive compared to OECD options.

With regard to climate change, China is examining the applicability of CCS to its national situation. This includes an extensive R&D programme, with the aim to establish one or more demonstration projects. While China is keen to cooperate with other nations, it is already well placed to build most of the required equipment to international standards. If it does introduce overseas technology, it seems likely that the Government will require that similar technology transfer arrangements will need to be implemented as for the introduction of clean coal technology. This means that China will then be well placed to play a major role in ensuring that technology deployment becomes established both nationally and also worldwide. This suggests a global market in which China is both a user and a prominent supplier of cleaner coal technologies including CCS.

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Acronyms and abbreviations

AC	alternating current
ADB	Asian Development Bank
B&W	Babcock and Wilcox
CCS	Carbon dioxide Capture and Storage
CCT	Clean Coal Technology
CFBC	circulating fluidised bed combustion
CHP	combined heat and power
CO_2	carbon dioxide
CSG	China Southern Power Grid Company
DBC	Dongfang Boiler Company
DC	direct current
DCS	distributed control systems
DECC	Department of Energy and Climate Change
DME	dimethyl ether
DTC	Dongfang Turbine Company
EC	European Commission
EOR	enhanced oil recovery
EPC	engineering, procurement & construction
ESP	electrostatic precipitator
FGD	flue gas desulphurisation
gce/kWh	grams of coal equivalent per kilowatt hour
GDP	gross domestic product
GE	General Electric
GHG	greenhouse gas
GWe	Gigawatt electric
H_2	hydrogen
HBC	Harbin Boiler Company
HPEC	Harbin Power Equipment Corporation
HRSG	heat recovery steam generator
HTC	Harbin Turbine Company
IGCC	Integrated Gasification Combined Cycle
IPR	Intellectual Property Rights
JV	Joint Venture
LNG	liquefied natural gas
MEP	Ministry of Environmental Protection
MHI	Mitsubishi Heavy Industries
MOST	Ministry of Science and Technology
MPa	MegaPascal
Mt	million tonnes
MWe	megawatts electric
NDRC	National Development & Reform Commission
NEA	National Energy Administration
NOx	nitrogen oxides
NSCR	Non-Selective Catalytic Reduction
NTC	Nanjing Turbine Company
OECD	Organisation for Economic Co-operation and Development
PC	pulverised coal
R&D	Research & Development
R,D&D	Research, Development & Demonstration
RMB	Reminbi
SAPP	Southern African Power Pool
SBWL	Shanghai Boiler Works Limited
SC	supercritical
SCR	selective catalytic reduction
SECPG	Shanghai Electric Corporation Power Group
SEPA	State Environmental Protection Administration
SERC	State Electricity Regulatory Commission
SG	State Electric Power Grid Corporation
SNCG	Shenhua Ningxia Coal Group
SNG	synthetic natural gas
SOE	State Owned Enterprise
SO_2	sulphur dioxide
SPC	State Power Corporation
STWL	Shanghai Turbine Works Limited
UK	United Kingdom
USC	ultra-supercritical
USA	United States of America
US$	United States dollar
US DOE	Department of Energy
VAT	Value Added Tax

Contents

1 Introduction

1.1 Background

Since 1990, the Chinese economy has achieved an average annual growth rate of close to 10% and at the end of 2008 it had the third largest overall GDP in the world after the USA and Japan (China View, 2009a) although on a per capita basis it was one-fourteenth that of the USA (The Economist, 2009). Increasing amounts of electricity are needed to support this ongoing industrial growth and, between 1990 and 2004, generation capacity increased more than threefold. Subsequently there were further increases in the rate of power plant capacity introduction, up to 15% year on year, most of which has been coal based (Global Power Review, 2007). By the end of 2008, the total installed power generation capacity reached 792 GWe. This comprised some 170 GWe of hydropower, 601 GWe of thermal power (nearly 75% of the total), almost all of which is coal fired, nearly 12 GWe wind power and 9 GWe nuclear (CRI, 2009). The year-on-year increase in capacity is over 10% although, after the end of 2006, this represents a continued reduction from the peak level at that time.

For the future, the overall rate of increase is expected to ease further, perhaps to 7% year on year by 2020. This will continue to represent a very significant level of capital investment for the power generation industry. However, the focus of that investment is starting to change. There will be a significant level of spending to improve and integrate the transmission systems. At the same time, while investment in hydropower, wind power and nuclear power will increase, investment in coal-fired power generation will decrease although it is still expected to be significant (Reuters, 2008a). The Chinese Government expectation for the introduction of additional coal-fired plants is that the mix will comprise a very great majority of pulverised coal (PC) units, with the balance being circulating fluidised bed combustion (CFBC) systems, the latter being required for the utilisation of low grade coals and for waste materials in minemouth applications. This continuing overall growth means that there will continue to be significant coal supply and environmental compliance challenges for the coal-fired power generation sector (Minchener, 2004, 2007).

1.2 Structure of report

This report provides an update and in-depth review of the status of the Chinese coal-fired power sector, covering the period to end 2008. It includes a comprehensive survey of the current status of Chinese coal-fired power plants, and the likely development and deployment options within the overall power generation sector. This is complemented with comment on technology-related issues in the non-power industrial gasification sector, which might provide the basis for the subsequent introduction of gasification-based power generation systems. The capability and capacity to engage within an international context to address global concerns such as climate change and associated environmental issues are also considered.

The report is structured as follows. Chapter 2 provides a description of the Chinese electric power sector, with reference to its organisational evolution since the break-up of the State Power Corporation in 2002. Within the coal-fired sector, there is evidence of some changes in focus. This includes the formation of integrated energy companies, with the larger generation companies buying coal companies to better improve security of fuel supply as well as diversifying into the supply of coal-based chemicals. At the same time, the larger equipment manufacturers have formed commercial links with OECD suppliers to first introduce and then to manufacture modern power plants for use in the Chinese power sector and, subsequently, elsewhere. This is followed by a review of the recent policy issues and their impact on the diversification of the power generation choices available as China strives to broaden its technology portfolio while still maintaining very significant growth within the sector. Within the framework of the government forecasts for total future power plant development and deployment, comment is made on the impact that this will have on the introduction of further advanced coal-fired power plants.

Chapter 3 focuses on the core business of coal-fired power generation within China, which continues to dwarf activity in the rest of the world. This starts with a description of the various Government directives to improve overall coal use efficiency and environmental performance, and the effect that this is having on the numbers and sizes of units. This includes the closure of many of the smaller, less efficient units, in line with State Government directives, together with the introduction of advanced PC technologies with supercritical (SC) and ultra-supercritical (USC) steam conditions. The associated drive to introduce improved SO_2 and NOx control systems is then described. Information is also provided on the complementary activities to scale up CFBC systems while also introducing advanced steam conditions that are beyond anything yet undertaken on a commercial basis in the OECD countries.

In Chapter 4, there is an overview of the ongoing Chinese plans for development and demonstration of IGCC as an alternative to combustion-based power generation systems. This is complemented with an overview of the rapid introduction of large-scale gasification units for industrial applications, particularly the push to establish significant coal-to-chemicals projects using gasification technology, some of which is being undertaken by the major power generation companies as they diversify their activities.

In Chapter 5, the focus is on how the major Chinese equipment manufacturers, either on their own or in alliance with their OECD partners, have been making initial forays into the power sector equipment export markets.

There is increasing concern regarding global emissions of

CO_2, with a recognition that measures will have to be established to mitigate such emissions, especially in major coal using economies such as China, India, the USA and Europe. There are a number of initiatives that China has started to take and these are considered in Chapter 6, with the recognition that this is an area where international co-operation must play a key role in establishing possible ways forward.

Finally, in Chapter 7, the prospects and challenges for the future are considered and summarised.

2 The Chinese electric power sector

2.1 Organisational evolution

In 2002, the Chinese Government maintained a state-run near monopoly in the power sector, with 90% of the power transmission capacity and 46% of the generating capacity being part of the State Power Corporation (SPC). This excluded nuclear and very large hydro schemes such as the Three Gorges Project, which were also under direct State control via a different structure. In December of that year, as part of the ongoing reforms, the SPC was broken into eleven separate companies. These are all still State-owned and include two power grid operators, five electricity generation companies and four service companies (IEA, 2006).

The two power grid companies are the State Electric Power Grid Corporation (SG) and the China Southern Power Grid Company Limited (CSG). The former is the largest grid company, covering 26 provinces, with this territory divided among five regional subsidiaries. The latter was formed from the original grids of five southern provinces (Guangdong, Guangxi, Guizhou, Yunnan and Hainan). The grid companies also maintained a small share of the SPC's generation assets and took the lead in establishing certain new technologies for power generation. This included, for example, the SG taking responsibility for the now moribund IGCC project at Yantai, Shandong Province, which the newly established major generating companies (*see below*) did not consider part of their remit since it was not deemed a fully commercial prospect.

The five generation companies are the China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, and the China Power Investment Corporation. In 2002, the combined capacity of these five largest electric power generation companies accounted for some 45.6% of the total. The remainder were owned by many local small power companies, which are part of the county level government, large SOEs such as major coal producers, steel mills and chemical plants, plus investors from Hong Kong and Taiwan, as well as the two grid companies.

Finally, four power service companies were formed, the China Power Engineering Consulting Group, the China Hydropower Engineering Consulting Group, the China Water Resources and Hydropower Construction Group, and the China Gezhouba Group, which is a contracting engineering company particularly for hydroelectric projects and other large infrastructure ventures (Corporate Information, 2009). Thus these entities combined key ancillary services that had been previously integrated into the SPC.

2.1.1 The role of government

The National Development and Reform Commission (NDRC) is responsible for overall policy/long-term planning and overall management in all the industrial sectors. This has included the development plans for the power sector within the National 11th Five Year Plan (2006-10), which in the context of the coal-fired power plants is considered in Section 2.3.

There is a recently formed National Energy Administration (NEA) attached to the NDRC, with specific responsibilities for the energy sectors. This was established in 2008, as part of a move to strengthen the centralised management of energy sectors and deal with the major energy issues, while ensuring the sustainable and steady development of the national economy (Xinhua, 2008).

Previously, energy sectors in China were administered by the State Electricity Regulatory Commission (SERC), the NDRC and Ministry of Commerce. This was seen as administratively inefficient. The main responsibilities of the new administration include:

- The management of energy conservation and comprehensive resource use, including the preparation of standards and promotion of energy-saving technologies and equipment.
- The management of the oil and gas industry, including planning of oil and natural gas development, together with control of national and commercial oil reserves.
- The drafting of energy legislation.
- The planning of thermal and nuclear power development, including the management of the national power network
- The direction and coordination of rural energy development, including planning of the use of new and renewable energy.
- The formulation of suggestions on energy development strategy, together with the drafting of yearly plans, and industrial policy.
- The management of the coal industry, including the drafting of plans for coal mining, and the development of advanced technology for reducing pollution caused by coal burning.
- The implementation of international energy co-operation, including the drafting of strategies, laws, and policies for opening up China's energy sector.

Prior to this new structure being established, there was growing support for a ministry of energy to provide a means to make the country's energy institutions effective (Downs, 2008). It is understood that this position was not supported by the NDRC and the state-owned energy companies. The NDRC felt that the establishment of such a ministry would deprive it of a substantial portion of its portfolio and the associated tools of macro-economic control. At the same time, the energy corporations did not welcome the loss of direct access to China's leadership. It remains to be seen if the new arrangements will be effective for managing China's energy challenges and consequently the new administration may yet turn out to be a transitional arrangement.

Beyond the NEA, the Ministry of Science and Technology (MOST) continues to have responsibility for R,D&D, and in the context of coal this covers all market sectors but with an emphasis on the power sector and the establishment of advanced technology (MOST, 2009). The Ministry of Environmental Protection's remit includes the prevention and control of environmental pollution, and the safeguard of public health and environmental safety. Within the context of coal-fired power generation, the Ministry establishes environmental standards and emissions limits (MEP, 2009).

2.1.2 The generation companies

The Big Five power generation companies, formed from the break-up of the SPC, continue to be State-owned, although certain subsidiaries are quoted on the international stock exchanges. This has offered these companies a means both to raise capital for future expansion and to raise standards of corporate governance, transparency, and risk management, especially where they have sought to establish overseas ventures. When the generating assets of the SPC were divided amongst these five, it did not result in an exactly equal division of either assets or liabilities. For example the Huaneng Group had a greater share of the capacity, having received about 23% with the others each getting between 18% and 20%. It also received a greater share of the newer power plants and, as such, less staff liabilities (Minchener, 2004). At the same time, the division of assets was done in such a way that each had less than 20% of the market share in any one region. This has created some problems in establishing regional critical mass, even though all five companies have increased capacity with a vigorous building programme, in line with the State requirement to massively increase national power generation capacity. This has included the purchase from the two distribution companies of some of their generating assets (Market Avenue, 2007).

The importance of these five companies is emphasised in Table 1 (CEC, 2008). This shows at the end of 2007 that these companies accounted for 42.4% of China's total installed power capacity and generated 41.4% of total electricity. The capacity mix varies with company. Thus the installed capacity for Huaneng and, to a lesser extent, Datang is dominated by thermal (coal-fired) power plants. While the average coal consumption for coal-fired units in China was 357 gce/kWh, for the five largest power companies, it was 347 gce/kWh, albeit over quite a wide range. As such, these five companies exert a considerable influence on the coal-fired sector performance statistics.

As has been reported previously, wholesale and retail electricity prices are controlled and capped by the NDRC/NEA, as part of their macro-economic control of the sector (Minchener, 2007). However, the coal price is allowed to float and in recent years the price of power station coal has more than doubled, reflecting supply limitations. This has increased power generation costs. At the same time, the NDRC has not agreed to fully pass on fuel cost increases to the consumers. Consequently, the generating companies have accrued considerable financial losses, particularly up to mid 2008 when coal prices peaked and these fuel prices could not be passed on to the grid and the electricity end-users

Although international coal prices have fallen significantly in 2009, due to the global financial crisis, the Chinese coal producers were arguing for an increase in the price paid by the generators. The latter mostly rejected this and demanded a price reduction to reflect the decrease in demand due to fall in electricity demand. As the proposed domestic prices were above the international market level, in the first half of 2009, this led to a surge in imports as the larger generating companies chose to obtain supplies from alternative sources, while also buying from smaller suppliers and running down stocks at the power plants. For example, coal imports in the first four months of 2009 surged 56% to 22.8 Mt, far above market expectations (Reuters, 2009). The NDRC/NEA is currently drafting a reform of electricity prices, with an

Table 1 Capacity data for the five largest power generation companies in China at the end of 2007 (CEC, 2008)

Item	Total of China	Huaneng	Datang	Huadian	Guodian	China Power
Ratio between thermal and hydro power installed capacity	3.8	11.1	9.0	2.9	4.0	2.4
Installed capacity, net GWe	713	72	65	63	60	43
Proportion of China's total installed net capacity, %	100	10.0	9.1	8.8	8.4	6.0
Annual power generation, 10^9 kWh	32,559	3,270	3,048	2,563	3,468	1,879
Proportion of power generation in 2007, %	100	10.0	9.4	7.9	7.6	5.8
Average net coal consumption, gce/kWh	357	337	343	347	348	358
Average net coal consumption for the ≥600 MWe units, gce/kWh		328	328	327	327	325
Proportion of coal fired plant with FGD installed, %		57	65	68	–	23

The metric unit for measuring aggregate energy production and use is the gram of standard coal equivalent (gce), equal to 29.31 J on a lower heating value basis.

announcement of their plans expected by the end of 2009. The issue of coal imports and their growing importance for China are covered in other studies by the Clean Coal Centre (Minchener, 2007, 2009).

In this context, there have been moves by the major generating companies to establish medium- to long-term coal supply agreements with various State-owned coal production companies in order to introduce some stability into a major cost item for their core business (China CSR, 2008). At the same time, they are diversifying their income streams, through the establishment of vertically integrated energy companies. The leader in this has been the Huaneng Group.

Huaneng's power capacity in China is expected to reach 80 GWe by 2010, which will require the annual supply of some 200 Mt of coal. It is considered too risky to purchase all that coal in the market. Accordingly, it is buying up coal mining interests, with a declared intention to source some 45 Mt from locations such as Inner Mongolia, Shanxi Province and the western regions (Reuters, 2008a). It also has overseas interests, including a part share in the Monto Coal Joint Venture, which is a large Australian coal project. This can supply up to 10 Mt of coal each year to those Huaneng power stations that are close to the coast in Southern China (China CSR, 2007a). Alongside these activities, as part of its diversification activities, it has established various wholly-owned subsidiaries to better develop coal, coal chemical and coal power integrated projects within China (China CSR, 2007a).

2.1.3 The Chinese equipment manufacturing companies

The Chinese power plant manufacture and supply industry has developed rapidly since 2000, with the overall upturn in coal-fired power plant orders, and since 2003, with the associated demand for larger units with advanced SC and then USC steam conditions. In 2006 and 2007, annual Chinese production of coal-fired power generation equipment was 96 GWe and 76 GWe respectively (China coal resource, 2009a). The main domestic manufacturers of the key components for coal-fired power plants in China are listed in Table 2.

The three major Chinese electric power equipment manufacturers are the Dongfang Electric Corporation Limited, the Harbin Power Equipment Company Limited and the Shanghai Electric Corporation Limited. Each manufactures a variety of coal-fired power generation systems that includes boilers, steam turbines, gas turbines, generators, environmental control equipment and auxiliary equipment. Between them, these three are believed to have over 70% of the market share for domestic production and a 73% market share of domestic sales (Mills, 2008a). These companies established the key international co-operation agreements through which they gained access to OECD technology.

Dongfang Electric Corporation Limited

This State-owned company is principally engaged in the manufacture and sale of electric power generating equipment, covering thermal, hydro, nuclear and wind systems. The company provides boilers, steam turbines, generators, gas turbines, control systems, condensers, heaters and transmission lines as well as environmental protection equipment. Its headquarters are in Chengdu, Sichuan Province, and at present the very great majority of its business activities are focused on domestic markets where it has some 30% of the major thermal power equipment business (DEC, 2008). During 2007, the Company obtained approximately 81% and 11% of its total revenue from the sale of thermal power generating equipment and hydropower generating equipment respectively.

The Corporation, via the Dongfang Electrical Machinery Co Ltd, owns 99.67% of the Dongfang Boiler (Group) Co Ltd, and all of the share capital of the Dongfang Turbine Co Ltd. The principal activities of the former include developing, manufacturing and selling power boilers and environmental protection equipment, while the latter complements this through the design, manufacture and sales of steam turbines

Table 2 Key Chinese coal fired power plant equipment manufacturers

Boiler	Steam turbine	Gas turbine	Auxiliary equipment
Harbin Boiler Co*	Harbin Turbine Co*	Harbin Turbine Co*	China Huadian Eng Group
Dongfang Boiler Co†	Dongfang Turbine Co†	Dongfang Turbine Co†	Shanghai Heavy Machinery Co
Shanghai Boiler Co‡	Shanghai Turbine Co‡	Shanghai Turbine Co‡	Hangzhou Boiler Co
Wuxi Huaguang Boiler Co	Beijing Beizhong Turbine Co	Nanjing Turbine Co	Shanghai Power Equipment Co‡
Jinan Boiler Co	Nanjing Turbine Co		Beijing Power Equipment Factory
Hangzhou Boiler Co	Hangzhou Turbine Co		Haodunhua Engineering Co
Wuhan Boiler Co			Feida Group
Taiyuan Boiler Group			Shanghai Power Manufacturing Co‡

* Subsidiary of the Harbin Power Equipment Company
† Subsidiary of the Dongfang Electric Corporation
‡ Subsidiary of the Shanghai Electric Corporation

and gas turbines for the coal-fired plant and combined cycle applications respectively. There is extensive co-operation with OECD equipment suppliers, primarily for the manufacture of large boilers and large, advanced steam turbines, which are suitable for SC and USC applications, *see* Section 2.2.

Harbin Power Equipment Company Limited

The Harbin Power Equipment Company is a majority (60%) State-owned enterprise. The company and its subsidiaries are one of the largest manufacturers of power plant equipment in China, covering the thermal, hydro, and nuclear sectors as well as providing engineering, construction, and consulting services for the power generation sector (HPEC, 2008). The three primary subsidiaries are the Harbin Electrical Machinery Works, Harbin Boiler Co Ltd and Harbin Turbine Co Ltd. The former manufactures thermal generators and motors while the Harbin Boiler Co is the largest utility boiler manufacturer in China, capable of building all sizes including SC once-through boilers under licence from various OECD suppliers. Alongside this, the Harbin Turbine Co manufactures air and steam cooled turbines for fossil fuel power plants and gas turbines for combined cycle applications. All are active in domestic and international markets.

Shanghai Electric Corporation Limited

This company is engaged in the design, manufacture and sale of products and the provision of related services in the power equipment, electromechanical equipment, transportation equipment and environmental protection industries (SEG, 2008). The Shanghai Electric Power Generation Group (SECPG), part of the Shanghai Electric Corporation, is one of the larger industry groups for power generation equipment manufacturing in China, including turbine, generator, boiler and auxiliary equipment for thermal, nuclear and hydropower applications. It also offers engineering, procurement and construction (EPC) services and support for various power plant projects. The leading products include 1000 MWe and 600 MWe fossil-fired power generation equipment including desulphurisation and deNOx equipment as well as heavy duty gas turbines. It comprises a series of subsidiary companies, each specialising in certain aspects of power plant equipment production (SECPG, 2008), several of which are linked via joint ventures to Siemens. The latter is also a 5% shareholder in the Corporation.

The Shanghai Boiler Works Ltd produces power plant boilers, environmental protection equipment, chemical equipment and boiler renovations. Since it established international standard quality assurance systems, its products have been sold in more than 20 countries across the world. In addition to its major role in manufacturing coal-fired utility-scale boilers, it also produces components for nuclear power stations.

The Shanghai Turbine Co designs and manufactures fossil-fired steam turbines, nuclear turbines and heavy-duty gas

Table 3 Listing of the co-operation routes between the larger Chinese power plant equipment manufacturers and

Company	Major thermal power plant products	International co-operation
		Joint ventures with
Beijing Boiler Works	PC and CFBC boilers	Babcock & Wilcox for various boiler
Beijing Heavy Electric Machinery Works	Large (600 MWe) steam turbines	Alstom Power for large SC turbines
Dongfang Electric Corporation	PC boilers, steam turbines, gas turbines, CFBCs, environmental control equipment	Babcock Hitachi for large SC tur Mitsubishi Heavy Industries both turbines and for gas turbines (two Energy International and others environmental control systems; Envirotherm for SCR products u power plants
Harbin Power Equipment Co Ltd	PC utility boilers, steam turbines, gas turbines, environmental control equipment	GE Energy and Nanjing Turbines various technologies;
Nanjing Turbine Co Ltd	Steam and gas turbines, combined cycle units, co-gen components	GE Energy and Harbin Power Eq for various technologies
Shanghai Electric Co Ltd	Boilers, steam turbines, gas turbines, environmental control equipment and auxiliary components	Siemens for various turbine relate plant equipment and services; IHI for import of advanced enviro
Wuhan Boiler Group	Power station boilers and auxiliaries including environmental control equipment	
Wuxi Huaguang Boiler Company	PC and CFBC boilers, emissions control equipment	

turbines. It has more than 35% of the domestic market and also exports products to many countries in Southeast Asia. In 2006, the production output was 36 GWe, which ranked first in the world. It was responsible for the production and successful operation of the first 1000 MWe USC turbine unit in China.

The SEPG Power Station Auxiliary Equipment Co specialises in designing and manufacturing heat exchangers, its products being mainly used for power plants and the chemical industry. It is the largest manufacturer of power station auxiliary equipment in China. Its domestic market share is over 50%.

The SEPG Electric Machinery Co Ltd (SEMW) is a comprehensive large electric motor manufacturer. Its major products include turbine generators, large- or medium-size AC motors and generators, DC motors and generators, and wind power generators. The turbine generators made by SEMW are used in over one-third of the fossil-fired units in China while the large or medium size AC/DC motors also cover one-third of the China market.

2.2 International links for coal-based technology introduction and deployment

China now has a well-established equipment manufacture and supply network of companies that are primarily State-owned enterprises (SOEs). Previously, these companies produced small, Chinese designed equipment to local standards. However, the NDRC recognised that, in order for China to establish modern, high efficiency coal-fired power stations, these Chinese companies could no longer work in relative isolation and needed access to OECD technology. It further determined that, in order for China to make rapid progress, the advanced coal-fired power plants would need to be produced domestically and that China would need to establish its own manufacturing capability to produce a very large proportion of the equipment needed for such power plants.

At that time, the major OECD equipment manufacturers had established SC and, to a lesser extent, USC PC power plants with efficient emissions control systems as the main technology for coal-fired power generation (Bluewave Resources and others, 2007; Nalbandian, 2008). The main way forward has been for all of the major OECD equipment suppliers to license their power plant technology, including in many cases downstream emissions control equipment. Alongside this, various OECD suppliers and Chinese major equipment manufacturers and suppliers have established either locally-based JV companies or manufacturing subsidiaries. These arrangements have provided the OECD suppliers with improved understanding of local requirements and allowed access primarily to the Chinese market. The key collaborative links are set out in Table 3 and considered

OECD industry

	Licensees of	Other links
options		
bines; for components for large SC jvs); for thermal power plant sed in large-scale thermal	Alstom Power for large CFBCs; Babcock Hitachi for USC PC technology	
for support services for	Alstom Power for large CFBCs; GE Energy for advanced turbines and other power plant equipment; Doosan Babcock for supercritical boilers, burners and auxiliary components; Mitsubishi Heavy Industries for steam turbine components	
uipment for support services	GE Energy for assembly of advanced gas turbines	
d components, other power nmental control technology	Alstom Power for large CFBCs; Foster Wheeler for arch fired boilers and supercritical steam turbines; IHI for advanced environmental control units	5% shareholding by Siemens
		51% shareholding by Alstom of the Group's subsidiary, Wuhan Boiler Company
	Foster Wheeler for CFBC steam boilers; IHI for supply of ESP, FGD and SCR units	

below. Additional information on the OECD products is given in another IEA Clean Coal Centre report (Mills, 2008b).

2.2.1 Alstom Power

Alstom Power designs, manufactures and supplies products and systems to the global power generation industry, with a product range that includes complete turnkey power plants, air quality control systems, boilers, gas and steam turbines, generators and ancillary equipment. Various types of utility boilers are manufactured, including drum-types and advanced once-through (subcritical and SC) units with a complete range of firing systems. Individual boilers up to 1200 MWe are available. The company owns and manages a global network of pressure parts and boiler-related manufacturing facilities, while production of fossil fuel fired equipment is undertaken in several parts of the world, including China.

Alstom Power's declared strategy in China is to be present locally and industrially for the long term. To this end, the company established a programme for training and developing its own Chinese managers, while at the same time creating an industrial presence through joint ventures and other co-operation methods with Chinese partners, whereby it transfers technical know-how and managerial expertise.

In 1999, the Alstom (China) Investment Co Ltd was founded in Beijing as a means to establish various ventures in the power and transportation sectors. In 2000, this was followed by a further wholly-owned foreign enterprise, namely Alstom Technical Services (Shanghai) Co Ltd. As a 100% subsidiary of Alstom (China) Investment Co Ltd, its business scope includes the provision of local engineering and technical services, and the assembly of components. Its main focus is support for Alstom's power and environmental control systems activities in China (Alstom, 2008a). Since then Alstom has formed eight joint ventures plus one subsidiary (in Hong Kong) covering both the power and transportation sectors.

With regard to fossil fuel power generation activities, in 2004, together with the Beijing Beizhong Turbine Co Ltd, a subsidiary of the Beijing Heavy Electric Machinery Works, Alstom established the Alstom Beizhong Power (Beijing) Co Ltd, a joint venture company in which Alstom has a 60% holding. This company was set up to design and manufacture Alstom 600 MWe subcritical, SC and USC steam turbines together with the associated generator equipment (Alstom, 2006).

In 2005 the Alstom (China) Investment Company (with an 80% shareholding) and the Central South Electrical Power Design Institute (20% shareholding) formed the Alstom (Wuhan) Engineering & Technology Co Ltd joint venture to meet the specific needs of the Alstom Turbomachines Group in both its Chinese and regional activities. This covers components and auxiliary systems engineering for both nuclear and fossil fuel fired power plants (Alstom, 2008b).

The Alstom Sizhou Electric Power Equipment (Qingdao) Co Ltd joint venture was formed in April 2007 between Alstom and the Qingdao Sizhou Electric Power Equipment Co Ltd This company designs and manufactures slag-handling systems, dry and wet boiler bottom ash-handling systems, coal feeding systems, ESP fly ash conveying systems and water treatment systems and solutions and is certified to design and manufacture pressure vessels up to 10 MPa. The company also supplies wind towers for the wind power industry (EVCN.COM, 2007).

The most recent development was in August 2007, when Alstom acquired a 51% stake in the Wuhan Boiler Company, a subsidiary of the Wuhan Boiler Group, the latter retaining a small stake in the new company. The rationale for this was to give Alstom a further manufacturing base while improving access to the Chinese market for coal-fired boilers as the Wuhan Boiler Company is the fourth largest manufacturer with a 10% market share (China Daily, 2007). Products include 600 MWe and 1000 MWe SC and USC boiler sets together with low NOx burners. It will also provide Alstom with a strategic manufacturing base for global exports.

2.2.2 Babcock-Hitachi K K

Babcock-Hitachi K K is a wholly-owned subsidiary of Hitachi. Its product range includes subcritical and SC PC boilers up to 1000 MWe and environmental control systems. The company has established a standardised design concept for SC coal-fired sliding pressure boilers and it supplies units worldwide. In addition, it manufactures the full range of GE Energy heavy-duty gas turbines based on a manufacturing associate agreement made in 1964. The company also supplies NOx, SO_2 and particulates emissions control systems for coal-fired plants. In particular this includes SCR units for NOx control.

Babcock-Hitachi has long standing links to China. The Babcock-Hitachi Dongfang Boiler Co Ltd joint venture was established in 1996 to address the coal-fired power plant market opportunities, with manufacturing facilities established in Jiaxing City to produce components of Benson boilers with generating capacities of 300 MWe and above. This is owned 50% by Dongfang Boiler, 45% by Babcock-Hitachi K K and 5% by the Itochu Corporation. In 1997, a joint venture was established with the Dalian Machinery & Equipment Co Ltd, a significant Chinese manufacturer of power plant equipment. In 2005, this became the Dalian Hitachi Machinery & Equipment Co Ltd, now a wholly-owned subsidiary of Hitachi. In 2004, a licensing agreement was signed with the Dongfang Electric Corporation for Hitachi's USC PC technology (Mills, 2008b). The company also has a technology transfer agreement with the Guizhou Xingyun Environmental Protection Corporation of China for its FGD technology. Finally there is a strong focus on the growing Chinese market for SCR systems and a number of projects have recently been undertaken.

2.2.3 Babcock & Wilcox

Babcock & Wilcox (B&W) is a subsidiary of McDermott International Inc, a leading worldwide energy services company. The B&W Power Generation Group Inc designs, manufactures and constructs a range of steam generating systems, with a focus on fossil fuel power generation equipment and associated environmental systems. Alongside its subcritical and sliding pressure SC PC boilers, and CFBC systems, the company also manufactures particulates, NOx, SO_2 and mercury emissions control systems.

While its manufacturing facilities are concentrated in North America, B&W has a joint venture link in China. Thus, in 1986, B&W and the Beijing Boiler Works established a joint venture, the Babcock & Wilcox Beijing Company, to serve the Chinese and Far Eastern utility and industrial markets. Its main focus is now the production of SC PC boilers (B&W, 2008).

2.2.4 Doosan Babcock

Doosan Heavy Industries & Construction Co Ltd is South Korea's major power plant engineering company and the Power Plant Division manufactures most major types of power plant equipment including boilers, steam turbines, generators, gas turbines, and HRSGs. The company also builds power plants on a turnkey basis. As part of its strategy to increase its global presence, in 2006, Doosan Heavy Industries purchased the UK-based company, Mitsui Babcock Energy Ltd, renaming it Doosan Babcock. This became the company's global R&D centre for boilers, with a view to securing technology for expanding company activities into potentially major markets in the USA, Europe and China.

Doosan Babcock is an international developer and supplier of various PC boilers and a range of environmental control equipment for fossil-fired plants such as systems for NOx control, FGD plant, and techniques for mercury control. This includes SC once-through steam generators and circulation (drum type) boilers (Welford, 2008). In China, in 2004, Doosan Babcock (while Mitsui Babcock Energy Ltd) established a licence agreement with the Harbin Boiler Company for the introduction of its once-through SC boiler technology, including the capability for sliding pressure operation (PEI, 2005). In addition, Harbin Boilers now use Doosan Babcock's low NOx burners where required (Platform, 2004).

2.2.5 Foster Wheeler

Foster Wheeler Ltd offers a broad range of engineering, procurement, construction, manufacturing, project development and management, research and plant operation services. Its Global Power Group produces a range of power plant equipment that includes various types of utility boilers, CFBCs, and environmental control systems, including subcritical and SC PC boilers with individual units up to 1000 MWe. All steam generation units are now offered with the option of Benson vertical tube SC steam technology, which extends to Foster Wheeler's arch-fired combustion technology that is used predominantly for burning difficult coals. The company also offers a wide range of environmental products that includes low NOx firing systems, fuel/air balancing and over-fire air systems, SCR and NSCR systems.

In China, in 2006, Foster Wheeler provided a technology licence to the Shanghai Boiler Works Ltd for its arch-fired subcritical and SC steam generators (Bnet, 2006).

It has further established a manufacturing base via its majority-owned joint venture, Foster Wheeler Power Machinery, which is located in Xinhui City, Guangdong Province. The Chinese partners include China Huadian Engineering, Guangdong Electric Power Industry Development and Jiangmen Da Guang Ming Power Enterprise Group.

Foster Wheeler has also co-operated with the Wuxi Huaguang Boiler Company, which for some years has been a primary subcontractor for projects in China and elsewhere in the Asian region. In 2006, Foster Wheeler established a 15-year agreement with this company to provide a technology licence for subcritical pressure CFBC steam generators for the Chinese market (Mills, 2008b).

2.2.6 Fuji Electric Systems

The company's main manufacturing base is in Kawasaki, Japan, where subcritical and SC steam turbines are manufactured by the Thermal Power Division, including SC units up to 1000 MWe for both combined cycle applications and coal-fired power applications. The company has a co-operation agreement with Siemens for the technical development of large capacity steam turbines and the two companies have also worked together on the supply of combined cycle power plants.

It is understood that Fuji Electric Systems is now increasing its marketing activities outside Japan (Mills, 2008b). The company is believed to have sold turbine units for projects in China while other units are at the design stage. However, there does not appear to be any local manufacturing partner involved although in other non-power generation product areas Fuji Electric Systems has established local co-operative arrangements.

2.2.7 General Electric

GE has a wide-ranging business portfolio, of which GE Energy is a major global supplier of power generation and energy delivery technologies. This includes the manufacture and supply of CCT-related equipment such as gasification/ gas turbines/IGCC systems, SC steam turbines, and emission control equipment. The SC steam turbine range is up to 700 MWe while gas turbines are available up to 750 MWe.

GE Energy has a longstanding presence in China. Via GE Energy China as its initial foreign-owned enterprise, it has subsequently established extensive co-operative links with Chinese companies across all sectors of its business.

In 2000, it formed the GE China Technology Centre in

Shanghai, which includes technology support and supplier development as well as R&D activities, while also serving to showcase technology to its customers in Asia (GE, 2008). In 2002, it established its first joint venture in China with the Shenyang Blower Works to form the GE Shenyang Turbomachinery Technology Co Ltd, with GE Energy the majority shareholder. Its purpose is to provide support for the gas turbine after-sales market in China by providing spare parts, repairs, customer technical assistance and field services. It also covers conversions, modifications and upgrades of existing equipment to enhance plant performance (GE Energy, 2003).

In 2003, GE Energy established a licence arrangement with the Harbin Power Equipment Company (HPEC) for the manufacture of turbines and other power plant equipment. Also, since 2004, GE gas turbines have been assembled under a further technology transfer agreement with the Nanjing Turbine and Electric (Group) Company (NTC), itself a joint venture enterprise between the Nanjing Provincial Government and some Hong Kong investors (Nanjing, 2008). Manufacture started in 2006 in Nanjing, Jiangshu Province, with units being supplied mainly to the Chinese market (Diesel and Gas Turbine Worldwide, 2006).

In February 2004, GE Energy then signed an agreement to establish a service joint venture, the GE-HPEC-NTC Energy Service Company, to provide repair and field services for power generation equipment in China including Frame 9FA heavy-duty gas turbines (GE Energy, 2004a). GE Energy is the majority owner of this joint venture with its partners HPEC and NTC (GE Energy, 2004a,b).

In 2005, GE Energy formed a further joint venture partnership with the Shanghai Xin Hua Control Technology (Group) Co Ltd, through the acquisition of a majority share in its subsidiary Xin Hua Control Engineering Co Ltd. The joint venture company designs, manufactures and installs steam turbine and power plant control systems and software for application in power generation, pulp and paper, oil and gas, and general industrial sectors (Findarticles, 2005).

The same year, this was followed by the formation of the Shenyang GE Liming Gas Turbine Component Co Ltd, which comprises a 51:49 joint venture between GE Energy and Shenyang Liming Aero-Engine Group Corporation Ltd. This was established to provide combustion parts such as liners, transition pieces, buckets and nozzles for use in GE's 9FA and 9E gas turbines in China (GE Energy, 2005).

GE Energy has also signed several contractual service agreements to provide maintenance, parts and additional services for power plants using its turbine technology in China.

The company has also been active in promoting its IGCC concept, for which it has optimised system configurations for all major gasifier types and all GE gas turbine models. GE Energy's strategy, in collaboration with Bechtel, is to design and construct a commercial plant with full guarantees and warrantees for both the gasification island and power block, where these are both based on GE technology although it will also become involved in projects that utilise alternative gasifiers. Alongside the gas turbine based power generation activities, there has also been a major focus on the licensing of GE gasification technology for non-power applications, including coal to chemicals production, which is discussed in Chapter 4.

2.2.8 IHI Corporation

IHI manufactures a range of power plant equipment for thermal, nuclear and hydroelectric power plants. This includes the supply of SC sliding pressure PC boilers up to 1050 MWe, CFBC boilers, gas turbines up to 1000 MWe, heat recovery steam generators, and various advanced environmental control systems such as FGD and SCR. It has some involvement in China, through a joint venture and licensing agreement with Shanghai Electric Co for the supply of the environmental control systems for power plant applications.

2.2.9 Kawasaki Heavy Industries

Kawasaki's Plant Systems Division produces a range of power generation equipment that includes gas turbine cogeneration power plants, combined cycle power plants, gas turbines, steam turbines and FGD units. The company holds licences from Siemens for SC PC boilers using Benson technology and it uses gas turbines from major manufacturers such as Alstom and GE.

With regard to China, it has sold some FGD units and increasingly is targeting the growing Chinese boiler market, albeit outside the utility sector. In December 2006, Kawasaki Plant Systems Ltd and the Anhui Conch Venture Investment Co Ltd of China's Anhui Conch Group established the Anhui Conch Kawasaki Engineering Co Ltd to design, procure and sell waste heat recovery power generation systems for cement plants. This was followed in 2007 with the Anhui Conch Kawasaki Energy Conservation Equipment Manufacturing Co Ltd, a joint venture for the production and sale of waste heat recovery boilers for such plants (Kawasaki, 2007). In 2008, this collaboration was extended further, with expansion of the joint venture production base to include the production and sales of environmental systems, particularly gasification systems for waste recycling (Kawasaki, 2008).

2.2.10 Mitsubishi Heavy Industries

The company is active in the supply of key components for both coal and gas fired power generation systems. These include drum boilers, CFBC boilers, HRSGs, and once-though SC PC units of 1000 MWe or greater, SCR systems, gas turbines up to 300 MWe, and steam turbines up to 1600 MWe. It has recently developed USC steam turbines for operation with steam conditions of 25 MPa/600°C/600°C, and a number of these are now operating in Japanese coal-fired power plants. Alongside its established product line, MHI is also developing its own IGCC technology, based on a two-stage air-blown entrained flow gasifier using a dry coal feed.

In China, MHI has collaborated extensively with the Harbin Boiler Company in the delivery of coal-fired plant and components. In 2002, the two companies worked together on the construction of China's first domestic build SC power plant. Subsequently, in 2004, MHI won an order from Harbin Turbines for the supply of major components for twelve 600 MWe SC steam turbines. This included high-temperature, high-pressure turbine blades and rotors, with Harbin Turbine manufacturing the peripheral equipment and assembling the turbines for delivery to Chinese electric power companies. At that time, Harbin Boilers also placed an order covering all major components for the first four USC boilers to be installed in China, each having a power-generation capacity of 1000 MWe (Mitsubishi, 2004). The collaboration included the licensing to the HPEC of the 600 MWe class USC steam turbine technology and auxiliary equipment. MHI has recently established a similar collaborative arrangement with the Harbin Power Equipment Company, via its boilers and turbines subsidiaries, with the licences applying to 1200 MW-class large-size steam turbines for nuclear power plants (PEI, 2008).

Back in 2004, in order to further meet the Chinese Government's desire for technology transfer and better co-operation on coal-fired systems, MHI established two joint venture companies. Thus MHI, the Guangzhou Nansha ETDZ Construction Centre, and the China Dongfang Steam Turbine Works (DSTW) signed an agreement to set up a joint venture to produce steam turbine components, which is located in the Guangzhou Nansha Economic Zone (AsiaInfoServices, 2004). This was followed in 2005 by the formation of the MHI Dongfang Gas Turbine (Guangzhou) Co Ltd, which was jointly established by MHI and the Dongfang Steam Turbine Works. The focus of the joint venture is the manufacture of gas-fired combustors and other equipment, to be used in natural gas fired gas turbine combined-cycle power plant, for which MHI can supply key components of the gas turbines including blades, rotors and control systems (Japancorp.net, 2006).

2.2.11 Power Machines Group

Established in 2000, the Power Machines Group is Russia's major manufacturer of power equipment. The company comprises five leading Russian power equipment suppliers: JSC Leningradsky Metallichesky Zavod (LMZ), JSC Elektrosila (ZTL – turbine blade works), JSC Kaluga Turbine Works (KTZ), JSC Turbine Blades Plant, JSC NPO CKTI (power engineering R&D) and a sales company, Energomachexport. The product range spans all major power generating technologies, including steam and gas turbine power plants. Various designs of steam turbines, up to 1200 MWe, and gas turbines, up to 160 MWe, are available (Power Machines, 2009). Their turbines and generators have been used in various advanced coal-fired power plants in China, which are believed to include some of the early SC units that were introduced in about 2003 (Mao, 2008a).

Since the beginning of the 1990s, the Siemens Power Generation Group has co-operated with Power Machines and, in 2006, Siemens acquired a 25% stake in the company with a view primarily to increasing its influence in the growing Russian market.

2.2.12 Shell Global Solutions International

Shell Global Solutions International B.V. is the owner and licensor of the Shell Gasification Process for liquid feedstocks and the Shell Coal Gasification Process. Udhe GmbH is Shell's engineering partner for these processes. Since 2004, Shell and Uhde, with Black & Veatch, have maintained a commercial alliance to pursue coal gasification and IGCC opportunities. There have been a significant number of licences established in China for industrial applications, as discussed in Chapter 4.

2.2.13 Siemens

Siemens, via its Power Generation Group, offers large gas turbines, medium and large steam turbines, electrical generators, combined cycle and steam power plants together with services such as plant diagnostics, operating plant, boiler and environmental support. It is also active in the gasification and IGCC sector (Siemens, 2006).

The turbine product range includes gas-fired machines of up to 100 MWe (acquired from Alstom) and its own 300–1200 MWe units that are suitable for use in either combined cycle plants or in steam power plants. Such turbines can be supplied for main steam temperature operation of up to 600°C and pressure up to 30 MPa, with reheat steam temperatures up to 620°C.

The power generation related activities in China are handled by Siemens Ltd, which include four joint ventures with the appropriate subsidiaries of the Shanghai Electric Corporation:

- Shanghai Turbine Co (32% Siemens share);
- Shanghai Turbine Generator Co (40%);
- Shanghai Power Equipment Co (30%);
- Shanghai Advanced Power Projects Co (35%).

In 2007, Siemens and Shanghai Electric rationalised their co-operation arrangements with the formation of a further joint venture, the Shanghai Electric Power Generation Equipment Co, into which the business operations of the Shanghai Turbine Company, Shanghai Turbine Generator Company and Shanghai Power Equipment Company were combined. In addition, Siemens and Shanghai Electric have further expanded their strategic partnership in the Chinese power plant market with the opening of a major manufacturing plant in Lingang, near Shanghai, to produce major components for fossil-fuelled power plants (Siemens, 2007a; BLC, 2007). Linked to this is the formation of another joint venture, the Siemens Long Wei Power Generation Technical Service Co Ltd, in which Siemens has a 50% share (Siemens, 2008). The rationale for these changes is to better position Siemens and Shanghai Electric to meet China's increasing demand for advanced steam power plants in the capacity class of 1000 MWe and above (Siemens, 2007a).

There is a commercial arrangement with the Harbin Turbine Company for the use of advanced digital software systems to enhance its manufacturing processes. This has allowed the Harbin Turbine Company to move toward a greater level of standardisation with its products and to improve technical management.

Siemens is also active in the gasification and IGCC market. It acquired Sustec's coal gasification activities in mid-2006 in order to supplement its power plant business with products and services related to coal gasification. In addition to gaining an alternative key technology for the generation of electrical power based on coal, Siemens can also use this technology to produce synthetic fuels and chemical products, for which in China there are significant market opportunities (*see* Chapter 4).

2.2.14 Toshiba

Toshiba through its subsidiary, Toshiba Power Systems, is a major provider of steam turbines and generators, including SC steam turbine generator units up to 1000 MWe. It is actively involved with business prospects in China for the provision of large-scale steam turbines and generators for thermal power plants, although it is not clear as to how many of these have been for SC coal-fired units.

In 2007, in order to enhance its business prospects, Toshiba entered into a joint venture agreement with the Xian Xingyi Technology Co Ltd, a leading Chinese manufacturer of control and instrumentation systems for thermal power plants, and its parent company, Xian Xingyi Enterprise Investment Co Ltd (known as the Xian Xingyi Group). This covers the development, design, manufacture, sale and after-market service in the Chinese market of distributed control systems (DCS) and related information, control and instrumentation systems for thermal power plants (Toshiba, 2007).

The Toshiba Xingyi Control System (Xian) Co Ltd was established in Xian, Shaanxi Province, and is 50% owned by the Toshiba Corporation, 10% by Toshiba China Co Ltd (Toshiba's China subsidiary), and 40% by Xian Xingyi Group. The rationale behind the joint venture is that it will combine Toshiba's technology and Xian Xingyi Group's strong sales force to quickly build a significant presence in China's fast growing market for information, control and instrumentation systems for thermal power plants. The spin-off benefit will be to enhance sales opportunities for Toshiba's large steam turbines within China.

2.3 Overall capacity growth and technology choice in the sector

China remains a region with huge infrastructure needs and it has boosted internal investment with a sweeping government spending plan (Barton, 2008). This includes significant investment being maintained in the power sector. At the same time, the NDRC is taking advantage of the downturn in overall generating requirements to push ahead with an ambitious programme to improve the efficiency and environmental performance of the coal-fired power sector, while increasing the investment in zero carbon and low carbon alternatives.

2.3.1 Policy issues

The power sector like all strategically important energy sectors is controlled on a macro basis by the State Government via the NDRC/NEA. As such, its targets are enshrined within each of the Government's five-year plans. In the past, such plans were very much focused on GDP and related issues. However, in contrast, the 11th Five Year Plan for China (2006-10) is, in overall terms, a guidance document to shape the future direction of the nation. It includes policy guidelines that address both pressing problems and longer-term needs. As such, it considers issues that go well beyond the 2006-10 period and there is considerable emphasis on the need for balance.

Within this context, the Chinese Government sees three major energy challenges, namely long-term energy security, limiting local environmental impacts and addressing global environmental impacts (NDRC, 2004). Thus, having recognised that resources and environment are major constraints to further development, the government committed to a major shift in the development pattern from being resource intensive to environment and resource sustainable, thereby emphasising efficiency, resource conservation and environmental sustainability. Consequently, while the Government recognises and is addressing the need for an increased energy demand, at the same time the plan reflects the intention to introduce a less energy intensive approach. Thus, although economic growth is intended to rise, with GDP expected to grow 7.5% annually, it set a target of a 20% reduction in energy intensity and 10% reduction in SO_2 emissions below 2005 levels by 2010 (NDRC, 2006). The NDRC has allocated this target among provinces and industrial sectors, and energy efficiency improvement is now among the criteria used to evaluate the job performance of local officials (China View, 2009b).

This includes China's 1000 largest enterprises, which together consume one-third of China's primary energy. The group includes the largest energy users in the energy supply sectors (coal, electricity, oil) and in the largest energy-using industrial sub-sectors (including iron and steel). Under the programme, each enterprise has had to agree to an energy efficiency improvement plan and have its energy use monitored. Objectives have been set for limiting the energy intensities of products produced based on advanced domestic and international standards (Pew Center, 2007). Since power generation accounts for more than half of the total coal use and is responsible for over 50% of SO_2 emissions, this is one of the priority sectors to be targeted.

In addition, the sector must also ensure that power generation from renewable sources is actively pursued. Thus, on 7 June 2007, the State Council adopted the Medium- and Long-Term Development Plan for Renewable Energy, which was formally issued by the NDRC. The Plan determines that the consumption of renewable energy should account for 10% of the total energy consumption by 2010 and 15% by 2020, with a focus on hydropower, biomass energy, wind energy and solar energy. For the electricity sector, the target is 20% of capacity from renewables by 2020, and as a first step measure the generating companies must ensure that 10% of electricity production is provided from renewable sources by 2010. This can include hydropower but it is also required that a mandatory 3% of the10% is from other renewable energy sources. Under this renewable energy law, there are various financial incentives, such as a national fund to foster renewable energy development together with discounted lending and tax preferences for renewable energy projects. The NDRC also reduces risks for project developers by mandating grid interconnection and guaranteeing minimum prices for certain types of renewable energy. These various requirements have had very significant effects on coal-fired power generation, as are considered in detail in Chapter 3. At the same time, it has resulted in a change of emphasis for the power sector as a whole, as is described below.

Table 4 Annual power plant capacity and growth rate in China (NEA, 2009; Mao, 2008b)

Year	Installed net capacity, GWe	Annual increase in net capacity, GWe	Annual growth rate, %
2001	338	–	6.0
2002	357	19	5.6
2003	385	28	7.8
2004	442	54	14.8
2005	508	66	14.9
2006	622	114*	22.4
2007	713	91*	14.6
2008	793	80*	11.2

* Net annual increase as some coal-fired plant closed during each year

2.3.2 Recent historical overview

The power sector is very large and the overall capacity has grown very rapidly in the period from end 2001 to end 2008, as shown in Table 4. This shows that total capacity has increased by more than 130% in seven years. It also shows that year on year increases in capacity appear to have peaked at the end of 2006, with the subsequent yearly increases, although massive in absolute terms, representing a decline from that peak value.

Table 5 provides information on that capacity on a technology basis for the period from end 2003 to end 2008. This indicates the dominance of coal-fired power generation within the

Table 5 Total installed capacity 2003-08, GWe (NEA, 2009)

	2003	2004	2005	2006	2007	2008
Total installed net capacity	385	442	508	622	713	793
Hydropower	92 (24%)	105 (24%)	117 (23%)	129 (21%)	145 (20%)	170 (21%)
Thermal power* (Coal & gas)	286 (74%)	330 (75%)	384 (76%)	483 (78%)	554 (78%)	601 (76%)
Nuclear power	6.2 (1.6%)	7.0 (1.6%)	7.0 (1.4%)	8.6 (1.4%)	8.9 (1.2%)	9.1 (1.1%)
Renewable power†				0.7 (0.1%)	4.7 (0.7%)	12.2 (1.6%)

* The level of gas and oil fired power generation at the end of 2007 was <30 GWe, which is negligible compared to the amount of coal-fired capacity
† This comprises wind power plus a tiny proportion of biomass-fired units

Table 6 China's generated electricity 2001-08 (Mao, 2009a)

Year	Total generated electricity, TWh	Annual growth rate of total generated electricity, %	Electricity generated from thermal power units, TWh	Proportion of electricity generated from thermal power units, %
2001	1484	8.4	1205	81.2
2002	1654	11.5	1352	81.7
2003	1905	15.2	1579	82.9
2004	2194	15.2	1810	82.5
2005	2475	12.8	2018	81.6
2006	2834	14.5	2357	83.2
2007	3256	14.9	2698	82.9
2008	3433	5.4	2779	80.9

sector. Firstly, the great majority of that annual increase in capacity is due to the construction of coal-fired plants. Over the period to end of 2008 the level of coal-fired capacity has more than doubled. This is also reflected to a great extent in the proportion of coal-fired power within the overall capacity, which has increased year on year from 2003 to 2006-07. Hydropower, which currently comprises most of the rest of the capacity has doubled over the same period but in proportional terms has shown a steady decline. The other important points to note are the very small but steady increase in nuclear power and the new and rapid introduction of wind power.

Table 6 shows the levels of total electricity generated and the proportion that is provided from thermal fired plants, which are almost all coal-fired units. This shows that the coal-fired plants produced a greater proportion of power than would be suggested by the capacity mix. This was primarily as a result of some problems with hydropower operations due to water shortages.

The other key statistic is the level of investment in the power sector and the distribution of that investment between the various types of power generation technologies and the transmission/distribution systems (Research in China, 2009). For 2008, the national electricity investment in the power sector was some 576 billion RMB (~€58 billion), an increase of 1.5% year on year. However, for the first time, investment in transmission and distribution systems, at 50.05% of the total, exceeded that used for new power plants (Research & markets, 2009). This is in line with the Government's plan to focus on improving the integration of the regional grids, and to uprate the system to handle the expected introduction of wind power from the more remote regions of China, as outlined below. This will require the installation of extra high tension power lines (China coal resource, 2009a).

With regard to technology choices, in 2008, investment in nuclear power increased by 72% as China approved the construction of 14 nuclear power generation units with a total capacity of over 15 GWe (China Environmental 2009). Investment in wind power increased 88%, year on year, with some 5 GWe of capacity added. Hydropower investment remained steady as another 20 GWe of capacity was added. However, investment in coal-fired power plants declined by 2%, year on year, even though some 69 GWe of capacity was added. These shifts in emphasis are important when future power plant deployment is considered.

2.3.3 Forecasts for future power plant development and deployment

China is trying to use the introduction of targets and policies to manage its high power demand, and consequential high CO_2 emissions, by encouraging the diversification of its fuel mix. It is seeking to increase the proportion of low carbon and carbon free power plants within the capacity mix. Various initiatives are under way, including plans to:

- Increase the numbers of nuclear power plants being established, including manufacture by domestic equipment manufacturers. However, while the proportional change will be very significant, the current capacity is very small and so the overall impact by 2020-30 will be limited.
- Rapidly introduce wind power, including the building of seven very large-scale wind bases in the western provinces (PEI, 2009a). This is expected to show the fastest growth rate of all generation technologies in China and in absolute terms is likely to be the largest market in the world for this carbon free option.
- Speed up progress with the development and utilisation of solar energy for power generation applications.
- Introduce biomass fired units, which will primarily fire agricultural residues. However, the overall impact will be limited due to the problematic nature of the feedstock (*see* Section 6.5).
- Continue the introduction of high efficiency large coal-fired units with advanced steam conditions, coupled with the increasing closure of the older, smaller, lower efficiency units.
- Further introduce natural gas combined cycle plant.

As noted in the 2008 data, there is now evidence that China has begun to shift the investment profile in the power sector, to implement these initiatives with the new emphasis on nuclear and renewable power rather than the recent massive focus on coal-fired units.

The China Electricity Council has indicated that the annual capacity increases will continue to be similar to those in recent years and that, by the end of 2009, overall capacity is likely to reach 860 GWe (China coal resource, 2009a). Within that overall number, China's wind power capacity is expected to grow by 8 GWe to 20 GWe (China coal resource, 2009b), with hydropower providing up to an additional 20 GWe and the remainder (some 50 GWe) being advanced coal-fired units.

For the medium and longer term, the official predictions for both coal and power demand have generally been found to be significant underestimates of the actual situation (Minchener, 2007), due to the limitations of the state planning function. All predictions since 2000 have been exceeded several years in advance as shown in Table 7. For example, the capacity for 2010 that was predicted in 2000 was achieved before the end of 2006 while the revised level, as predicted in 2007, will certainly be exceeded early in 2009. With that in mind, recent semi-official suggestions of the total installed capacity and the capacity mix for 2020 must be treated with caution. Nevertheless they offer an insight into the likely evolution of the Chinese power sector.

Table 7 Official predictions of power sector total installed capacity, GWe (CEC, 2009)

	2010	2020
2000	600	950
2005	769	1200
2007	840	1340

Despite the shortfalls in the State planning system, the expectation is that while the overall capacity will grow significantly, the relative proportion of coal-fired units will decrease, albeit from a very high level. Thus, for the future, overall investment is likely to be at or close to the 2008 levels, with the split between infrastructure and power plants being at least maintained. At the same time, in line with the 11th Five Year Plan, the shift of funding towards hydropower, nuclear and wind power at the expense of thermal units will continue. This position is supported by recent NDRC pronouncements, which have indicated that China is likely to revise upwards its renewable energy targets for 2020 (China coal resource, 2009c).

The NEA official plan for 2020, as set out in early 2009, suggests that the capacity mix might comprise 1000 GWe coal-fired units, 300 GWe hydropower, 100 GWe wind power, some 40 GWe nuclear and 1–2 GWe of solar power (China coal resource, 2009d). Various non-government commentators have suggested that the total capacity might be a little higher at 1500 GWe, with essentially a similar mix but including up to 75 GWe nuclear and possibly 32 GWe of biomass fired units (Huang, 2009). In each case, coal will contribute about 1000 GWe or some 69% of the total capacity. If the Government maintains its current policy, this coal-fired capacity will mostly be very large advanced SC/USC units.

In July 2009 the NEA stated that China will soon announce revised power supply capacity targets for 2020 (Fu, 2009). While the likely total capacity is still given as 1500 GWe, the suggested revised 2020 targets are:

- Nuclear up to 75 GWe, in line with the government expectations.
- Solar to increase from 1.8 GWe to some 10 GWe.
- Wind to reach close to 150 GWe, compared with the target of 30 GWe set in 2007.

Hydropower is not expected to increase beyond 300 GWe as this appears to be the likely limit in terms of natural resources available. If the total capacity is close to 1500 GWe, the likely increase in coal-fired power plants will be some 330–400 GWe over the next 11 years. This is still a massive increase, to which must be added some allowance for replacement units as the Government implements its policy of closing down the older power plants, which is likely to continue beyond the original end date of 2011. Consequently, the numbers of new and replacement power plants could be considerably in excess of 400 GWe by 2020. Certainly, there is a considerable number of advanced coal-fired plants either at the design or construction phase.

3 Status and development of coal-fired power generation

Until some ten years ago, China's coal-fired power sector comprised small, old and inefficient units with limited emissions control systems. However, in the last decade, the number of units has increased enormously year on year, with total capacity having more than doubled between 2000 and 2006. At the same time, especially since about 2004, there has been an overriding transformation with China installing some of the largest, most advanced coal-fired units in the world, with SC/USC steam conditions and modern SO_2/NOx and dust control systems. This has been driven by the NDRC's policies, in line with the objectives as set out in the 11th Five Year Plan. An example of a modern plant, comprising 4 x 1000 MWe USC units, is shown in Figure 1.

3.1 Policies for improving overall performance

It is important to recognise that any initiatives in the coal-fired power generation sector are but one part of the overall intended transformation of the power sector. Thus, as discussed above, the focus up to 2006 was very much on increasing coal-fired capacity as quickly as possible to ensure supply could match demand. However, now that a more balanced position has been reached, the focus is on establishing a more sustainable position.

For coal-fired power generation, China has a series of technology development and deployment initiatives, with the overriding remit being to ensure an integrated approach, which includes consideration of possible linkages between coal resource, water resource, environmental performance, power plant deployment, market situation and access to transmission lines. The focus remains on large, high efficiency PC units to optimise efficient power production. At the same time, as part of the plan to promote electricity generation with clean coal technology (CCT), there is an intention to:

- Develop and build new, large air cooled PC power generation systems for use in regions with limited water supplies.
- Build a CFBC unit with a single capacity of 600 MWe.
- Start up the IGCC project.
- Encourage the development of pithead power plants while building a large coal-to-electricity base.

Figure 1 The Huaneng Power International 4x1000 MWe USC PC power plant at Yuhuan, Zheijiang Province (Mao, 2009b)

Within this overall framework, the NDRC has started to implement some other measures to force through fundamental changes within the coal-fired power generation sector. The need to improve overall efficiency is seen as critical. Previously, in 2003, the NDRC approved SC and USC PC plants as the most appropriate way forward for large-scale power generation. Consequently there was a subsequent trend towards new larger PC units with higher efficiencies, together with the introduction of high quality emissions control systems such as high efficiency ESPs and FGD. These units have also had to meet the required NOx emissions standards, which have generally required the installation of some form of deNOx control system. However, as the NDRC position was not legally enforced at that time, a lot of smaller less efficient units continued to be built.

From the start of the 11th Five Year Plan, as a further reinforcement of the need for energy saving, the drive has been for larger units with ever higher steam temperatures and pressures. The NDRC declared that all new PC plants, except those for CHP applications, would only be approved if they are 600 MWe and above with SC/USC steam parameters. All such plants are also required to include deSOx and deNOx technologies, except where the sulphur content of the coal is less than 0.7%. The only exceptions are CFBC units that are introduced to burn low grade coals or coal wastes. These can be smaller and do not need USC/SC steam conditions. For CHP, the preference is to seek economies of scale, with 300 MWe units being preferred. However, depending on local circumstances, smaller units can be built. Regulations state that electricity generation from CHP plants should be driven by the heat load and subcritical units are still acceptable for these applications. Priority for CHP approval will be given to centralised heat supply in large or medium cities in north China.

The average coal consumption in the power generation sector in 2006 in China was 357 gce/kWh. The reason for this was that the capacity mix still included a very large proportion of small, old units, as shown in Table 8. While the performance of the Big Five companies (*see* Section 2.1) was better at an average of 347 gce/kWh, this value was still comparatively poor even though they had installed most of the newer, larger, more efficient units. To put this in context, at the end of 2006, of the 453 GWe of coal-fired power plant available for operation, some 114 GWe (over 25%) were 100 MWe unit size or smaller.

This problem is further compounded by the original policy for an even-load power generation scheduling on the power grids. This means that the grid load is evenly dispatched to all grid-connected power generating units, regardless of their efficiency in energy use and effectiveness in emission control.

Table 8 Structure of coal-fired power capacity in China at end of 2006 (CEC, 2007)

Class of capacity, MW	Installed capacity, GWe	Proportion, %
⩾600	126	27.8
300-599	82	18.1
101-299	131	28.9
⩽100	114	25.2
Total	453	100

In 2006, total installed thermal capacity was 484 GWe, which included a small portion of gas power and some oil fired units. This table only provides data for coal power, for which the total installed capacity was 453 GWe

When the grid load is reduced due to lower demand, all grid-connected generating units are required to evenly reduce their power output. Recently, this arrangement has increasingly led to the larger, advanced units not operating for long enough each year to ensure a fully adequate return on investment, since it has actually provided an incentive to the survival of inefficient, small subcritical power generating units (Tian, 2008). Indeed, until the NDRC prevented the approval of such small units in 2006, this arrangement actually encouraged the building of new small units, in direct contradiction to China's energy conservation initiative.

Consequently, the NDRC has adopted the approach of forcing the inefficient small units to close, while substituting them with efficient, large units. At the same time, it is developing a change in approach to power generation scheduling to ensure that only the modern units will gain access to the grid, to comprise renewable, nuclear, natural gas, and efficient and clean coal power plants. The two major programmes are:

- The 'Large Substitute for Small (LSS)' programme.
- The Energy Conservation power generation (ECPG) scheduling programme.

Their combined aim is to remove most of the existing 114 GWe of small units from operations, with the LSS programme closing about 50% of this capacity by end 2011, and the Energy Conservation power generation scheduling programme then forcing the closure of the remainder.

3.1.1 The 'large substitute for small (LSS)' programme

In 2006, overall power supply broadly matched demand, and there was a large order book to provide a very significant number of advanced coal-fired plants to be brought on to the grid. Consequently at that time the NDRC initiated its energy efficiency initiative, with the launch of the LSS programme to help meet the national target by end 2010 of a 20% reduction in energy intensity. The intention was to decommission some 50 GWe of small thermal units (NDRC, 2007a). This included:

- All conventional thermal power generation units of 50 MWe class and below.
- All conventional thermal power generation units of 100 MWe class and below with 20 or more years of service.
- All conventional thermal power generation units of 200 MWe class and below with design service lives shorter than their actual periods of service.
- All coal-fired generation units with a net heat rate that in 2005 was either higher than the provincial average by at least 10% or higher than the national average by at least 15%.
- All generation units of all kinds not meeting environmental standards.
- All generation units not complying with laws and regulations.

To support this closure programme, the NDRC requires any power company that wants to increase its installed coal-fired power generation capacity to also close some of its small capacity. The amount to be closed is calculated according to a NDRC formula, which encourages the construction of large units with advanced steam conditions. Thus, in order to build a new 600 MWe station some 420 MWe of old capacity must be closed while for a 1000 MWe new unit, the number is 600 MWe (NDRC, 2007a).

Many of these small units have benefited from local subsidies since they are often owned by local governments and can be important sources of local fiscal revenue while also being a source of jobs. The NDRC has closed off these market distortions in another step to force such units off the grid.

Alongside this, the NDRC reinforced its initiative for the installation of FGD on new coal-fired power plants and the

Table 9 Changes in the proportion of small coal-fired power plant capacity in China for the period 2000-08 (Tian, 2008; Mao 2008a)

	Total installed thermal capacity, GWe	Total capacity of small units, MWe	Proportion of small capacity, %
2000	238	67	28.2
2001	253	68	26.9
2002	265	67	25.3
2003	290	71	24.5
2004	329	85	25.8
2005	391	121	30.9
2006	484	114	23.6
2007	554	104	18.8
2008	601	83	13.8

Unit capacity equal to or smaller than 100 MWe is defined as small capacity
Total capacity includes oil fired and gas fired units

accelerated desulphurisation retrofit to all coal-based generating units larger than 135 MWe that are not included in the LSS programme.

By the end of 2007, 56 GWe of small units had been proposed by the provinces and power producers to the NDRC for participation in the LSS programme, thereby already meeting the target for 2011. From 2006 to end 2008, some 34 GWe of the most inefficient plants were closed, comprising 2.9 GWe in 2006, 14.4 GWe in 2007 and 16.7 GWe in 2008. This surpassed the planned programme of 10 GWe and 13 GWe in 2007 and 2008 respectively. The plans for 2009 onwards include the closure of 13 GWe of capacity by the end of the year, to be followed by 10 GWe in 2010 and 8 GWe in 2011 (Cleantech, 2009a).

The early impact is given in Table 9. This shows the absolute numbers of small units decreasing from 2006 onwards, which in percentage terms is accentuated as the new plants coming on line from 2007 onwards are all large units. However, while this is encouraging, in 2008, the National Audit Authority determined that the five largest power generating companies (Huaneng, Datang, Huadian, Guodian and China Power Investment) had all initiated the construction of about 100 large power projects without any LSS activities and subsequent approval. This indicates the ongoing problems of implementing state edicts at the provincial level in a very large country (Minchener, 2007).

3.1.2 The Energy Conservation power generation scheduling programme

Complementary to the LSS, the Programme of Energy Efficient and Environmental Friendly Power Generation Scheduling (ECPG scheduling) is being designed to create a market mechanism by substituting the current even load power generation scheduling rule on the grids with an energy efficiency based one that is designed to support the use of lower carbon power generation (NDRC, 2007b).

Under the new rule, all grid connected generating units are classified into the following priority categories (Planet Ark, 2007):

- Unadjustable wind power, solar power, ocean power and hydro power.
- Adjustable hydro, biomass, geothermal power and solid waste fired units.
- Nuclear power.
- Coal-fired cogeneration units and units for the comprehensive use of resources, including those using residual heat, residual gas, residual pressure, coal gangue, coal bed/coalmine methane.
- Natural gas and coal gasification based combined cycle units.
- Other coal-fired generating units including cogeneration without heat load.
- Oil and oil product based generation units.

Within each category, units will be ranked according to their energy efficiency. Units with the same energy efficiency will then be ranked according to their emission levels and water usage. Individual units will be scheduled for generation only when all units in upper categories and ranks are operating at full capacity.

Based on the current and projected capacity mix, the expected impact will be that all grid connected renewable, nuclear and gas (including coal bed/mine methane) fired units will be operated at full capacity with the expectation that the planned increases in capacity as set out in the 2020-30 plans will also operate in the same way. For coal-fired units, some will operate at full capacity and others at less than full capacity depending on their position in the energy efficiency merit order. The expected boundary below which there will be very limited opportunity to operate except at peak load will be between the 110 and 135 MWe class coal-fired units.

An ongoing consequence of this scheduling arrangement is that the power generation companies will choose to install new coal-fired generating units that are as large and efficient as possible to stay away from the ascending cut-off boundary. This, in turn, would accelerate the ascendance of the boundary, mutually reinforcing an energy efficiency improvement in the sector.

What is not clear is how the NDRC might reform the electricity pricing mechanism. On this basis of the proposed approach, the smaller units plus those units that fire diesel or other oil products will be out of the base load market and presumably will then close on economic grounds. However, there would need to be some emergency back-up units and it is not clear how a company would be compensated for maintaining such units for use for perhaps a few hundred hours each year.

Four central government agencies, headed by the NDRC, jointly issued the new rules in August 2007. A trial has been ongoing since December 2007 in Guizhou, Jiangsu, Sichuan, Henan and Guangdong Provinces. It was intended that the experiment would be completed by the middle of 2008. However, no information is forthcoming as to how well the implementation measures and operational plans have worked and no date has been announced for when the new ECPG scheduling rule will become effective nationwide.

3.2 Review of advanced pulverised coal technologies

From 1999 to 2004, there was some limited introduction of advanced coal-fired units from overseas sources, mainly from Russia, and typically with modest SC steam conditions compared to those introduced more recently. However, from 2004 onwards, the numbers and sizes of units, with more advanced steam conditions, increased very significantly.

3.2.1 Status overview

Under current policies, the average efficiency of China's coal-fired power plants is rising as the small units are closed and the new, large, efficient units are brought on line. The expectation is that the 300 MWe subcritical units will eventually represent the likely minimum size in the capacity mix. At the end of 2007, the total installed thermal power capacity was 554 GWe, of which 333 GWe comprised units of 300 MWe or greater (~60%). Table 10 provides some information on the ongoing surge of advanced coal-fired units, which shows that almost 300 GWe of such capacity are either operational, under construction or on order at the end of 2007.

Table 11 provides details of their typical cycle efficiencies and coal consumption rates. Bearing in mind the numbers of such units at the design and construction stage, it is evident that once these are all operational, and coupled with the closing of further small units, then there will be a very significant further uplift in the average efficiency of Chinese coal-fired power plants.

Table 12 provides additional information on all USC units that had been ordered but were not yet operational by May 2008. This indicates a further enormous incremental increase in USC units that are either at the design/manufacture or construction stage. This also indicates the coming dominance of this type of advanced power plant unit within the Chinese capacity mix, especially at the 1000 MWe size.

3.2.2 International technology transfer to Chinese manufacturers

Table 12 also indicates the dominance of the three major Chinese power plant equipment manufacturers for the production of these advanced units. This point is emphasised further in Tables 13 and 14, which provide information relating to the 600 MWe SC and USC units respectively. Besides providing basic technical data, these indicate that these PC technologies with advanced steam conditions were introduced from companies in Japan and Europe (*see* Section 2.2 for details of the companies involved). Table 15 provides comparable information for the 1000 MWe USC units. It should be noted that, unlike for the 600 MWe SC and USC units where Chinese developed generators were used, for the 1000 MWe units, overseas technologies were introduced in addition to the boilers and steam turbines.

As noted in Chapter 2, significant co-operation arrangements have been established between the three major Chinese power plant equipment manufacturers and various OECD suppliers. Some specific examples are summarised in Table 16.

Table 10 Status of SC/USC units in China at end of 2007

	In operation		Under construction	Ordered and at the design stage	
Capacity, GWe	99.5		>100	82.4	
Designation	SC	USC	SC/USC	SC	USC
Capacity, GWe	90.7	8.8		25.4	57.0
Number of units	112	10	>167	66	65

Table 11 Typical cycle efficiencies and coal consumption rates by end of 2007

	Coal consumption, gce/kWh	Cycle efficiency, % net, LHV basis
USC 1000 MWe	286	43.0
USC 600 MWe	292	42.1
SC 600 MWe	299	41.1

Table 12 Status of USC boilers ordered by end of May 2008

Supplier	1000 MWe		660 MWe		600 MWe	
	No	Capacity, GWe	No	Capacity, GWe	No	Capacity, GWe
Harbin	16	16.0	18	11.9	10	6.0
Shanghai	36	36.0	16	10.6		
Dongfang	28	28.0	10	6.6		
Beijing B&W	4	4.0	2	1.3	4	2.4
Sub-total	84	84.0	46	30.4	14	8.4

Table 13 General information on 600 MWe SC units at the end of 2007

	600 MWe Class SC boiler	600 MWe Class SC steam turbine	600 MWe class SC generator
Steam parameters	BMCR:1900~2100t/h Steam pressure of SH: 25.4 MPa(g) Steam temperature of SH: 571 °C Steam temperature of RH: 571 °C Boiler efficiency: ~94%	TMCR: 640~700 MW Inlet steam pressure of SH: 24.2 MPa(g) Inlet steam temperature of SH: 566 °C Inlet steam temperature of RH: 566 °C Heat rate of turbine: 7545 KJ/KW h	Same as 600 MWe class subcritical generator
Chinese suppliers	Harbin Boiler Co Ltd (HBC) Dongfang Boiler Co Ltd (DBC) Shanghai Boiler Co Ltd (SBWL)	Harbin Turbine Co Ltd (HTC) Dongfang Turbine Co Ltd (DTC) Shanghai Turbine Co Ltd (STWL)	Harbin Gen. Co Ltd (HGC) Dongfang Gen. Co Ltd (DGC) Shanghai Gen. Co Ltd (SGWL)
Sources of technology transfer	Alstom (France) Mitsubishi (Japan) Hitachi (Japan) IHI (Japan) Doosan Babcock (UK)	Alstom (France) Mitsubishi (Japan) Hitachi (Japan) Toshiba (Japan) Siemens (Germany)	Technology designed and developed by Chinese companies

Table 14 General information on 600 MWe USC units at the end of 2007

	600 MWe class USC boiler	600 MWe class USC steam turbine	600 MWe class USC generator
Steam parameters	BMCR: 1850 t/h Steam pressure of SH: 26.2 MPa(g) Steam temperature of SH: 605°C Steam temperature of RH: 603°C Boiler efficiency: 94 %	TMCR: ~640 MW Inlet steam pressure of SH: ~25 MPa(g) Inlet steam temperature of SH: 600°C Inlet steam temperature of RH: 600°C Heat rate of Turbine: ~7424 kJ/KWh	Same as 600 MWe class subcritical generator
Chinese suppliers	Harbin Boiler Co Ltd Dongfang Boiler Co Ltd Shanghai Boiler Co Ltd	Harbin Turbine Co Ltd Dongfang Turbine Co Ltd Shanghai Turbine Co Ltd	Harbin Gen. Co Ltd Dongfang Gen. Co Ltd Shanghai Gen. Co Ltd
Sources of technology transfer	Alstom (France) Mitsubishi (Japan) Hitachi (Japan) IHI (Japan) Doosan Babcock (UK)	Alstom (France) Mitsubishi (Japan) Hitachi (Japan) Toshiba (Japan) Siemens (Germany)	Technology designed and developed by Chinese companies

Table 15 General information on 1000 MWe USC units at the end of 2007

	1000 MWe class USC boiler	1000 MWe class USC steam turbine	1000 MWe class USC generator
Steam parameters	BMCR: ~3000 t/h Steam pressure of SH: 26.25~28 MPa Steam temperature of SH: 05°C Steam temperature of RH: 603°C Boiler efficiency: ~94%	TMCR: ~1005 MW Inlet steam pressure of SH: 25~26.25 MPa Inlet steam temperature of SH: 600°C Inlet steam temperature of RH: 600°C Heat rate of Turbine: ~7420 kJ/KWh	Capacity: ~1111 MVA Capacity: ~1000 MW Voltage of Stator: 27 kV Capacity factor: 0.9
Chinese suppliers	Harbin Boiler Co Ltd Dongfang Boiler Co Ltd Shanghai Boiler Co Ltd	Harbin Turbine Co Ltd Dongfang Turbine Co Ltd Shanghai Turbine Co Ltd	Harbin Gen. Co Ltd Dongfang Gen. Co Ltd Shanghai Gen. Co Ltd
Sources of technology transfer	Alstom (France) Mitsubishi (Japan) Hitachi (Japan) IHI (Japan)	Alstom (France) Mitsubishi (Japan) Hitachi (Japan) Toshiba (Japan) Siemens (Germany)	Hitachi (Japan) Toshiba (Japan) Siemens (Germany)

Table 16 Examples of specific partnerships between the three major Chinese manufacturers and various OECD suppliers of SC/USC technology

Boiler	HBC—Mitsubishi	DBC—Hitachi	SBWL—Alstom
	Vertical tube furnace, variable pressure operation, single furnace with double tangential firing system, Π type arrangement of boiler.	Spiral tube furnace, variable pressure operation, single furnace with opposed wall firing system, Π type arrangement of boiler.	Spiral tube furnace, variable pressure operation, single furnace with tangential firing system, tower arrangement of boiler
Turbine	HTC—Toshiba	DTC—Hitachi	STWL—Siemens
	Single reheat, condensation, single shaft with four steam cylinders	Single reheat, condensation, single shaft with our steam cylinders	Single reheat, condensation, single shaft with four steam cylinders
Generator	HGC—Toshiba	DGC—Hitachi	SGWL—Siemens
	Water-hydrogen-hydrogen cooling system Static excitation	Water-hydrogen-hydrogen cooling system Excitation without brush	Water-hydrogen-hydrogen cooling system Excitation without brush

3.2.3 Design information for Chinese advanced PC power plants

Table 17 provides an overview of the key parameters for the SC and USC boilers that are offered by the Chinese manufacturers.

Table 18 provides a comparison of boiler designs offered by the three major manufacturers in China, the differences being a consequence of the technology transfer source.

Two examples of these designs are provided in Figures 2 and 3.

3.2.4 Overview of performance data

Table 19 provides a comparison between the coal consumption rates and cycle efficiency for a series of SC/USC units compared to a 600 MWe unit with subcritical steam conditions. This shows the positive impact both of the improved steam conditions and the economies of scale.

An indication of the capital investment requirements is given in Table 20. For all sizes and types of unit, the capital investment costs are much lower for coal-fired power plants that are built in China compared to those in OECD countries. There are various reasons for this. Firstly, China is a lower cost production centre compared to OECD countries. However, this difference is also a result of China learning by doing, as it has established so many large manufacturing production capabilities and at the same time has built so many advanced units, unlike the rest of the world. This has provided many opportunities for improving the designs of the units while also improving the efficiency of the production processes.

The other key point is that the specific capital investment for the 1000 MWe unit is lower than for the 600 MWe unit while also offering significant efficiency advantages. This supports the Chinese approach to make the 1000 MWe unit a key technology standard module, as is shown in Table 10, which indicates the very significant number of such units on order.

A further example of what is being achieved in China are the results from the performance test carried out in May 2008 on the Shanghai Waigaoqiao No 3 power plant, which comprises 2x1000 MWe USC Units. The following standards were

Table 17 Key parameters for Chinese PC boilers with advanced steam conditions

	600 MWe	600 MWe	600 MWe	1000 MWe	1000 MWe	1000 MWe
Main steam flow rate (MCR), t/h	1900	1900	1795	2953	2953	3033
Main steam pressure, MPa	25.4	25.4	26.2	27.6	27.7	26.3
Main steam temperature, °C	543	571	605	605	605	605
Reheat steam flow rate, t/h	1640	1608	1464	2457	2446	2470
Reheat inlet pressure, MPa	4.61	4.71	4.84	6.0	4.92	4.99
Reheat outlet pressure, MPa	4.42	4.52	4.64	5.8	4.77	4.79
Reheat inlet temperature, °C	297	322	350	359	375	356.3
Reheat outlet temperature, °C	569	569	603	603	603	603
Feed water temperature, °C	283	284	293	296	297	302
Firing system	Opposed firing	Opposed firing	Tangential firing	Double tangential firing	Double tangential firing	Opposed firing
Waterwall construction	Spiral tube	Spiral tube	Vertical tube	Vertical tube	Vertical tube	Spiral tube
Type of waterwall tube	Rifled tube	Rifled tube	Rifled tube	Rifled tube	Rifled tube	Rifled tube
Boiler Manufacturer	Beijing B&W	DBC	HBC	HBC	SBWL	DBC
Typical reference plant	Lanxi, Zhejiang Province	Qinbei, Henan Province	Shenzhen, Heyuan, Guangdong Province	Yuhuan, Zhejiang Province	Waigaoqiao, Shanghai	Zouxian, Shandong Province

Table 18 Comparison of 1000 MWe USC boilers between various boiler suppliers in China			
	DBC-1000 MWe	HBC-1000 MWe	SBWL-1000 MWe
Technology source	Babcock-Hitachi	Mitsubishi	Alstom
Type of start-up system	Recirculation pump + flash tank	Recirculation pump + flash tank	Recirculation pump + flash tank
Steam temperature adjustment	Flue gas damper + water spray	Flue gas damper + tilt burner + water spray	Flue gas damper + tilt burner + water spray
Type of burner	HT-NR3 swirling low NOx burner + OFA	PM low NOx burner +MACT	LNCFS low NOx burner + SOFA
Mode of firing system	Opposed wall firing	Single furnace with double tangential firing	Single furnace with double tangential firing
Design coal	Bituminous coal	Bituminous coal	Bituminous coal
Size of Furnace, m	33.9734×15.5584×64	32.084×15.67×66.6	35.5×14.86×66.9
Furnace volumetric heat release rate, kW/m^3	79	82.7	
Furnace sectional heat release rate, MW/m^2	4.5	5.6	
Type of water wall	Spiral rifled tube + vertical smooth tube	Vertical rifled tube +vertical smooth tube	Vertical rifled tube
Mill and milling system	Double end ball mill, direct milling system	Vertical mill, direct milling system	Vertical mill, direct milling system
Stages of water spray and percentage	2 stages, 8%	3 stages, 7%	3 stages
Name of Chinese boiler company	Dongfang Boiler Co Ltd	Harbin Boiler Co Ltd	Shanghai Boiler Works. Ltd
Reference power plant	Xouxian plant in Shandong Province	Yuhuan plant in Zhejiang Province	Waigaoqiao plant in Shanghai

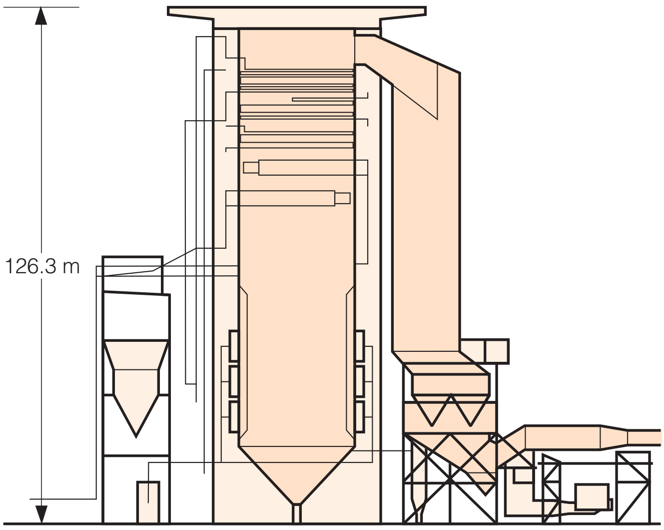

Figure 2 Design of 1000 MWe USC boiler by Shanghai Boiler Works

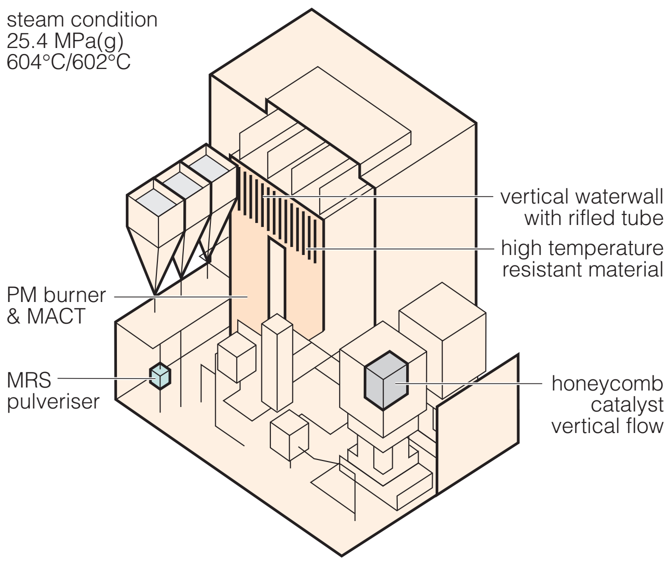

Figure 3 Configuration of 1000 MWe USC boiler by Harbin Boiler Co

achieved, which are comparable with the best in the world:

- Power consumption rate with FGD: 3.7%;
- Net coal consumption with FGD (gce/kWh): 272.6–272.9;
- Net efficiency for power supply with FGD: 45%;
- Net heat rate (kJ/kWh): 7239.3–7241.2;
- Boiler efficiency: > 94%;
- Average LOI (UBC) of boiler: 0.1%;
- Lowest turndown ratio without oil support for boiler: 20%.

Table 19 Comparison of the performance for various coal-fired power generation units with different steam parameters

	Sub-critical 2×600 MWe	Supercritical 2×600 MWe		Ultra-supercritical 2×1000 MWe
Steam parameters	16.7 MPa 538/538°C	24.5 MPa 538/566°C	24.5 MPa 566/566°C	27.5 MPa 600/600°C
Heat rate of steam turbine, kcal/kWh	1877	1830	1780	1772
Efficiency, %	42.0	42.9	43.6	45.0
Coal consumption, gec/kWh	293	286	282	273
Increase of efficiency, percentage points	0	+2.2	+4.0	+7.2

Table 20 Comparison of capital costs for various coal-fired power generation units in China (2007 costs)

Type of units	Capital investment, million RMB	Specific capital investment, RMB/kW	Increase in efficiency rate compared to subcritical unit, percentage points
Sub-critical 2×600 MWe	4046.4	3372	0
Supercritical 2×600 MWe	4208.3	3507	+4
Ultra-supercritical 2×1000 MWe	6990.0	3495	+7.6
Costs do not include FGD			

3.3 Environmental control issues for PC systems

Even with these significant efficiency increases, the continuing massive expansion in coal use in the power sector raises significant environmental issues due to SO_2, NOx and particulate emissions, which are being addressed as set out below.

3.3.1 Policies and regulations

Prior to 2004, China had very undemanding coal-fired power plant emission limits, compared with OECD countries (Minchener, 2004). Subsequently, SEPA (now the MEP) and the State Bureau of Technical Supervision, Inspection and Quarantine jointly formulated a new standard. This 'Emission Standard of Air Pollutants for Thermal Power Plants (GB13223-2003)' was issued on 23 December 2003 and became effective from 1 January 2004 (Wang and Zeng, 2008). The key standards are given in Table 21.

Table 21 Emission limits for thermal power plants in China (Wang and Zeng 2008)

Particulates, mg/m^3	SO_2, mg/m^3	NOx, mg/m^3
50	400	450 (Bituminous coal) 650 (Lean coal) 1100 (anthracite

These 2004 standards are within World Bank guidelines and equivalent to the OECD average. For big international cities and scenic areas such as Beijing, Shanghai, Guangzhou, Hangzhou and Guilin, the local EPA can issue local air pollutant emission legislation, which can be far stricter than the national emission standards.

3.3.2 Control of SO_2 emissions

In order to ensure that these standards are met, the Government developed a three pronged 'carrot and stick' approach to force the power generation companies to deal with acid gas emissions, especially SO_2, due to the national requirement to reduce emissions by 10% (Chen, 2008b; Wang and Zeng, 2008). This required that:

- All the new thermal power plants for which construction started after 1 January 2004 must be equipped with FGD to achieve the 400 mg/m^3 SO_2 emissions limit, unless the sulphur content of the designated coal for the plant is less than 0.7%.
- Subject to coal sulphur content, all the existing thermal power plants not on a closure list shall be equipped with FGD by the end of 2010, no matter when the plant was built. The MEP takes the lead in deciding the actual date by which FGD will be applied to any particular plant.
- Various incentives are offered to ensure compliance with the limits. Thus, from July 2004, a tax has been levied at the rate of 0.65 RMB/kg of SO_2/NOx emitted (0.07 €/kg). At the same time, the price paid for electricity generated from plants that have FGD installed has been enhanced by 0.015 RMB/kWh.

Table 22 Overview of SO_2 emissions in China (2002-07)

	Total emissions of SO_2, Mt	Emissions from thermal power plants		
		SO_2, Mt	Proportion of total, %	Specific emissions, gSO_2/kWh
2002	19.27	8.20	42.6	6.1
2003	21.59	10.00	46.3	6.3
2004	22.55	12.00	53.2	6.6
2005	25.49	13.00	51.0	6.4
2006	25.89	15.00	52.1	5.7
2007	24.68	12.00	48.6	4.4

Table 23 Overview of installed FGD capacity for 2007

Capacity of power unit, MWe	Installed capacity with FGD, GWe	Ratio of total, %
⩾600	61.6	53
300	41.1	35
200	9.0	8
100	4.5	4
Total	116.2	100

There is also now a water use quota for thermal power plants, for which a high price can be levied upon enterprises exceeding the quota standard. Enterprises failing to reach the standard shall also be ordered to make corrections within a time limit (Chen, 2008a).

These policy drivers have led to significant installation of FGD in recent years, especially in 2007 and 2008. To put this in context, Table 22 shows that the total SO_2 emissions increased from 19.27 Mt in 2002 to 25.89 Mt in 2006, a 34% increase during 5 years with a very large proportion of this arising from the major increase in coal-fired power generation. However, despite a further significant increase in power produced from coal-fired units, in 2007 the total emissions of SO_2 fell to 24.68 Mt, which was primarily a result of the significant introduction of FGD. This trend has continued. For example, by the end of 2008, the annual capacity of newly installed FGD was 110 GWe equivalent while the total installed capacity of FGD reached 379 GWe equivalent, which accounted for 66% of the total installed thermal power capacity in China (China Business News, 2009).

Table 23 provides information for 2007 on the relative proportion of thermal power plants with FGD installed by size of unit. This emphasises the far greater inclusion of FGD on the larger (⩾600 MWe) units, which since 2006 have represented the very great majority of new plant build. Much of the FGD installed on the smaller units represents the completion of retrofit applications on units selected by the MEP, often for local reasons such as use of high sulphur coal at a small plant that cannot be closed for very specific strategic reasons.

Although there is a longstanding target of installing FGD on all coal-fired power plants, this will not be achieved by 2010. This is due to some uncertainty as to how the power plant closure programme will be extended in terms of the sizes and ages of plant that could well be added to the list. There are also bottlenecks in the production of the FGD units themselves as the sheer volume of equipment manufacture is creating strains within the overall system.

Table 24 lists those FGD suppliers in 2008 that each had achieved a total sold capacity in excess of 1 GWe equivalent. It further provides information on their total capacity in operation and their product ranges. The very great majority (some 95%) of FGD systems installed have been limestone-gypsum wet scrubbers. The others have included seawater FGD in some coastal locations and the Chinese designed CFB FGD system.

Looking to the future, the installed capacity of FGD systems in China is projected to rise from 379 GWe of coal-fired power plants at end 2008 to 723 GWe in 2020, according to the latest trade forecast. To put this in perspective, over the next eleven years China will add 32 GWe equivalent of FGD per year. This represents 75% of all the new FGD to be installed globally each year (PEI, 2009b).

The system for technology deployment mirrors that for coal-fired power plants. Although there is co-operation between Chinese and international companies on some components, the former can produce much of the equipment alone. The prices of FGD systems in China are 50% lower than on the international market (PEI, 2009b).

3.3.3 Control of NOx emissions

For NOx emission control, based on the current NOx emission limit (Table 21), the use of low NOx combustion technologies ensures that the standard can be met. China has access to OECD burner types based on technology transfer agreements and to others based on Chinese developments. The Chinese designs are cheaper while the OECD designs are more efficient. Both have significant market niches as both offer a cost effective means to meet the environmental drivers. Should the limit be tightened to, say, 200 mg/m^3 or below, then selective catalytic reduction systems (SCR) will need to be introduced. Several demonstration projects of SCR are

Table 24 Major FGD suppliers in China as of end 2008

Ranking	Name of FGD supplier	Capacity of FGD in operation, GWe	Product range as a percentage of company FGD sales
1	Beijing Guodian Long Yuan	39.7	Limestone scrubber (89.9) Sea water FGD (9.9) CFB-FGD (0.2)
2	Wuhan Kaidi Power and Environment	34.3	Limestone scrubber (90) CFB-FGD (10)
3	China Boqi Environment and Technology	32.9	Limestone scrubber (100)
4	Zhejiang University Wangxin Engineering	22.2	Limestone scrubber (100)
5	China Power Investment Yuanda Environment	20.7	Limestone scrubber (99) CFB-FGD (1)
6	Shandong Sanrong Environment Engineering	19.1	Limestone scrubber (95) CFB-FGD (5)
7	Fujian Longjing Environment	18.0	Limestone scrubber (72) CFB-FGD (28)
8	Zhejiang Tiandi Environment Engineering	16.4	Limestone scrubber (99) Sea Water FGD (1)
9	Qinghua Tongfang Environment	16.1	Limestone scrubber (100)
10	China Huadian Engineering	14.3	Limestone scrubber (100)
11	Jiangsu Suyuan Environmental Engineering	13.7	Limestone scrubber (100)
12	China Datang Science and Technology Engineering	12.1	Limestone scrubber (100)
13	Beijing Guodian Qingxin Environment	10.8	Limestone scrubber (100)
14	Guizhou Xingyun Environment	8.5	Limestone scrubber (100)
15	Beijing Langxinming Environment	5.5	Limestone scrubber (100)
16	Zhejiang Feida Environmental Technology	5.1	Limestone scrubber (76) NID FGD (24)
17	Guangzhou Tiancisanhe Environmental Engineering	4.4	Limestone scrubber (67) Double alkali FGD (17) Spray dry FGD (16)
18	Shandong Power Engineering Consultant Co	4.0	Limestone scrubber (96) CFB-FGD (4)
19	Zhejiang Lantian Qiushi Environment	4.0	Limestone scrubber (95) CFB-FGD (5)
20	Hunan Yongqing Desulfurization Co	4.0	Limestone scrubber (100)
21	Wuhan Jingyuan Environmental Engineering	3.9	Sea water FGD (100)
22	Guodian Environmental Institute	3.2	Limestone scrubber (100)
23	Lantian Environment	2.2	CFB-FGD (100)
24	Shandong Danengyuan Environment	2.1	CFB-FGD (69) Limestone scrubber (31)
25	Jiangsu Century Jiangnan Environment	1.9	Ammonia FGD (100)
26	Guangzhou Yueshou Industry	1.6	In furnace calcium injection (100)
27	Guangdong Power Design Institute	1.4	Limestone scrubber (100)
28	Sichuasn Hengtai Environmental Technology	1.3	Limestone scrubber (92) double alkali FGD (8)
29	Hunan Luna Desulphurization/De-dust Co	1.3	Limestone scrubber (89) Calcium/sodium double alkali FGD (11)

under way, some in co-operation with OECD equipment suppliers, to ensure that the coal-fired power sector can become familiar with the technology. In addition, for all the new thermal power projects, it is a requirement from the NDRC that, when the power plant is designed, enough space must be allowed for future SCR installation.

3.4 CFBC development and deployment

The alternative technology to PC fired systems is CFBC, which has established a significant niche in the power sector of China.

3.4.1 Background

The 11th Five Year Plan (2006-10) includes several measures to utilise CFBC for ensuring improved efficiency of energy utilisation in power generation. For every 100 Mt of raw coal produced, some 14 Mt of coal mine waste is removed from the pit and, if the raw coal is then washed, there is up to an additional 14 Mt of coal washery waste. The latter is particularly problematic, being difficult to stabilise within tips. National estimates suggest that there is over 3 Gt of coal related wastes at various coal mines in China (ADB, 2004).

In order to maximise energy utilisation from such wastes as well as to ensure stability of the tips and to provide a material suitable for use in aggregates and other low grade materials, the NEA intends to establish some 20 GWe of coal mine/washery waste fired CFBC units in line with Government policy to encourage mine-mouth power generation. For example, in Shanxi Province, which is the largest coal producing province in China, the intention by 2010 is to build 5–6 GWe of CFBC power plants to be fired with coal mine and coal washery wastes (Mao, 2008b). In addition, CFBC is recognised as a suitably flexible technology for firing low grade and variable quality coals, including those with high sulphur contents, while ensuring low emissions.

3.4.2 Status of CFBC deployment in China

As with advanced PC-based technologies, China is leading the way in establishing significant numbers of large CFBC power plants, including those with unit capacity of 300 MWe and greater. Table 25 provides an overview of Chinese CFBC power plant boilers at end of 2008.

The sources of CFBC boiler technologies in China comprise:

- Domestic units developed by the Xian Thermal Power Research Institute, Thermal Engineering Physics Institute and Tsinghua University (mostly small scale).
- 100 MWe design licensed from Foster Wheeler to the Dongfang Boiler Company.
- 150–300 MWe design licensed from Foster Wheeler to the Wuxi Boiler Company.
- 135 MWe design licensed from EVT to the Harbin Boiler Company.
- 135 MWe design licensed from Combustion Engineering to the Shanghai Boiler Company.
- 300 MWe design licensed from Alstom Power to the major boiler manufacturers, namely the Harbin/Dongfang/Shanghai Boiler companies.

Thus while there are local designs, the momentum to establish larger-scale technologies has been provided via technology transfer arrangements that, as with PC plant, have been applied to ensure that technology application in China is optimised. Thus, 100 MWe and 300 MWe CFBC boilers have been transferred to selected power equipment manufacturers under licence arrangements. In particular, in 2003, the State government approved an agreement for a combination of equipment purchase and technology transfer for the Alstom Power 300 MWe technology. A 300 MWe CFBC demonstration power plant burning high sulphur coal was built at Baima in Sichuan Province, with the equipment supplied by Alstom Power at an agreed commercial price with Baima Power Plant. In addition, a contract was agreed with the three largest boilermakers, Harbin, Shanghai and Dongfang, each of which has become a licensee of the supplier with the rights to replicate the 300 MWe technology in China.

The Baima CFBC started operation in 2006. Figure 4 gives an outline schematic of the design while Table 26 shows the design parameters and the measured operating data that are available from the public domain (Mao, 2008b).

At the same time, there has been collaboration between the major Chinese boilermakers and various universities and institutes, to develop their own large-scale designs. Dongfang, Shanghai and Harbin Boiler Companies worked together with universities (such as Tsinghua) and research institutes (such

Table 25 Status of CFBC power plant boilers in China at the end of 2008

Capacity, t/h	Nominal electrical output, MWe	Number of CFBC units in operation	Total number of CFBC units (including all units ordered, under construction and in operation
25–50	n/a	886	1024
65–90	25	1159	1340
100–130	50	188	218
130–180	75	69	86
200–280	90	184	214
310–410	100	46	55
420–485	135	96	184
500–700	200	1	6
1000	300	7	71
Total	–	2636	3198

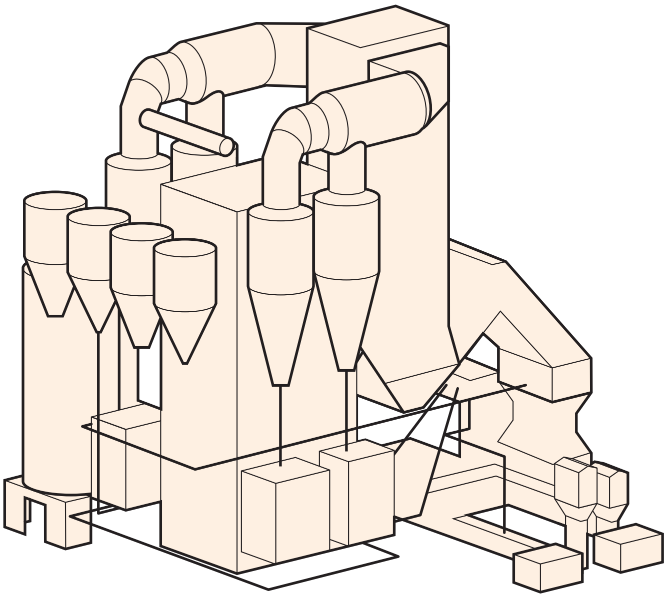

Figure 4 Schematic of China's first 300 MWe CFBC boiler at Baima Power Plant

as Xian) to develop their own 300 MWe CFBC products. For example, the 330 MWe CFBC installed at Fenyi Power Plant in Jiangxi Province, which was supplied by the Harbin Boiler Company, was jointly developed by Harbin and the Xian Thermal Engineering Institute, *see* Figure 5 and Table 27 (CPI, 2007).

The situation is changing rapidly. At the end of 2008, the number of CFBCs with unit capacity of 300 MWe/330 MWe in operation was seven (Table 25) but by May 2009 this had risen to fifteen (all being included in the listing of Table 27). Another sixty-four 300 MWe CFBC units were on order or under construction. At that time, over 3000 CFBC boilers with a total installed capacity of 67 GWe had been established, accounting for 11.6% of total installed coal power capacity in China (Mi, 2009).

Figure 5 330 MWe CFBC boiler in operation in January 2009 at Fenyi Power Plant

Table 26 Design parameters and measured operating data of the Baima 300 MWe CFBC boiler (Mao, 2008b)

	BMCR Design data	BRL Design data	BMCR Operating data
Steam flow rate, t/h	1025	977	1025
Main steam pressure, MPa	17.4	17.4	17.4
Main steam temperature, °C	540	540	540
Main steam flow rate, t/h	844	807	
Reheat steam inlet pressure, MPa	3.9	3.71	3.71
Reheat steam outlet pressure, MPa	3.7	3.53	3.53
Reheat steam inlet temperature, °C	330	325.6	325.6
Reheat steam outlet temperature, °C	540	540	540
Feed water temperature, °C	280	278	278
CFB boiler efficiency, %	91.8		93.3
Sulphur capture, %	94.1		94.7
Ca/S mole ratio	1.8		1.7
Lowest load without oil support, %BMCR	35		35
SO_2 emissions (6% O_2, dry), mg/m^3	600		550
NOx emissions (6% O_2, dry), mg/m^3	250		90

Table 27 Listing of 300 MWe CFBC boilers expectedto be in operation in China by end 2009

Name of power plant	Capacity, MWe	Number of units	Supplier	Fuel	Year in operation
Sichuan Baima	300	1	Alstom	Lean coal	2006
Yunnan Honghe	300	2	Harbin	Lignite	2006
Hebei Qinhuandao	300	2	Harbin	Bituminous coal	2006
Yunnan Xunjiansi	300	2	Harbin	Lignite	2007
Yunnan Guodian Kaiyuan	300	2	Shanghai	Lignite	2007
Anhui Huaibei Linhuan	300	2	Harbin	Coal washery slurry and coal mine waste	2009
Jiangxi Fenyi	330	1	Harbin	Anthracite	2009
Heilongjiang Datang Jixi B	300	2	Harbin	Coal mine waste	2009
Inner Mongonia Xilingele	300	2	Harbin	Lignite	2009
Inner Mongonia Shendong Guojiawan	300	2	Harbin	Bituminous coal	2009
Inner Mongonia Shendong Salaqi	300	2	Harbin	Bituminous coal	2009
Inner Mongonia Monxi	300	2	Shanghai	Low grade bituminous coal	2008
Shanxi Pingshuo	300	2	Shanghai	Coal washery waste +coal mine waste	2009
Inner Mongonia Zhungeer Dafanpu	300	2	Shanghai	Lignite	2009
Liaoning Diaobingshan	300	2	Shanghai	Bituminous coal	2009
Inner Mongonia Hangmian	300	2	Shanghai	Bituminous coal	2009
Guangdong Baolihua	300	2	Dongfang	Anthracite	2008
Guangdong Pingshi	300	2	Dongfang	Anthracite	2009
Fujian Longyan	300	2	Dongfang	Anthracite	2009
Fujian Zhnagping	300	2	Dongfang	Anthracite	2009
Jinghai Coal Mine Waste	300	2	Dongfang	Bituminous coal/waste	2009
Hubei Yichang Yangguang	300	2	Dongfang	Bituminous coal	2009
Inner Mongonia Zhungeer Energy	300	2	Dongfang	Bituminous coal	2009
Xinjiang Shendong Power Midong	300	2	Dongfang	Bituminous coal	2009
Shanxi Shendong Power Hequ	300	2	Dongfang	Bituminous coal	2009

In China, a key driver for CFBC development is to establish significant economies of scale by going to larger thermal capacities while increasingly taking advantages of the growing knowledge of the use of advanced steam conditions. Accordingly, the High Technology Development 863 Programme, which is funded by MOST, has included work to develop a design for a 600 MWe CFBC boiler with SC steam conditions. Three groups have been working on various options, namely the Harbin Boiler Company with Tsinghua Univesity, the Shanghai Boiler Company with the Thermal Engineering Physics Institute, and the Dongfang Boiler Company.

On the basis of this work, it is understood that a 600 MWe supercritical CFBC utility boiler to burn anthracite will be built at Baima Power Plant, for which the supply contract was signed in March 2009 between the power plant and the Dongfang Boiler Company (Mao, 2008c). This will be the first 600 MWe supercritical unit and the largest CFBC in the world. It incorporates the highly efficient Benson vertical-tube supercritical steam technology, which has already been used on the Foster Wheeler 460 MWe supercritical CFBC that has successfully started operations at the Lagisza power plant in Poland (PEI, 2009c). The approach is similar to that being adopted in the USA and Europe by Foster Wheeler and others to establish an 800 MWe CFBC design with USC steam conditions (Venäläinen and Hämäläinen, 2006).

The Chinese design includes:

- smooth tube rather than rifled tube within the furnace, due to the relatively low and even heat flux and temperature within the CFB furnace. The technology for low mass flow rate and vertical tube once-through boiler has been licensed from Siemens;

- pants leg furnace, based on the design introduced by Alstom Power;
- coal feed through a loop seal system;
- combined ignition system both under bed and above bed;
- six cyclones with six external heat exchangers;
- bottom ash drained from both two side walls through roller type ash cooler;
- regenerated air heaters with four sections.

4 Gasification-based developments

It is evident that SC PC and USC PC power generation technology coupled with emissions control technologies can meet the requirements of China's current emission standards (Zhao and others, 2008). These technologies are highly efficient, technically mature, and cost-effective. The Chinese emphasis on learning by doing has paid dividends, with the capital costs being reduced to very low levels. At the same time China continues to have an interest in assessing alternative technologies, both for the near and longer term.

4.1 IGCC development and demonstration

One such technology that has attracted longstanding interest in China is integrated gasification combined cycle (IGCC) power plant. However, no IGCC power plant is yet in commercial operation in China. This is due to the NDRC and utilities' concerns with higher capital costs, compared to advanced PC plant, which would translate into the need for higher electricity tariffs if IGCC plant should be built. At the same time, as in other countries, the low levels of component reliability and availability compared to PC power generation systems remain major concerns.

The have been several comparative studies of the cost of electricity generation from various coal-fired technologies in China. One of the more recent was undertaken as part of the APEC co-operation programme. This compared the techno-economic performance for two operational PC units, at 600 MWe and 1000 MWe, and a 200 MWe IGCC that is currently at the design stage. The lack of maturity for the IGCC is reflected in its unit size being much smaller than that of the PC units, which are regularly being installed and operated in China. All data were supplied by the Huadian Corporation. This modelling exercise confirmed the current advantages of PC over IGCC in China. Thus the levelised life cycle costs were some 40% lower for the USC PC compared to the IGCC under Chinese technical and economic conditions (WorleyParsons, 2008; Timko, 2008).

However, IGCC has the potential to provide a high efficiency system, with very low pollutant emissions. At the same time, the possibility that CO_2 capture via IGCC could result in a lower overall cost, compared to PC alternatives, has maintained interest in the technology. China sees IGCC as a possible choice for co-production of power, transport fuels and chemicals plus, in the future, integrated for CCS as a means to meeting energy and environmental challenges for coal-fired power generation. This is reflected in the MOST 863 programme, where there are 16 projects associated with IGCC and coproduction. The programme goals, which to some extent link with those for the CCS activities (*see* Chapter 6), include the intention to:

- scale up key technologies for gasification and indirect liquefaction;
- retrofit heavy gas turbines to utilise syngas;
- develop operation and control technologies and system integration technologies;
- demonstrate and validate the technologies, for which it is understood that three IGCC and two co-production demonstration plants might be considered.

An early success, in April 2006, was the construction of the co-production demonstration project, with a projected capacity of 60 MWe and an annual output of up to 240,000 tonnes of methanol (Xiao, 2006). From a Chinese perspective, there is some advantage in building these relatively small units as the current market opportunities are attractive and almost all the components can be supplied by Chinese manufacturers.

This includes wet feed gasifiers, with a coal throughput of 1150 t/d, while F-class industrial-scale gas turbines can be produced under licence at:

- Dongfang (Mitsubishi);
- Harbin (GE Energy);
- Shanghai (Siemens);
- Nanjing (GE Energy).

Table 28 shows active IGCC projects in China. The most

Table 28 Active coal-based IGCC projects in China

	Location	Power capacity, MWe	Gasifier vendor	CO_2 capture
Dongguan IGCC repowering project	Dongguan, Guandong	2x60	CAS	Study
Dongguan IGCC project	Dongguan, Guandong	4x200	CAS	Study
Huadian Banshan IGCC project	Hangzhou, Zhejiang	200	ECUST	Study
Greengen IGCC project	Tianjin	250	TPRI	Approval given. Construction under way
China Power Investment Corporation IGCC project	Langfang, Hebei	2x400		Study

advanced project is GreenGen, which ultimately aims to establish a high-efficiency, coal-based power generation system with hydrogen production through coal gasification, power generation from a combined-cycle gas turbine and fuel cells, and efficient treatment of pollutants with near-zero emissions of CO_2.

The GreenGen Company was formed in December 2005 to implement the project. The founding shareholders comprise China Huaneng Group, with a 52% share, together with the other four main power generation companies, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, and China Power Investment Company; the two largest coal mining companies, Shenhua Group and China Coal Group, and the State Development and Investment Company, each of which holds a 6% share. GreenGen has sought international co-operation to take forward this project and, in December 2007, Peabody Energy of the USA took a 6% equity stake in the GreenGen Company.

The official plan is to design, build and operate the first 250 MWe IGCC power plant in China, to be followed within five years by an expansion to 650 MWe through the addition of a 400 MWe unit, at which time CCS will be considered (GreenGen, 2008), *see* Chapter 6. The 250 MWe IGCC power plant will be located in the Harbour Industrial Park of Tianjin City, *see* Figure 6. On completion, the Project will generate 1690 GWh of electricity each year, which will be sold to the Northern China Power Grid Co through a 220 kilovolt (kV) interconnecting transmission line. The Project will also annually sell about 117 million m^3 of syngas to the Tianjin Bohua Group for chemical production. In addition, waste heat from the power plant will be the main source of heat and steam to consumers located in the Harbour Industrial Park, which will further improve the overall process efficiency (Su, 2009).

The original schedule for the first phase of the project included operation of the 250 MWe IGCC by the end of 2009. However, there has been a delay due to the NDRC being unsure about the technology's suitability for the Chinese power sector from a capital cost perspective. The projected capital cost of 1200 US$/kW, based primarily on a

Figure 6 Schematic of the intended 250 MWe IGCC at Tianjin (GreenGen, 2008)

domestically developed technology, is far higher than the Government guideline. The less than impressive reliability records of the demonstration units in Europe and the USA also rather curbed the enthusiasm for this technology, at least in government circles in China. Eventually, approval was given in May 2009 and since the feasibility study had been completed successfully and all permitting had been issued by the authorities, site preparation has commenced and equipment construction is expected to start in the very near future (Easybourse, 2009). The likely completion date for Phase 1 has been rescheduled for 2012.

From a technical standpoint, almost all the equipment will be built in China. The gas turbine will be a Siemens design to be built by the Shanghai Turbine Co, a Siemens-Shanghai Electric Co joint venture, with subsequent technology transfer into the joint venture already agreed. The gasifier will be a 2000 t/d, two-stage entrained flow TPRI design, which represents a considerable scale-up for this Chinese technology. For sulphur recovery, the intention is to use the LO-CAT technology from the USA. At this time it is not clear if all the equipment will be imported or whether some may be produced in China (Cao, 2009).

The other IGCC pilot projects are less advanced although the Government is reported to be considering rapid implementation of the 250 MWe unit at Zhejiang and the 400 MWe unit at Langfang. If approved, the overall intention would be to undertake demonstration of a critical mass of IGCC projects using different gasifier technologies and plant sizes (ADB, 2008).

4.2 Gasification for associated industrial activities

In contrast to IGCC, there is an active and significant programme to deploy gasification systems for non-power applications. This includes both domestic designed units as well as the extensive introduction of OECD equipment under licence.

The State Government has encouraged a build-up of the coal-to-chemicals industry, based on coal gasification, in an effort to reduce the nation's growing dependence on imported oil and natural gas. Since 2006, China has established nearly 40 industrial gasification projects to convert coal into syngas, which can be used to make fertilisers, plastics and pharmaceuticals (Campoy and Oster, 2007). At the same time, it has encouraged the introduction of advanced technology to replace the largely obsolete, polluting systems already in place. The new plants draw extensively on technology developed by OECD companies, with GE Energy and Shell Global Solutions as the market leaders. In addition, local alternatives are also featuring strongly (Modern Power Systems, 2008).

4.2.1 OECD technologies

GE Energy has issued 38 licences since the mid-1970s, including 16 in the last three years, mostly for ammonia and methanol production projects (ThomasNet, 2009). Some 23 are in commercial operation, with more than 90% of the gasification equipment for the resulting projects being fabricated locally in China (China Sourcing News, 2008). These long-term licence agreements include the gasification process design package, process and instrumentation design review with EPC, start-up support, operator training, on-going technical support and specialist products supply (GE Energy, 2008).

By the end of 2008, Shell had set up 19 Shell Coal Gasification Process (SCGP) licensing agreements in China, including several repeat arrangements, as listed in Table 29. Among these 19 licensees, 12 gasifiers of 11 companies are now operational (Shell, 2008), with most of the others at the equipment procurement and construction phase. This includes the Yueyang Sinopec & Shell Coal Gasification Co Ltd, which is a 50:50 joint venture with Sinopec (Fava, 2007). Shell has also provided and commissioned two large coal gasification units for the provision of hydrogen for the Shenhua direct coal-to-liquids demonstration project in Inner Mongolia, which started operation towards the end of 2008 (Si, 2009).

Shell has also established a clean coal technology service centre in Beijing to serve Chinese users of this process (Shell, 2008). More recently, in May 2009, via Shell Global Solutions International, it signed a certification agreement with the China Shipbuilding Industry Corp 711 Research Institute in Shanghai, to grant the right in China to fabricate key equipment for the Shell gasification process, including the pulverised coal burner (Asia Chemical Weekly, 2009). This was part of an initiative to reduce the general cost of Chinese projects that will use the Shell gasification process while also providing Chinese users with more effective post-sale service.

The technology is also part of the company's indirect coal-to-liquids technology, which it had been looking to develop in China in partnership with Shenhua Ningxia Coal Ltd with whom it signed a Memorandum of Understanding in 2006. The intended plant would have had an annual output of 3 Mt of petroleum and diesel a year. It would have used Shell's indirect coal liquefaction technology, with an estimated capital cost of US$5–6 billion. However, Shell recently announced that it had postponed its investment in the project, in the current period of global economic downturn (China.org, 2009).

The other significant OECD gasifier supplier in China is Siemens. Thus the Siemens Power Generation Group, after its acquisition of Sustec, launched a new business division focused on the supply of gasifiers both for IGCC and industrial applications. It now offers IGCC power-island and reference plant designs as well as gas and steam turbines,

Table 29 List of Shell coal gasification licensees in China

Company	Project
Yueyang Sinopec & Shell Coal Gasification Co Ltd	2000 t/d plant to supply syngas for a fertiliser plant
Hubei Shuanghuan Chemical Group Co Ltd	900 t/d plant to supply syngas for a fertiliser plant
Liuzhou Chemical Industry Co Ltd	1100 t/d plant to supply syngas for a fertiliser plant
Sinopec Hubei Chemical Fertiliser Co Ltd	2000 t/d plant to supply syngas for a fertiliser plant
Sinopec Anqing Company	2000 t/d plant to supply syngas for a fertiliser plant
Yunnan Tianan Chemical Co Ltd	2700 t/d plant to supply syngas for a fertiliser plant
Yunnan Zhanhua Co Ltd	2700 t/d plant to supply syngas for a fertiliser plant
Dahua Group Ltd	1100 t/d plant to supply syngas for a methanol plant
Yongcheng Coal and Power Group	2100 t/d plant to supply syngas for a methanol plant
China Shenhua Coal Liquefaction Corporation	2x2200 t/d plant to supply hydrogen for DCL
Henan Zhongyuan Dahua Group	2100 t/d plant to supply syngas for a methanol plant
Henan Yima Kaixiang Group	1100 t/d plant to supply syngas for a methanol plant
A power company in Inner Mongolia	3x 4000 t/d plant to supply syngas for a methanol plant
Tianjin Soda Plant of Tianjin Bohai Chemical Group	2x2000 t/d plant to supply syngas for ammonia and methanol plants
Guizhou Chemical Company	2000 t/d plant to supply syngas for a chemical plant
Henan Zhongyuan Coal Chemical Group Co Ltd	2100 t/d plant to supply syngas for a methanol plant
Yongcheng Longyu Coal Chemical Co Ltd	Plant to supply syngas for a 500,000 t/y methanol plant
Datong Coal Mine Group	Plant to supply syngas for a 600,000 t/y methanol plant
Yunnan Yuntianhua Co Ltd	Plant to supply syngas for a 260,000 t/y methanol plant

generators, IGCC plant instrumentation and control systems, gasifiers, and syngas compressor trains. For areas outside Siemen's scope, the company has adopted a partnering approach, co-operating with other companies for the supply of gas clean-up/shift, optional CO_2 capture, and equipment for synthesis to transport fuels, SNG and hydrogen.

A consequence of the Sustec acquisition was that it included the German firm Future Energy GmbH together with a 50% stake in a joint venture with the Shenhua Ningxia Coal Group (SNCG), a subsidiary of the Shenhua Group, the largest Chinese coal producer of China. In early 2007, this led to Siemens being awarded a contract by SNCG to supply two entrained-flow gasifiers, each with a thermal capacity of 500 MW, and further key equipment for a coal gasification plant in China (China CSR, 2007b). The latter is to be used for the Shenhua Ningmei project in Ningxia Province in North Western China. When the plant is ready to operate in 2009-10, it will produce 830,000 t/y of dimethyl ether (DME). Later in 2007, Siemens was awarded a follow-up contract by SNCG to supply three additional entrained-flow gasifiers, each with a thermal capacity of 500 MW (PEI, 2008). These are to be used in the largest facility in the world for the production of polypropylene from coal, in Lingwu City in Ningxia Province. This is scheduled to start operation in 2010, with an annual output of 520,000 t (Siemens, 2007b).

4.2.2 Chinese technologies

China has developed four technology variants, namely:

- Ash agglomerating fluidised bed coal gasification technology (in operation).
- Two-stage entrained flow gasification technology (in operation)
- Two-stage Dry Feed Entrained Flow Gasification Technology (under development).
- Coal water slurry (CWS) gasification with opposed multi-burner technology (in operation).

The ash agglomerating fluidised bed coal gasification technology was developed by the Institute of Coal Chemistry at the Chinese Academy of Science. There has been limited deployment to date, with the scale of operation below 500 tonnes of coal per day, either for ammonia or methanol production (Fang, 2005).

Similarly, a two stage entrained flow gasification technology was developed by the Department of Thermal Engineering at Tsinghua University but there has been limited application up to 500 tonnes per day coal use (Ma, 2009).

The third domestic technology is the two-stage dry feed entrained flow gasification process that was developed by the Xian Thermal Power Research Institute (TPRI). Its industrial applications have been small scale although it will be used at the 2000 t/d scale in the GreenGen IGCC project.

The technology that currently shows greatest promise is the entrained flow coal water slurry (CWS) gasifier with opposed multi-burners that has been developed by the East China University of Science and Technology (ECUST). There has been quite significant deployment of this option at reasonably large scale, as shown in Table 30. Of these twelve projects, four are operational, with the remainder expected to be completed by the end of 2010 (Ma, 2009).

Table 30 List of CWS gasifier applications in China (WorleyParsons, 2008)

Company	Project
Shandong Hua Lu Heng-Sheng Chemicals	750 t/d plant to supply syngas for an ammonia plant
Yankuang Cathy Coal Chemicals	1150 t/d plant (2 gasifiers) to supply syngas for a methanol and power plant
Jiangsu LingGu Chemicals	1800 t/d plant (2 gasifiers) to supply syngas for a ammonia plant
Jiangsu SuoPu Group	1500 t/d plant (3 gasifiers) to supply syngas for a methanol plant
Shandong Phoenix Fertilisers	1500 t/d plant (3 gasifiers) to supply syngas for a methanol and ammonia plant
Yankuang Lunan Fertilisers	1150 t/d plant to supply syngas for an ammonia plant
Shenhua Ningxia Coal Group	2000 t/d plant (3 gasifiers) to supply syngas for a methanol plant
Ningbo Wanhua Polyurethane Co	1000 t/d plant (3 gasifiers) to supply syngas for a methanol and CO_2 plant
Tengzhou Fenghuang	1150 t/d plant (3 gasifiers) to supply syngas for a methanol and ammonia plant
Shenhua Ningmei	1900 t/d plant (3 gasifiers) to supply syngas for a DME plant
Shandong Jiutai	2000 t/d plant (6 gasifiers) to supply syngas for a methanol plant
Anhui Huayi	1500 t/d plant (3 gasifiers) to supply syngas for a methanol plant

5 Technology exports from China

While the emphasis to date has been on the rapid deployment of advanced coal-fired power plants within China, Chinese companies are also seeking overseas opportunities either to supply equipment for power plant projects or to buy stakes in overseas power companies.

5.1 China-OECD co-operation

As noted previously, several of the OECD companies have established joint ventures with Chinese manufacturing companies. This has provided them with a relatively low cost base for the supply of power plant equipment for overseas markets.

For example, the Alstom Sizhou Electric Power Equipment (Qingdao) Co Ltd joint venture, which was formed in April 2007, has provided a means to both meet Chinese domestic market needs and to provide products for foreign markets such as the USA, Thailand, Malaysia, Indonesia, India, Philippines, Egypt and Bangladesh (EVCN.COM, 2007). The Alstom (Wuhan) Engineering & Technology Co Ltd joint venture was also established to meet the specific needs of the Alstom Turbomachines Group in both its Chinese and regional activities, with 80% of its business in overseas markets. The rationale is similar for the acquisition of a majority share in the Wuhan Boiler Company. This established a further manufacturing base while also providing Alstom with the means to meet global export needs. The expectation is that the Wuhan Boiler Company will eventually export a third of its output (People's Daily on line, 2007), covering both hydro-generation equipment and thermal power products.

As well as providing a technology licence for arch-fired subcritical and SC steam generators, Foster Wheeler Ltd has established a co-operation arrangement with the Shanghai Boiler Works Ltd. Thus in addition to the Chinese market where the Shanghai Boiler Works will lead the contracting activities, the two companies also agreed to co-operate for projects outside China, with Foster Wheeler providing design packages and other project support (Bnet, 2006). In its licensing co-operation with the Wuxi Huaguang Boiler Company, the expectation is that the two companies will also co-operate for projects outside China (Mills, 2008b).

GE Energy established the GE China Technology Centre in Shanghai, in part as a means to showcase technology to its customers across Asia (GE, 2008). A further move was the joint venture partnership with the Shanghai Xin Hua Control Technology (Group) Co Ltd, in order to increase GE Energy's presence in China while also providing the opportunity to expand its technology and services capabilities outside of China (Findarticles, 2005).

Several of the larger Chinese power generation companies have purchased shares in overseas power sector companies as part of a diversification programme. These include Huaneng, which in 2003, bought a 50% stake in OzGen in Australia. This was the first time that a Chinese power company had invested in a foreign power market. In March 2008, the company bought Singapore's Tuas Power Ltd. This gave it close to 2.7 GWe power-generating capacity, which accounts for over 25% of the power generation market share in Singapore (Market Avenue, 2008). The driver is not just to diversify its assets but also to assimilate new technologies and management techniques.

5.2 Chinese activities

The entry of new power plant equipment suppliers from China has created a significant perturbation in the international power plant market. The difference in price levels between manufacturers in the Chinese market and international competitors is significant (World Bank, 2008). Equally importantly, the level of manufacturing capacity available for export activities in China is likely to become significant. Thus the annual manufacturing capacity of China is understood to be in the range 100–120 GWe. Some 30% of this comes from second and third tier manufacturers while the remainder is provided by Harbin, Shanghai and Dongfang. These first tier manufacturers are booked for next two-three years (2008-11) with domestic orders for SC and USC plants. Consequently, the focus of the current export drive is expected to be on subcritical PC units. However, in a few years time, annual demand for SC/USC units in China is expected to fall (*see* Section 2.3). Consequently, the first tier manufacturers will then be in a position to seek further export opportunities, covering both subcritical and SC/USC units.

Chinese power plant equipment manufacturers and turnkey contractors have all been involved in successful tenders to supply coal-fired power plants to overseas customers. There are clear market inroads in countries such as Botswana, India, Indonesia, Nigeria, Pakistan, Philippines and Vietnam. A particular market has been the supply of equipment for coal-fired plants to Indonesia in response to that country's 'crash programme' to build 10 GWe of coal-fired power plant capacity, which is scheduled for completion during 2010 (IFCCI, 2008). The crash programme was launched to cope with power shortages that have often affected the manufacturing industries' production processes in the country (Minchener, 2009). Among the large suppliers of power plant equipment from China have been DongFang Electric, Harbin Electric, and Huadian Engineering Group, The Chinese are noted as being very competitive in the coal-fired sector due to their extensive experience in being able to quickly build power plants (Goliath, 2008). It is understood that the Chinese suppliers are underbidding the prices of other international suppliers, but are achieving better margins than in their domestic market (World Bank, 2008).

In theory, all the Chinese equipment suppliers are allowed to undertake contracts with overseas companies. However, the State Government has encouraged the formation of consortia, comprising the equipment suppliers under the guidance and leadership of an engineering procurement contractor. Such contractors are state-owned enterprises that have traditionally been authorised to co-operate or do business with foreign companies and as such possess the necessary import and export licences. These include the Sichuan Machinery and Equipment Corporation (SCMEC), the Shandong Electric Power Construction Corporation (SEPCO), the China National Technical Export Import Company (CNTIC) and the China National Electric Equipment Corporation (CNEEC).

The latter example is a State-owned company that is engaged in turn-key contracting for thermal power generation, transmission and distribution, both in China and overseas (CNEEC, 2009). Previously, this company was involved in the importation of OECD technology to China. While the rights to that technology (for example, boiler, turbine, generator and auxiliary equipment) were transferred to the major Chinese manufacturers, CNEEC has built up turnkey contracting expertise. Accordingly, CNEEC is using this both to bid for work within China but also to take the lead on overseas projects, the latter comprising about 80% of their business. Client countries include Pakistan, Philippines, Singapore, Yugoslavia, Malaysia, Sudan, Indonesia, Nigeria, Thailand and Azerbaijan. Their portfolio includes thermal power only and CHP plants, as well as coal waste power plants. In principle, they can offer the supercritical power plant to overseas clients although the focus of their business has been on smaller, subcritical units, which better meet the power demands and/or the lower grade coals available to their clients.

Chinese equipment manufacturers are currently processing orders from India for boilers, turbines and generators with a total capacity of 20 GWe. The major Indian customers include industrial groups Reliance, Essar, KSK Industries, JSW Energy, Jindal Steel & Power and Adani Power, with the main suppliers being Shanghai Electric, Dongfang Electric and Harbin Electric (Reuters, 2008b). It is understood that, compared with their Western counterparts, Chinese companies can deliver their products in a shorter time, and at a price that is about 30% lower (China Economic Net, 2009). It is understood that while orders to date have been for coal-fired units, discussions are under way regarding the development of hydropower plants in India using Chinese equipment.

However, this export drive to India has provoked a backlash as Indian domestic companies fear the major loss of business (ASSAP, 2008). The Indian Government has proposed that it will be mandatory for suppliers from China to develop production facilities in India if they seek to win contracts for future power projects. This will not affect those orders that have already been placed with Chinese manufacturers.

There are also ongoing discussions between the China Electricity Council International and representatives of the Southern African Power Pool (SAPP) regarding the promotion of international trade, particularly for the electric power industry. These have covered various power generation and transmission system technologies, with the prospect of China offering its expertise on a commercial basis (AllAfrica.com, 2009). China is active already in the SAPP region. For example, the Hangzhou Boiler Works, one of the larger manufacturers of waste heat boilers in China, has built up an export business including projects in Southern Africa although its current focus is on Southeast Asia and South America (HBW, 2008).

In a further development, the Huaneng Group has signed an agreement for its subsidiary, the Xian Thermal Power Research Institute, to supply Future Fuels in the USA with its two-stage entrained flow coal gasification technology (Cleantech, 2009b). The gasifier is expected to be incorporated in Future Fuel's 150 MWe IGCC plant to be built in 2010 in Pennsylvania.

6 CO_2 issues and implications

Although China is making great progress to establish a modern, high efficiency fleet of coal-fired plants, with an increasing higher efficiency than most other countries in the world, the sheer scale of its coal-fired power generation activities is a matter of global concern since, without other mitigation measures, CO_2 emissions will continue to rise in absolute terms. Accordingly, there is considerable interest in the additional steps such as carbon dioxide capture and storage (CCS) that might be undertaken in China to control GHG emissions.

CCS systems are not yet available anywhere for installation and operation on coal-fired power generation plant, not least since such systems have yet to be proven at the commercial prototype scale while there is not yet a regulatory framework in place that would encourage the uptake of the technology on a commercial basis. Consequently, at present, there is a relatively small number of OECD companies that are capable of manufacturing and supplying major items of CCS equipment. Thus, possible suppliers of post-combustion capture equipment include Fluor Daniel, MHI, Alstom Power, Cansolv, Hitachi Babcock, HTC Pure Energy and BASF. Those that could supply equipment for oxyfuel plant (boilers and burners for example) include Foster Wheeler, Alstom Power, Doosan Babcock, IHI, B&W, and Hitachi Babcock (Santos, 2008). There are similar numbers of companies that could offer IGCC systems equipped with pre-combustion capture, such as Shell, GE Energy and Siemens.

In many OECD countries, there are significant R,D&D programmes that are designed to take forward the technology towards commercial deployment. For example, Europe has expansive plans for a series of major demonstrations of CCS technology variants, subject to viable financing plans being established (ZEP, 2009).

In China, before 2006, there was very little interest, even at the academic level, in CCS. However, since then, there has been an upsurge of technical interest, with several relatively large scale projects being established, as set out below.

6.1 Policy issues

China has issued a series of policies, which relate to climate change and possible mitigation approaches, in which it has publicly recognised the potential importance of CCS in order to establish near zero emissions fossil fuel power generation systems. Thus the 'Outline of the National Programme for Medium- and Long-Term Science and Technology Development' was issued by the State Council in February 2006. This provided guidelines, objectives and the general layout for China's science and technology development for the next 15 years (MOST, 2007a). In particular, CCS was highlighted in the Programme as an important but long-term technology, while 'the development of efficient, clean and near-zero emissions fossil energy technology' was listed as a key component within the advanced energy area.

In June 2007, the State Council issued 'China's National Climate Change Programme' which set out the objectives, principles, priority areas and countermeasures, positions, and need for international co-operation to address climate change (NDRC, 2007c). This states that the strategic goal of China in order to respond to climate change includes making significant achievements in controlling GHG emissions, and that it will pursue a number of mitigation and adaptation approaches.

These principles were developed further by MOST and other ministries and then published as a listing of Scientific and Technological Actions on Climate Change, in late June 2007. In terms of technological development for GHG emission controls and climate change mitigation, this included:

- CO_2 capture, utilisation and storage technologies, namely through the development of key technologies and measures for capturing, utilising and storing CO_2.
- The design of a technology roadmap for CO_2 capture, utilisation and storage.
- The implementation of capacity building.
- The establishment of an engineering and technical demonstration project.

MOST is now developing an outline overall plan, which will define the objectives of CCS technology in the period up to 2030 and identify key tasks for implementation during the forthcoming 12th Five Year Plan.

Within the context of CCS, it is important to note that China is very much focused on the utilisation of CO_2, as a means to enhance energy security, Thus the technological development programme has some emphasis on developing coal gasification based multi-generation system technology (polygeneration) and on the use of CO_2 for EOR applications. At the same time, ministers have stressed that there are more urgent energy priorities for China than CCS. Thus while they will actively participate in various CCS initiatives, in many cases, they will only do so if international support and finance are available to take forward the activities. As such, there is a domestic R&D programme, which is largely undertaken by Chinese R&D institutes, universities and industry. Alongside this, and to a degree overlapping that programme, there are various international co-operative CCS initiatives. There are also various industrial initiatives, which are led by various energy companies, some of which include some level of international co-operation. These are described briefly below.

6.2 National key technologies R&D programme for CCS

This programme, which is funded by MOST, includes strategic studies focused on the applicability of CCS in China, and the associated impact on energy systems and GHG emission reduction (MOST, 2007b). The participants include organisations such as ACCA 21 and the Energy Research Institute of the NDRC.

The major practical research activities are undertaken within the 973 and 863 R&D programmes. Thus:

- The National Basic Research (973) Programme includes a major programme of fundamental research on CO_2 use for EOR applications, on syngas production from coal gasification and pyrolysis, and the high efficiency conversion of natural gas and syngas either for chemical products or for carbon free use in gas turbines.
- The National High-Tech Research and Development (863) Programme includes several projects to develop advanced CO_2 capture technologies based on adsorption and absorption processes, and to explore CO_2 storage technology.

For example, since the latter stages of the 10th Five Year Plan (2001-05) and then during the 11th Five Year Plan, the 973 Programme has included a series of projects that have examined the various technical issues associated with utilising CO_2 as a resource for EOR applications, this being seen as a nearer-term opportunity for CO_2 geological storage. The driver has been China's desire to limit imports of oil and to find some economic benefit for possible CO_2 emission mitigation processes. The various participants include PetroChina, Institute of Geology and Geophysics, Chinese Academy of Sciences, Peking University, China University of Petroleum, Huazhong University of Science and Technology, Tsinghua University, and the operators of the Jilin oilfield.

The coal gasification and pyrolysis projects include fundamental engineering research on large-scale coal gasification suitable for dual gas multi-generation, H_2 production, CO_2 emission reduction, desulphurisation, coal slurry preparation, catalyst-based syngas and combustion enhancement. Participants include Taiyuan University of Technology, Tsinghua University, China University of Petroleum, Institute of Coal Chemistry, East China University of Science and Technology, Xi'an Jiaotong University, Institute of Engineering Thermophysics, Research Institute of Petroleum Exploration and Development.

The other aspect of polygeneration being studied covers the high efficiency conversion of natural gas and syngas into high quality liquid fuel and high extra value chemicals suitable for lower cost transportation. The main focus is on catalyst development and optimisation. Participants include the Dalian Institute of Chemical Physics, Institute of Coal Chemistry, Nanjing University and Xiamen University.

The gas turbine projects are concerned with the fuel chemical release, heat-work transfer process, integration of heat and work, hydrogen production by gasification, technology fundamentals, system characteristics and optimisation of an advanced humid-air gas turbine cycle. There is participation by the South China University of Technology, Huazhong University of Science and Technology, Tianjin University, Sichuan University, Zhejiang University, Lanzhou Institute of Chemical Physics (Chinese Academy of Sciences), University of Science and Technology of China, China University of Mining & technology, East China University of Science and Technology, Southeast University, Guangzhou Institute of Energy Conversion.

Under the 863 programme, there is a significant programme of work to develop lower cost CO_2 capture technologies, based on adsorption and absorption, and to explore CO_2 storage technology. Alongside this, is an integrated project to establish techniques for CO_2 emissions reduction, in conjunction with low NOx combustion, SOx control and multi-pollutants removal. The partners include the National Power Station Combustion Engineering Research Centre and Shenyang Normal University. These are just being established and full details of the participants are awaited. Further work on capture technology is under way at various universities covering longer-term capture possibilities such as chemical looping, the driver being to reduce the costs and energy penalty (Dong, 2009). There is also R&D under way to develop better and cheaper solvents for post-combustion capture. For pre-combustion capture, there is a lot of work on membranes. There are also some preliminary studies about CO_2 capture options for iron and steel, cement and other industry sectors.

For all of this work, the aim is to establish Chinese-based techniques upon which can be secured independent intellectual property rights. While this may be possible on work funded and undertaken by Chinese organisations, it will be less easy to do so for those development projects that involve input and finance from OECD industrial organisations, as are included in some of the descriptions below.

6.3 International collaborative R&D projects

These have arisen though various bilateral and multilateral collaborative agreements and in most cases are primarily undertaken by research organisations on both sides, although there is industrial participation in some cases.

The most comprehensive is the EU-China programme that is being progressed under the near zero emissions from coal (NZEC) umbrella. This currently comprises four projects, one funded by the UK Department of Energy and Climate Change (DECC) and three with funding from the European Commission (EC) Framework Programme, namely:

- The UK NZEC programme, which comprises strategic studies and scenario modelling, techno-economic studies on various capture options, CO_2 storage assessments and source-sink mapping, policy related studies, plus capacity building (NZEC, 2009).
- COACH, which includes some of the same activities as the UK funded project but with a focus on polygeneration (COACH, 2009).
- GEOCAPACITY, which comprises some CO_2 storage assessment work (GeoCapacity, 2009).
- STRACO2, which considers the CCS regulatory requirements (STRACO2, 2009).

In all cases, the majority of the work is being undertaken by research institutes and universities but there is specific industrial input and guidance being supplied for both sides. Completion of all projects is scheduled for late 2009. There is agreement in principle to move to the second phase, from

2010, which will be a detailed assessment of two options (pre- and post-combustion) followed by the selection of the preferred way forward to be linked to a FEED study plus detailed characterisation of the selected storage site. If all goes well, Phase 3 will be a full demonstration of CCS.

MOST has further indicated to the EC that it would like China to collaborate with the EU research community on:

- Knowledge-sharing between technical experts and researchers.
- The development and evaluation of novel CO_2 separation technologies for longer-term application.
- CCS systems with the multi-input of different fuels.
- Innovative integration of CO_2 capture in power systems.
- Methodology to evaluate CO_2 storage capacity in oil and gas reservoirs and deep saline aquifers.
- CO_2 emission sources and storage potentials assessment in the main regions of China and mapping of sources and sinks.
- Policy design to enable the potential role of CCS to mitigate CO_2 emissions in China to be realised.

In addition, there has been some involvement of individual Chinese organisations within other EC Framework Programme projects that are relevant to CCS. These include the input of PetroChina and RIPED in MOVECBM, an enhanced coal bed methane study, which was scheduled to finish late in 2008 (Movecbm, 2009), the participation of the Dalian Institute of Chemical Physics in the CACHET (pre-combustion capture R&D) project (Cachet, 2009), and Tsinghua University in the CAPRICE (CO_2 capture using amine processes) project (Caprice, 2009).

The UK has established further co-operation with China. Thus DECC, in collaboration with MOST, are also sponsoring some information gathering activities in China pertinent to the capture ready concept (CaptureReady, 2009). The aim is to develop and define options for integrating CO_2 capture plant with advanced Chinese PC power plants to allow a rapid transition to a high level of CO_2 emissions reduction. The partners include Imperial College, University of Cambridge, Doosan Babcock, Alstom Power, Harbin Institute of Technology, National Power Plant Combustion Engineering Technology Centre, Harbin Boiler Company Limited, Yuanbaoshan Power Plant, Datang International Power Generation Co Ltd, and the Xian Jiaotong University.

Australia has an ongoing CCS co-operation programme with China. There is some involvement in an industrial pilot-scale CO_2 capture project (*see below*) but the main focus is on CO_2 storage capacity assessments across various regions of China. Thus the China-Australia Geological Storage (CAGS) project is intended to complement the NZEC work, by mapping a further range of geological formations. Detailed discussions are under way to establish the scope of work, which will include a significant capacity building component. Likely partners from the Chinese side are the same as those in NZEC while the Australian input will be via the Australian Geological Survey.

There has been a coalbed methane technology development project agreement between China and Canada since 2002. The work to date by the China United Coal Bed Methane Group and the Alberta Research Council has focused on a micro-pilot field test of a shallow coal seam with single well

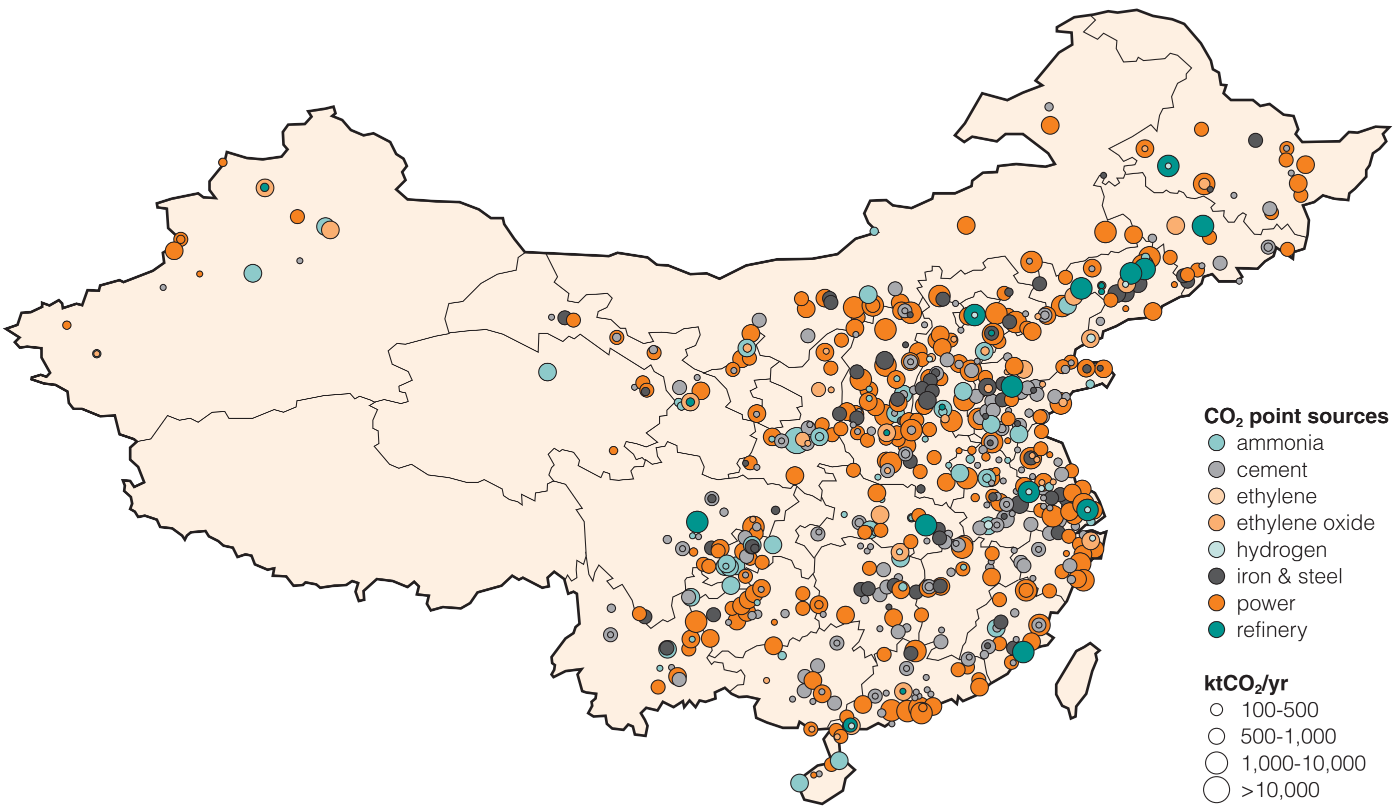

Figure 7 Map of large CO_2 point sources by type and annual emissions (Li and others, 2008)

injection in the South Qinshui Basin, Shanxi Province. However, a second phase has begun, which does have some relevance to CO_2 storage. This focuses on the development of technology for multi-well pilot CO_2 injection in deep unmineable coal seams to allow for geological storage. The partners are CUCBM, Petromin and EnviroEnergy. However, it is understood that coal seams in the region comprise prime anthracite and that the intended well depths are such that coal mining is very possible. As such, its value as a CO_2 storage project rather than a CBM project is questionable

Tsinghua University together with the World Resources Institute have prepared a draft set of 'Guidelines for Safe and Effective CCS in China'. This effort is being funded with support from the US Department of State under the Asia Pacific Partnership (APP, 2009).

MOST and the US DOE are jointly sponsoring a study to examine 'Regional Opportunities for Carbon Dioxide Capture and Storage in China'. Partners include the US/China Energy and Environmental Technology Centre, Tsinghua University, Institute of Rock and Soil Mechanics: Chinese Academy of Sciences, Leonardo Technologies Inc, Battelle Pacific Northwest National Laboratory and Montana State University (CSLF, 2008). An example of the initial output, which comprises an overview of large CO_2 point sources, is shown in Figure 7. These data will be linked to potential CO_2 storage options both onshore and offshore to get an overview of CO_2 storage capacity in relation to likely CO_2 emissions (Li and others, 2008).

China is one of the members of the Carbon Sequestration Leadership Forum (CSLF), with MOST as its representative (CSLF, 2009). The Chinese Government is also one of the founding members of the Global Carbon Capture and Storage Institute while the Huaneng Group has signed up as the representative of Chinese industry. It should also be noted that the Chinese government was among the foreign governments who had pledged to commit funding for the original FutureGen project in the USA. Although the original concept has been cancelled, due to overall funding problems, it may be resurrected in a different form (FutureGen, 2009).

The USA and China have agreed in principle to improve co-operation on climate change and have also announced a joint clean energy research centre, which is also intended to serve as a clearing-house for information looking at energy efficiency, clean coal technology and low-polluting cars. There is an expectation that CCS will be included within the technology portfolio for co-operation (Power Technology, 2009).

6.4 Industrial activities

The lead industrial organisations that are active on CCS are the Huaneng Group and Petrochina.

As China's largest electric utility, Huaneng is taking the lead on a range of CO_2 capture initiatives (China coal resource, 2009c). Thus they are very active in developing pre-combustion CO_2 capture options via the GreenGen project, of which the establishment of the demonstration-scale IGCC has been described in Section 4.1. This aims to prove the scale-up of the Chinese gasifier design and in particular to ensure overall reliability and acceptability. At that time, a side-stream will be established to allow various syngas characterisation activities to be undertaken. The second stage will be to scale up the power plant by building a 400 MWe IGCC, which should include hydrogen production based on coal, hydrogen rich power generation, CO_2 capture and storage, fuel cell power generation and other key technology assessments, including the integration of the various product systems.

The latest official schedule is that the 250 MWe IGCC demonstration plant will be built and commissioned by end 2011-early 2012 (Stage 1). This will be followed by testing and optimising of the gasification technology, plus implementation of the CCS side-stream work, which is scheduled for completion by end of 2013 (Stage 2). After this, subject to satisfactory results being obtained, the consortium will proceed with Stage 3, the construction of a 400 MWe IGCC with CCS, to be completed by the end of 2017 and followed by operation and assessment.

The Asian Development Bank has approved a loan for financial support of the 250 MWe IGCC excluding the CCS side-stream (ADB, 2009). In addition to the loan, the bank intends to support the development of a plan for the promotion of CCS demonstration projects, including the preparation of policies, as well as legal and regulatory frameworks. The technical assistance will also identify the priority demonstration projects and their financing requirements, as well as undertake capacity assessment and comprehensive capacity development in the areas of CCS demonstration (Business Review, 2009).

At the same time, Huaneng and the other major power generation companies are showing interest in post combustion capture in recognition of the continuing major increases in PC SC/USC systems that are being introduced each year (*see* Chapter 2). In particular, Huaneng is undertaking a post-combustion CO_2 capture project, with support from Australia's Commonwealth Scientific Industrial Research Organisation. The latter provided technical assistance for Huaneng to construct and operate an industrial pilot-scale CO_2 scrubber test facility. The unit was designed by the North China Power Engineering Co Ltd and supplied by the Thermal Power Research Institute (majority-owned by Huaneng). All components except for a limited number of imported valves were manufactured in China.

The test unit is operated on a side-stream, located after the ESP, deNOx SCR and FGD units of an 800 MWe PC plant in Beijing. Figure 8 provides a view of the CO_2 stripper and regenerator towers. It takes 1% of the exhaust gases, which after processing give CO_2 of 99% purity. This is further refined to give a 99.997% pure product that is sold to a local soft drinks company. The unit has been used to gain experience of the technology and to undertake parametric studies relevant to their company's assessment of post-combustion capture for possible future application. The annual amount of CO_2 that is expected to be captured is 3000 tonnes. The design parameters are:

Figure 8 Main structure showing stripper (left) and absorber (right) of the Huaneng post-combustion CO_2 capture pilot unit

- Flue gas flow to unit 2000–3000 m³/h;
- Steam consumption 3GJ/tCO_2;
- Solvent consumption < 1.35 kg/tCO_2.

Following this initial success, Huaneng is pursuing the scale-up to 100,000 tCO_2/y at their Shi-Dong-Kou supercritical coal-fired (2x660 MWe) power plant in North Shanghai. The project may include the prospect of some CO_2 storage trials. At the end of 2008, Huaneng reached an agreement with the Shanghai Electric Corporation to establish a joint Greenhouse Gas Mitigation R&D Centre, which includes CCS activities. This arrangement has been formally endorsed by the Shanghai Municipal Government.

On the storage side, PetroChina started China's first CO_2 storage and utilisation project at Jilin Oilfield in 2006. The company has injected CO_2 at industrial pilot-scale into ten wells to enhance oil recovery as well as to establish some level of geological storage.

As part of a much larger-scale development, in May 2008, Japan and China announced their intention to jointly develop a CCS and EOR project which aims to recover 3–4 MtCO_2/y from two coal-fired power plants in China. The Japanese partners, under the Ministry of Economy, Trade and Industry (METI), include the JGC Corporation (a partner in the Algerian In Salah CCS project), Japan Coal Energy Centre, Toyota Motors, Mitsubishi and the Research Institute of Innovative Technology for the Earth (RITE – a sustainable energy research establishment under METI). For China, the NDRC is the lead government department with input from PetroChina, Daqing Oil Field Ltd (local oil field partner), Harbin district government, Harbin Utilities Company and China Huadian Corporation (Webb, 2008).

This major industrial project will be located in Heilongjiang Province in North-East China, 100 km from the Daqing oil field. The project is due to start in 2009 and will involve both Japanese and Chinese power and coal industry investments. The research and design development phase is expected to be complete by 2011. Both sides have already agreed to provide funding of US$300 million, allocating $100 million per year for the next 2 to 3 years. It is understood that Japan will be responsible for developing the power generation, CO_2 capture and transportation aspects, while China will cover CO_2 storage and enhanced oil recovery (Reuters, 2008c). The intention is to use two 600 MWe coal-fired power plants, retrofitted for post-combustion CCS and linked by pipeline to a near-by mature oil field to enhance oil production by 30–40,000 bbl/d. The reason for using two power plants is to spread the 10–15% energy penalty associated with CO_2 capture and so limit local electricity supply disruptions. Based on initial tests in China, the partners believe that it will be possible to achieve a CO_2-to-oil recovery ratio of 2:1. Since the initial announcement, there has been very limited additional information made available and as such the status is unclear.

The Shenhua Corporation is looking at options to capture and store CO_2 from its direct coal liquefaction demonstration plant in Inner Mongolia in what is described as China's first CCS project. It is not yet clear if this will be for EOR or possibly storage in a saline aquifer (Li, 2009).

There have been several public declarations of intent to undertake further large-scale CCS projects but to date there are no firm plans established. These include, for example:

- The memorandum of understanding signed between EESTech and Tianjin Dagang Huashi Power to establish in China a carbon capture and storage project with EOR using EESTech's carbon management and storage technology (RedOrbit, 2008);
- The agreement between Huaneng and Duke Energy of the USA, to explore various renewable and other clean-energy technologies including CCS (EnergyBusiness Review, 2009).

Finally, BP and the Chinese Academy of Sciences have established a Clean Energy Commercialisation Centre (CECC) joint venture. The aim is to integrate individual clean energy related technologies – coal gasification, coal to liquids, coal to chemicals, CCS, coalbed methane and underground gasification – from CAS institutes and other organisations both within and outside China, into competitive integrated feedstock manufacturing and product distribution systems and solutions (CAS, 2008).

6.5 Mitigation through cofiring of biomass and organic wastes

Within this overview of CCS activities in China, it is worth mentioning the prospect to utilise the cofiring of biomass with coal as a means to partially mitigate CO_2 emissions while ensuring comprehensive utilisation of waste biomass resources. While it cannot on its own ensure deep enough cuts in GHG emissions, it can make a useful contribution since there are massive quantities of this carbon neutral waste material available and the potential to reduce coal use in power generation is significant.

To put that in context, the annual waste biomass resources potentially available for energy use in China include about 300 Mt of crop straw, 130 Mt of the residues from crop processing, 140 Mt of forest residues, more than 100 Mt of firewood, 70 Mt of abandoned wooden goods and fruit tree branches, as well as 50 Mt of organic material from municipal solid waste (MSW). All these biomass energy resources total 790 Mt, with a cumulative calorific value that is equivalent to 400 Mt of coal (Lu, 2009). There are possible alternative uses for such resources (for example, domestic fuels, fertiliser, paper making and fodder) and there will be regional issues and transportation requirements that will limit the possible applications. Even so, as a cautious estimate, this could still mean that 250 Mt of coal equivalent could be used for power generation applications, including cofiring.

6.5.1 Technical considerations

The cofiring route is seen as an important part of that process, not least since it offers distinct technical and economic advantages over the small 100% biomass direct-fired units that are starting to be established (Fernando, 2005). From a sustainability perspective, it offers a more efficient way to the comprehensive utilisation of resources and, providing the proportion of biomass fired is limited (to 10–20% on an energy basis depending on the feedstock), it avoids plant reliability problems that can affect the small, direct fired units (Brendstrup, 2008). The capital requirements are lower and the construction period is shorter, both of which result in a faster return on investment.

The key technical issues that will have an impact on the introduction of the technology are the availability of suitable coal-fired technologies and the appropriate biomass cofiring techniques, biomass feedstock availability and supply/processing logistics, together with ensuring overall power plant performance. There do not appear to be any insurmountable technical issues although there is a clear need to build awareness and confidence amongst the Chinese coal-fired power generation stakeholders.

Thus the coal-fired technologies in China cover the range available in the OECD countries. As such, there are no significant technical barriers to generating power by biomass cofiring and the various approaches to cofiring that have been commercially established in Europe and elsewhere should have equal technical merit in China. However, despite the success in OECD countries, the absence of mature and suitable technologies in China itself, including a lack of standards for engineering and operational management of cofired boilers needs to be addressed.

The main biomass materials available should not present insurmountable problems to Chinese power plant operators providing that the design of the cofiring system is carefully considered to avoid problems with increased plant outages. On the basis of experience in Europe and elsewhere, these issues are all manageable but they all require careful consideration of fuels, boiler operating conditions and boiler design (Karke, 2008).

At the same time, the distribution of crop straw, forestry residues and MSW in China has a strong regional feature. Even when ensuring these resources are used locally, in some cases, there will be a major logistics problem with the collection and processing of many of the agricultural wastes, since, in many instances, these can be quite widely dispersed. This limits the amount of biomass that can be substituted for coal cost effectively in a cofiring application. This lack of experience with fuel management systems in power plants, including the gathering, transportation and storage of biomass at an industrial scale therefore needs to be addressed.

Care is also needed in the design of the biomass handling, processing and feeding systems, which will vary with the size and type of the boiler/combustion system. It is also important to ensure a robust system that can process potentially large variations in the different types of biomass that could be supplied to a power plant in China. In Europe, the typical limit for biomass addition is about 5–10% of the coal feed on an energy basis. In China, preliminary studies suggest that for medium-size power plants the technical limit may range from 10% for PC fired units to 20% for CFBC systems (Karke, 2008). At this time, the economic limit is not known. In addition, the situation for larger plants with advanced steam conditions has yet to be examined, in part as until now the owners of such plant have not shown an awareness of cofiring.

Ultimately, with appropriate co-operation, the Chinese power sector could be equipped to ensure significant cofiring in its large number of coal-fired boilers. However, the key requirement is to provide a supporting financial framework, which can comprise some form of incentive to ensure that the use of this carbon neutral fuel can be sustained.

6.5.2 Policy considerations

In China there are various policies in place that are designed to encourage renewable power generation. The ‘Law on Renewable Energy of the People’s Republic of China’ encourages and supports power generation by renewable energy. It provides for priority access to the grid, establishes a mechanism for feed-in tariffs/subsidies and foresees the use of tax breaks and other financial incentives. Regulations associated with this law define technical, institutional and organisational issues, including the responsibilities and obligations of power generation and power grid enterprises.

The relevant laws and regulations ensure that all electricity generated by biomass-fired power plants is sold to the grid, while levies for importing equipment and value added tax (VAT) are exempted. An allowance of 0.25 RMB/kWh

(~0.025 €/kWh at 2009 exchange rates) is provided for electricity generated by biomass, in addition to the normal selling price of electricity produced by coal-fired plants. However, the allowance is only available for the power plants in which the boiler heat input from biomass is equal to 80% or more of the total heat input (Georgocostas, 2008). This, in effect, excludes cofiring projects from receiving the incentives since such projects normally use less than 20% biomass in the total heat input due to technical and economic reasons. This restrictive policy has been applied as the Chinese lack confidence that they can establish a transparent and reliable monitoring and auditing system to ensure that the quantities of biomass consumption declared by the power plants are actually used for power generation.

Consequently, at present, cofiring of biomass and coal for power generation is not being undertaken by Chinese industry. That said, the potential benefits of cofiring are recognised and there is an ongoing development of policy at government level to determine the best way to amend the policies such that cofiring can be established within China. The Chinese government and various electric utilities are now seeking to address a number of issues. These include the need:

- To determine the best use of agricultural residues in view of several options being available (which also applies to the direct fired units), including the need to avoid soil degradation that could be caused by excessive removal of crop residues.
- To ensure a sustainable supply of waste biomass fuel to the cofiring (and direct firing) end users.
- To establish a reliable monitoring and verification methodology suitable for China such that there is a transparent means to determine the proportion of biomass cofired in coal-based power plants. This is directly linked to the enhanced feed-in tariffs available for biomass or part-biomass based power generation.
- To establish appropriate policies and financial incentive schemes to support the deployment of cofiring.

Resolution of the latter two issues is critical if cofiring is to be established in China as a viable, sustainable carbon mitigation technique.

7 The way forward

It is evident that the further development of China's power sector is critical to the continued industrial development of the nation while the challenges to ensure a sustainable way forward are considerable. At the same time, China is increasingly operating within a global market, which results in additional challenges and opportunities.

7.1 Power sector impacts arising from the recent policy initiatives

For too long, China's growth has followed an increasingly difficult path with an ever growing dependence on coal without too much regard for environmental implications. However, this position is now changing and, as with all aspects of the power sector, it is changing fast. The recently announced plans through the NDRC to broaden the capacity mix to ensure the significant introduction of zero carbon and low carbon power generation technologies, such as nuclear, wind and solar power, represent a fundamental shift in approach, as a result of the policy initiatives arising from the 11th Five Year Plan. At the same time, there are key initiatives being implemented to improve the efficiency and environmental performance of coal-fired power generation. This is being complemented by massive investment in the transmission and distribution systems to move towards a modern grid system suitable for the 21st century.

There have been several positive outcomes from these initiatives. Thus (Green Leap Forward, 2009):

- Three of the ten biggest power companies have already reached a 10% or more share of electricity from renewable sources, and one (Guodian) has met its mandatory non-hydro renewable energy obligation of 3%.
- The Big Five power generation companies (*see* Section 2.1) have already met their 2010 target of reducing the average coal consumption for their coal-fired plants to 355 gce/kWh.
- China is well on course to close 85 GWe of small, inefficient coal plants by 2011.
- Alongside the closure programme, China is dominating the clean coal market by building a very large proportion of the most efficient coal-fired power plants in the world.
- China has installed an unprecedented 66% of its coal fleet with FGD and in many cases with deNOx systems.

However, there is scope for further improvement. Thus:

- The environmental and public health impacts in 2008 of coal burning by the ten biggest power companies is estimated to be 87 billion RMB (€8.5 billion).
- Five of the ten biggest power companies each generate less than 7% of their share of electricity production from renewable sources, and are unlikely to contribute adequately to China's national goal of achieving 10% of its energy from renewable sources by 2010.
- Eight of the ten biggest power generation companies are not yet half way to meeting their mandatory renewable (non-hydro) energy obligation of 3%, which makes it unlikely that they will reach the Government targets by 2010.

It should be noted that, in June 2009, Premier Wen Jiabao affirmed that China would put in place carbon emissions reduction targets in national development programmes. It is understood that this means that China would assess its economic performance by various factors, including how much less carbon it would emit per unit of GDP growth. Should such a commitment be put into practice, it is likely that China would accelerate the pace of the restructuring within the energy sector, with a corresponding greater environmental focus (China View, 2009b).

7.2 Globalisation and international co-operation

China's industrialisation programme has increasingly involved co-operation with other key stakeholders from around the world, in terms of energy resourcing, the introduction of improved technologies, and the provision of a market for Chinese products. China's power sector growth, as part of its overall energy use expansion, has a global impact, including short- and long-term environmental implications, worldwide resource availability, and the pricing of global commodities, particularly internationally traded fuels.

It is significant that China has become an active participant in multilateral international energy co-operation (IEA, 2009), including the energy working group and the coal-based R&D initiative of the Asia-Pacific Economic Cooperation (APEC), the Association of Southeast Asian Nations (ASEAN) plus China, Japan and the Republic of Korea (10+3) Energy Cooperation, the International Energy Forum, the Asia-Pacific Partnership for Clean Development and Climate (APP), and the Methane to Markets Partnership (M2M). It has also established strong bilateral co-operation agreements in the field of energy with various energy consuming and producing countries, such as nation states of the European Union, Japan, the USA and Russia. Such dialogue has involved extensive consideration of environmental issues that cover both regional emissions of acid gas pollutants as well as global concerns such as greenhouse gas emissions and climate change.

While such links are positive, it is noticeable that many of the initiatives have made limited progress compared to the declared ambitious objectives. There frequently seems to be overlap between the multi-lateral groupings, or even the same projects, being announced under various agreements, which may also be covered by bilateral agreements. At present, funding appears to be an issue. For example, the direct funding committed to the APP by the USA and Australia seems inadequate to achieve the stated goals, while the lack of any public commitments from the developing country partners suggests their contributions will be solely in kind. Consequently, while the APP proposes an attractive portfolio of coal-based projects, so far mostly only low-cost (but still important) capacity-building and training activities are proceeding. Unless large-scale commitments to R&D are made in the near future, however, these agreements risk losing credibility, harming overall global climate change initiatives (IEA, 2009).

7.3 OECD-China industrial co-operation on energy initiatives

Ultimately, while governments can agree co-operative ventures, it requires industrial co-operation to make such initiatives flourish. In the case of China, the State is either the major or sole shareholder of the industrial companies, which makes implementation relatively simple. However, amongst the OECD countries, this is not usually the case and industry's objectives will not necessarily align with those of the governments.

During the last decade, trade and investment links with China have been of increasing importance to various OECD power sector equipment suppliers as it represents the major technology export market while also offering opportunities to establish low cost production bases. These opportunities have come at a price and the Chinese government has ensured that technology transfer via licences and joint ventures has been the route to successful co-operation. However, it is a price that most suppliers have considered ultimately worth paying, not least because China has represented some 90% of the global market for advanced coal combustion power generation systems and associated environmental control systems.

At the same time OECD companies continue to face some obstacles for market access in China. As has been discussed previously:

- The Government has placed certain ownership restrictions on companies supplying power-generating equipment. Foreign enterprises cannot enter the industry as wholly-owned foreign enterprises but must establish joint ventures with domestic partners.
- For government procurement projects for machinery and equipment, 70% of the equipment must be sourced locally.
- There are continuing concerns regarding intellectual property rights (IPR) infringements.

However, although concerns continue to be expressed about industrial co-operation, especially regarding protection of IPR, the major OECD equipment suppliers all have a significant presence in China. Many of these commercial companies have already moved ahead in China, regardless of any outstanding IPR issues, to take advantage of China's low-cost manufacturing base.

7.4 Policies drive technologies

It is evident that the 11th Five Year Plan has led to a questioning of the 'growth at almost any cost culture' and the introduction of tougher targets for energy efficiency and environmental performance improvements has led to a radical change in approach. In particular, the introduction by the NDRC/NEA of new policies, and a plan to implement those policies, has been instrumental in bringing about potentially significant changes in the power sector, with a shift in emphasis that will impact on the future introduction of coal-fired power plants. It has also increased the realisation that the adoption and implementation of key policies is critical to achieving a different approach and that technological changes on their own will not succeed unless the appropriate enabling environment is established.

7.5 Where does the power sector go from here?

Brief comment is made on the future possible development of various aspects of the Chinese power sector, with emphasis on coal-fired power generation.

7.5.1 Further power sector reforms

Further reforms of the power sector are expected. These should include a more coherent electricity pricing system, such that the generating companies can pass on justifiable increases in costs to their customers, for which the NDRC are likely to make proposals by end 2009. As noted previously, coal prices have approximately tripled since 2002, while end-user electricity prices have risen by less than 30%, to the extent that in 2008 the major generating companies were reporting operating losses.

There is also a need to improve the interconnectivity of the regional grids, such that power-rich grids can profit by selling excess power to grids in shortage. This would be an intricate but worthwhile task (Dragonomics, 2008).

Perhaps the most important task is to attempt to get the overall system operating transparently, particularly by limiting the power of local governments to control coal mining, power generation and distribution as it is these local distortions that can overturn State-level efforts to regulate the industry (Dragonomics, 2008).

7.5.2 Towards cleaner coal power generation

Coal-fired power generation, although it will represent a smaller proportion of the total capacity in the future, will continue to grow in absolute terms in China. To meet this need, China is dominating the global market with its programme to introduce state-of-the-art coal-fired systems with advanced steam conditions. While the annual increases of close to, or in excess of, 100 GWe have most likely passed into history, the year on year introduction of modern new plant will probably still exceed 40 GWe over the period to at least 2020.

7.5.3 Consequences arising

It is important that all stakeholders recognise that the continued significant growth in coal-fired power generation has knock-on consequences that must be addressed. As has been considered previously (Minchener, 2007), the energy demand-supply balance remains a problem, with underlying issues in China's coal sector that need to be addressed in order to ensure long-term supply security. Therefore, the need to balance shorter-term needs with longer-term sustainability, while not unique to China, is a major concern due to the sheer scale of the energy needs in the country with such a rapidly growing economy. There have been major problems in delivering sufficient coal to meet the needs of the generating companies. Alongside the production issue, getting the product to the end-user has been a major problem and the solution will be entirely dependent on the success of the Government's plans to expand and integrate the railway network and to upgrade the port facilities. In consequence, to date, the macro-management approach has been short-term focused, and reactive rather than proactive in nature. This could best be addressed by the formulation of a comprehensive strategy that would address all aspects of the coal production, supply and utilisation chain (IEA, 2009).

7.5.4 Chinese clean coal technology outside the national borders

Chinese manufacturers are now in a position where they have advanced the technical quality of their products through a combination of technology transfer and R&D. The domestic market opportunities are likely to decrease to some degree as the emphasis shifts away from coal-fired power generation towards windpower, solar power and, to some degree, nuclear power. While these all offer Chinese manufacturers new opportunities, they will seek to maximise the return from their coal-fired equipment manufacturing facilities.

As discussed in Chapter 5, these facilities are extensive and the major manufacturers are already exporting subcritical units and, shortly, will be in a position to export advanced clean coal power plants as well (World Bank, 2008). The other point to stress is that China's determination to establish its own manufacturing capacity for power plant equipment and to build such a large number of advanced coal-fired plant has resulted in a massive reduction in the capital costs of such equipment, which is very competitive compared to OECD options.

The market opportunities will not be limited to 'traditional' export markets such as Southeast Asia but will also encompass new markets such as Southern Africa. It may also include more advanced OECD markets either in co-operation with their OECD partners or in due course on their own. There is also some evidence that Chinese exports to some markets are supported by government incentives to the host countries such as barter deals for oil (Ihrcke and Becker, 2007).

For the future, it is likely that the OECD suppliers' competitive edge will remain in their superior knowledge for producing specialised innovative, highly integrated, precise and high quality machines. Such manufacturers have also faced the need to meet stricter environmental regulations for much longer than Chinese companies. However, Chinese companies are now gaining that experience and as such the technological advantages of the OECD suppliers are likely to narrow.

7.5.5 CCS challenges and opportunities

China has ratified the primary international accords on climate change – the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. As a developing country, China has no binding emission limits under either accord, although it is a very active participant in the Clean Development Mechanism (CDM) established under the Kyoto Protocol. It is essential to recognise that China, and other developing countries, are unlikely to accept absolute greenhouse gas targets as they see these as a constraint on their economic growth. Rather, China is likely to propose intensity-based targets as these provide a measure for the efficiency of economic growth without limiting absolute energy use. The 11th Five-Year Plan has a significant range of domestic policy initiatives aimed at reducing energy intensity. Consequently, any future international climate agreement would probably need an arrangement whereby emissions mitigation measures can also advance the national priorities of developing countries, such as economic growth, energy security and public health.

While such an approach will reduce energy intensity, it may not reduce absolute greenhouse gas emissions. Consequently, CCS appears to be an essential part of any CO_2 abatement strategy. China's National Action Plan on Climate Change identifies clean coal technologies and CCS demonstration as priorities, and sees international scientific and technological collaboration as key to technology transfer. This is a good foundation for designing a framework whereby China has an incentive to introduce CCS at its large-scale power generation units and, if eventually established, its coal-to-liquids facilities. Thus, China has the opportunity to demonstrate a holistic approach that takes these aspects into account, and sets an example for other nations (IEA, 2009).

There has been significant international debate about China and GHG emissions reduction, with many nations seeking to co-operate with China, and in many cases seeking to introduce their own companies' technologies. However, it is important to recognise that China is already progressing large-scale trials for certain PC-based CO_2 capture systems and is about to demonstrate its own IGCC technology to which CO_2 capture is likely to be added in due course, subject to successful operation of the gasification-based power generation system. It also is developing other capture options on a longer-term basis, while attempting CO_2 storage trials, albeit based around EOR opportunities. Thus, while China may choose to co-operate with international partners on CCS, the techniques that will be demonstrated will either be their own (for example, as in GreenGen) or will be a co-operative venture between Chinese and OECD suppliers. If it is the latter, China is already well placed to build most of the required equipment to international standards and it seems likely that the Government's macro-control approach will mean that similar technology transfer arrangements will need to be implemented as those for the introduction of clean coal technology (Mei and Zhu, 2007). This means that China will then be best placed to play a major role in ensuring that technology deployment becomes established both nationally and worldwide. This suggests a global market in which China is both a user and a prominent supplier of cleaner coal technologies including CCS.

7.6 Final remarks

In conclusion, there is a clear policy direction being established. China will continue to use more coal for power generation but will be using it in an increasingly efficient way, with a correspondingly rigorous control of dust and acid gas emissions. With the arrangements already in place, China is well placed to export such technologies to the global market, not least since its domestic manufacturers currently have a significant cost advantage over international rivals. For the future, it could well establish a similar position for the CCS market. In the medium term, subject to an enabling environment being established, Chinese equipment manufacturers could become a lower cost producer of CO_2 capture equipment under licence from OECD suppliers. For the longer term, it seems most likely that Chinese utilities and manufacturers will be in a strong position to produce their own technologies at very competitive prices, as well as being in a position to provide expert support for CO_2 storage. The longer it takes for OECD countries to move forward their own CCS demonstrations, the stronger the Chinese market position is likely to be.

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