Non-greenhouse gas emissions from coal-fired power plants in China

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Abstract

Within the Twelfth Five-Year Plan, the Chinese Government has made addressing air quality problems a key environmental priority, with an intention to accelerate the development of systems, institutions and a technical knowledge base for sustained improvement. A major focus is on the coal power sector for which standards have been introduced that require the installation of modern, very high efficiency SO_2, NOx and particulates emissions control systems. Nine key regions, which are facing very significant air quality challenges, are the three major economic zones around the cities of Beijing, Shanghai (Yangtze River Delta) and Guangzhou (Pearl River Delta), together with six areas around the cities of Shenyang, Changsha, Wuhan, Chengdu Chongqing, the Shandong peninsula, and the coastal area west of the Taiwan strait. These regions comprise the population and economic centres of the country, accounting for 64% of national GDP, 43% of total energy use, and 39% of the population. In these locations, all existing and new coal-fired power plants will have to achieve particulate, SO_2 and NOx emissions limits of 20, 50 and 100 mg/m^3 respectively, with new plants expected to meet the standards from 1 January 2012 and existing plants by 1 July 2014. At the same time, there will be an increasing emphasis on limiting any new coal-fired power plants in these regions. For the rest of the country, the standards are not quite so strict and the SO_2 limits for existing plants are less severe than for new plants. The new pollutant that will be regulated on coal-fired power plants is mercury and its compounds, for which the limit has been set at a level that represents a core control. This means that providing the power plant operator meets the new particulate, SO_2 and NOx standards then the mercury standard should be met without the need to introduce an additional capture device, although the emissions level will have to be measured on a regular basis. From a global perspective, this major Chinese environmental initiative will lead to a fundamental shift in the market for power plant air pollution control systems and services, which will mean that, in due course, there will be some major Chinese suppliers that are well positioned to exploit international sales opportunities.

Acronyms and abbreviations

BACT	best achievable control technology
BAT	best available technology
BREF	BAT reference document
CAAA	Clean Air Act Amendments
CAIR	Clean Air Interstate Rule
CAMR	Clean Air Mercury Rule
CCS	carbon capture and storage
CEM	continuous emissions monitoring
CFB	circulating fluidised bed
CFBC	circulating fluidised bed combustor
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
DEFRA	Department of the Environment, Food and Rural Affairs
EC	European Commission
ELV	emission limit value
EPB	Environment Protection Bureau
ESP	electrostatic precipitator
EU	European Union
FBC	fluidised bed combustion
FGD	flue gas desulphurisation
FYP	Five-Year Plan
GDP	gross domestic product
GHG	greenhouse gas
GTCC	gas turbine combined cycle
GWe	gigawatt electric
Hg	mercury
IEA	International Energy Agency
IED	Industrial Emissions Directive
IGCC	integrated gasification combined cycle
IPPC	Integrated Pollution Prevention and Control
IT	information technology
LAER	lowest achievable emission rate
LCPD	Large Combustion Plant Directive
LHV	lower heating value
LNB	low NOx burner
MACT	maximum achievable control technology
MEP	Ministry of Environmental Protection
MOST	Ministry of Science and Technology
NAAQS	National Ambient Air Quality Standards
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NERP	National Emission Reduction Plan
NO_2	nitrogen dioxide
NOx	nitrogen oxides
NSPS	New Source Performance Standards
O_2	oxygen
O_3	ozone
OECD	Organisation for Economic Cooperation and Development
Pb	lead

PC	pulverised coal
$PM_{2.5}$	particulates with a mean diameter of 2.5 microns
PM_{10}	particulates with a mean diameter of 10 microns
RMB	Reminbi
S	sulphur
SC	supercritical
SCR	selective catalytic reduction
SEI	strategic emerging industry
SIP	State Implementation Plan
SNCR	selective non-catalytic reduction
SO_2	sulphur dioxide
SOE	State Owned Enterprise
TEC	total emission control
TSP	total suspended particulates
UNECE	United Nations Economic Commission for Europe
US	United States
USA	United States of America
USC	ultra-supercritical
US EPA	United States Environmental Protection Agency
VOC	volatile organic compound
WHO	World Health Organisation

Units

g/kWh	gramme per kilowatt hour
Gt	gigatonne
gce/kWh	gramme coal equivalent per kilowatt hour
kPa	kilopascal
m^3	cubic metre
mg/m^3	milligramme per cubic metre
mg/MJ	milligramme per megajoule
MJ/kg	megajoules per kilogramme
Mt	million tonnes
MWe	megawatt electric
MWth	megawatt thermal
t/h	tonne per hour

Currency converter

All costs quoted in this report are given in the units used in the original references. These are either the Reminbi (RMB), China's currency, which has been used in various Chinese estimates of equipment costs, or US dollars (US$), which have been used where such estimates have been attributed to, say, an international technology supplier. These data can be several years old. The current exchange rate as of 1 November 2011 is 6.36 RMB: 1 US$. However, caution must be used as while the RMB: US$ exchange rate was traditionally constant, it has changed significantly since the onset of the global financial crisis.

Contents

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1 Introduction

This study has been undertaken to provide input for the International Energy Agency (IEA) programme to develop a High Efficiency, Low Emissions Coal Technology Roadmap, which will be an important addition to the series of technology roadmaps that the organisation has been publishing since 2009. This roadmap focuses on coal use in power generation worldwide with an emphasis on the potential role of coal-fired power generation in reducing global energy-related CO_2 emissions substantially below current levels. At the same time, it is important that the non-greenhouse gas (non-GHG) emissions are also considered in terms of the overall environmental impact.

This report provides a review of the non-GHG emissions from coal-fired power plants in China, the country that will dominate coal use on a global basis for the foreseeable future. It first summarises Chinese Government policies and regulations for improving air quality throughout China, with a focus on the steps being taken to make significant energy and environmental improvements in the coal power sector. The emissions standards for SO_2, NOx and fine particulates have been significantly tightened with effect from 1 January 2012 and there are plans to address other pollutants of concern by 2015. Information is also provided on the changes to the associated ambient air quality regulations that are being introduced and how these will have an impact on the likelihood of further coal-fired power plants being established in certain regions.

A summary of the current capacity of coal-fired power plants in China, the expected growth of such capacity, the likely technology mix and the associated size of the units through to 2020, as defined in the various national plans, together with a broad estimate of subsequent future changes is presented. This is followed by a detailed review of past and current non-GHG emissions from such coal power plant. Information is also included on the main techniques used to control non-GHG emissions within the Chinese coal-fired sector and the scope for improvements in the light of new, more demanding, legislation. On this basis, the projected future emissions of these pollutants from coal-fired plant in China are then considered.

The other important requirement is to ensure effective implementation such that power plants meet the legislated emission standards, and comment is made on the previous procedures used by the State Government to ensure compliance and how these have evolved to provide the current system for monitoring, verification and control.

The likely market opportunities arising in China are considered and, as far as reliable information is available publicly, the capital and operational costs for the introduction of either new or upgraded emissions control equipment are reviewed. Comment is also provided on the changing trends in technology suppliers since, initially, equipment was sourced from international companies but now it is increasingly being supplied from within China.

The approach being adopted in China is further considered within the global context, with particular comparison being made to the current and likely future situation within Europe and the USA, both of which are significant coal users but have differing emissions legislation.

2 Government strategies and policies for non-GHG emissions control in the coal-fired power sector

There are various government bodies that have key roles for environmental policy issues within the energy sector (Minchener, 2011). The National Development and Reform Commission (NDRC) is responsible for overall policy/long-term planning and overall management in all the industrial sectors, which includes the development plans within the National Five-Year Plans (NDRC, 2011a). In addition, there is the National Energy Administration (NEA), which has specific responsibilities for the energy sectors (NDRC, 2011b). This was established in 2008, as part of a move to strengthen the centralised management of major energy issues, within the NDRC framework of ensuring the sustainable and steady development of the national economy. The remit of the Ministry of Environmental Protection (MEP) 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, 2009a).

In January 2010, in recognition that energy sector management was spread between various agencies, the National Energy Commission was established with the remit to co-ordinate national energy development strategy, address significant issues concerning energy security and energy development, and co-ordinate major programmes of domestic energy development and global co-operation. The Commission is led by the Chinese premier with senior representation from all the other energy related commissions and ministries (People's Daily Online, 2010a; China Greentech Initiative, 2011). That said, it should be noted that the NEA was previously given this role in 2008 and this change in approach reflects the difficulty in establishing a coherent and unified energy and environment policy.

The State Council is both the senior administration and executive body within China. It comprises the premier, vice-premiers, state councillors, ministers in charge of ministries and commissions, the auditor-general and the secretary-general (People's Daily Online, 2011).

2.1 Background

China operates on the basis of a five-year planning cycle, as defined by the Five-Year Plan (FYP) for National Economic and Social Development. This sets out the intended way forward for the nation and provides guidelines, policy frameworks, and targets for policy-makers at all levels of government (APCO, 2010). Each plan provides top down overall objectives and goals related to economic growth and industrial planning in key sectors and regions, while more recently also covering social issues. Although the timescale is nominally five years, many policies and directives flow through from one plan to the next.

The process begins with State Government guidelines and supporting policies together with targeted policy initiatives, which are prepared by various national commissions and ministries. These then form the framework against which provincial and local organisations provide detailed work plans for achieving the designated targets. Alongside the introduction of various policies and directives, the Government introduces specific regulations to enforce the achievement of the targets. There is also an ongoing process of review and revision over the five-year lifetime of the plan, not least because effective implementation at the provincial and local levels can be difficult (APCO, 2010).

In the context of balancing growth with environmental consequences, China has achieved rapid economic development, particularly since the mid-1990s, at an average level of 7–8% of gross domestic product (GDP) each year. This growth, which has been underpinned by significant increases in coal use especially for power generation, has caused severe air pollution problems, especially in urban areas (Minchener, 2004). There are severe acid rain problems across large regions of Southern

China, which have arisen from a combination of industrial emissions of acid gases and particulates due to coal combustion. At the same time, in cities throughout the country, the air pollution levels are high, with 90% of those assessed failing to meet WHO health-based standards (RAP, 2011).

These air pollution problems are responsible both for damage to crops and for various health problems, leading to hundreds of thousands of deaths a year in China. A major study (World Bank, 2007; MEP, 2008) between the State Environmental Protection Administration, now part of the MEP, and the World Bank reported that:

- the annual combined health and non-health cost of outdoor air and water pollution for China's economy is some $US100 billion a year;
- air pollution, especially in large cities, is leading to higher incidences of lung diseases, including cancer, respiratory system problems and therefore higher levels of work and school absenteeism;
- water pollution is also causing growing levels of cancer and diarrhoea particularly in young children;
- water pollution is further exacerbating China's severe water scarcity problems, raising the overall cost of water scarcity to about 1% of GDP.

Recently, the MEP has stated that China is facing very serious challenges in environmental protection, with more than half of China's cities affected by acid rain, about 40% of major rivers too polluted for the water to be used except for industrial purposes and landscaping, and with about 16% of the total unfit for agricultural irrigation (China Daily, 2011a,d). At the same time, less than 4% of the 471 cities monitored achieved top ratings for air cleanliness, and there was a continued loss of biodiversity around the country. Besides the air and water pollution in cities, heavy metal pollution was also a big concern, with fourteen major incidents in 2010.

Following these various assessments of the pollution challenges, the Chinese Government has made addressing such problems a key environmental priority, with an intention to accelerate the development of systems, institutions and a technical knowledge base for sustained air quality improvement. This is being supported with significant investments to meet the enormous national needs for cleaner energy, air and water (Global Impact Consulting, 2011).

2.2 Strategic target and objectives

The national strategic target for atmospheric environmental protection, through to 2050, is to protect public health and ensure ecological safety, with the intention that all regions of the country shall meet the national ambient air quality standard by achieving the World Health Organisation (WHO) ambient air quality guideline values (*see* Table 1).

In overall terms, based on 2005 levels, this will require that ambient SO_2 emissions should be reduced by 60%, NOx by 40%, PM_{10} by 50% and VOC by 40% (Hao, 2008). It is intended that a phased, if rather qualitative, approach will be adopted, as set out in Table 2.

Table 1 WHO ambient air quality guideline values, μg/m³ (Hao, 2008)

	$PM_{2.5}$	PM_{10}	O_3	NO_2		SO_2	
	Annual average	24-hour average	8-hour average	Annual average	Hourly average	Hourly average	10-minute average
Phase I	70	150				125	
Phase II	50	100	150			50	
Phase III	30	75		40	200		
Guide value	10	50	100			20	500

Table 2 Air quality targets through to 2050 (Hao, 2008)

	2020	2030	2050
Urban air quality	Over 95% of the cities reach the national class II ambient air quality standard. Developed areas achieve the phase II target value of WHO guidelines	Over 80% of the cities achieve the phase III target value of WHO guidelines	Most cities in China meet WHO ambient air quality guidelines

Within this context, the coal power sector will be required to make further improvements not only in terms of overall energy efficiency but also in the absolute reduction of pollutant emissions, namely SO_2, NOx and particulates. The expectation is that coal consumption for power generation and other energy-intensive sectors in China's coastal regions will be capped. At the very least, this will mean that permission for additional coal plants in such regions is unlikely to be granted. At the same time, in order to control acid deposition and other regional environmental problems effectively, national SO_2 emissions and, especially, emissions from the power sector will have to be reduced in order to meet designated emission caps. This approach will apply equally to NOx emissions in the coal-fired power sector, which until now have not been strictly regulated. The focus will be on the amendment of NOx emission standards, the closure of high-emission units, and the application of very low NOx combustion technologies. The other intention will be to strengthen primary fine particulate emission control, through an increase in the use of washed coal, which reduces the ash in coal and then reduces the fine particulate matter emissions, together with measures to install either higher efficiency electrostatic precipitators (ESP) or bag filters in power plants in order to meet tighter emission limits

Should such measures not result in compliance with the ambient air quality standards, then the State Government has declared that stricter control measures will have to be adopted to achieve the necessary air quality improvements.

There will also be a programme to improve the understanding of mercury emissions from coal-fired power plants while also establishing networks to monitor atmospheric mercury pollution and subsequent deposition. This will be complemented by the inclusion of mercury pollution control into the current environmental management constitution including environmental impact assessment, total amount control and an emission allowance, together with the development of mercury pollution control technology (Hao, 2008).

Previously, there have been major initiatives to improve energy efficiency and environmental performance, particularly within the period (2006-10) of the 11th FYP. These have been taken forward further, as part of the 12th FYP, with efforts to not only address the emissions of SO_2, NOx and dust and mercury in the coal power sector but also to meet other key targets such as reductions in both energy and carbon intensity per unit of GDP.

2.3 Historical review of the Eleventh Five-Year Plan

The 11th FYP included policy guidelines that addressed both near-term problems and longer-term needs. The Chinese Government focused on three major energy challenges, namely long-term energy security, limiting national environmental impacts and addressing global environmental issues (Zhong, 2010). It committed to a major shift from a resource-intensive development pattern to one that is towards resource-sustainable, with an emphasis on efficiency, resource conservation and the environment (NDRC, 2006).

Key targets were to reduce energy intensity and to control GHG emissions, for which enabling actions included:

- the establishment by the State Council of a National Leading Group to address climate change, energy conservation and pollutant discharge reduction;
- the launch of the 'Middle and Long Term Programme of Renewable Energy Development';
- the introduction of the 'General Work Plan', with appropriate public action, for energy conservation and pollutant discharge reduction;
- energy intensity (ie energy consumption per unit of GDP) to be cut by 20% from 2005 levels over the five-year lifetime of the plan;
- a 10% reduction of major pollutants (SO_2 and total suspended particulates) discharge to be achieved compared to 2005 levels over the same timescale.

The latter two actions were particularly significant, with the NDRC deciding how these two targets would be achieved between individual provinces and within the various industrial sectors (NDRC, 2006).

Considerable emphasis was put on the improvement of coal-fired power plant efficiency through the introduction of advanced high efficiency units and the closure of some 72 GWe of small, inefficient power plants (Minchener, 2010), together with the closure of small and obsolete steel and cement production units (NDRC, 2007a,b). For major pollutant discharge reductions, this was addressed through the introduction of improved ESP for fine particulate emissions control, together with the very extensive provision of flue gas desulphurisation (FGD) for SO_2 control on most existing operating and on all new coal-fired power plants (Minchener, 2010).

2.4 Overview of the Twelfth Five-Year Plan

The guidelines for the 12th FYP represent a continuation of broad policy direction and its key themes are rebalancing the economy, addressing social inequality and protecting the environment (China Daily, 2011a,b). From an economic perspective, a notional GDP annual growth rate target of 7% is assumed, with a greater emphasis on consumption-led inclusive growth rather than investments and exports (GCCSI, 2011).

For the first time, the plan gives a high profile to climate change and environmental issues as well as to energy (The Climate Group, 2011). The need to meet China's increasing energy demand, while simultaneously reducing pollution and ensuring a stable, reliable and clean energy supply, has become an ongoing priority of the government, which is also supported by a significant investment commitment.

During the 11th FYP, the government allocated RMB200 billion (US$31 billion) for energy efficiency and environmental protection measures, which is understood to have created a large knock-on effect by generating an additional RMB2 trillion in economic activity. For the 12th FYP period, it is understood that China's investment in the environmental protection industry will exceed RMB3 trillion, with the industry growing by 15–20%/y. Within this framework, the intention is to develop seven strategic emerging industries (SEI), which include energy conservation and environmental protection, new energy, together with biotechnology, high-end equipment manufacturing, clean-energy vehicles, new materials, and next-generation IT. The State Government will pilot the development of these industries by establishing industrial standards and supporting the entry of the main products into the international market (Global Times, 2010). This will include facilitating co-ordinated development together with support for international distribution. It is understood that the government expects to increase the SEI contribution to GDP from approximately 5% in 2010 to 8% by 2015 and to 15% by 2020 (APCO, 2010).

Several important energy and environment targets have been set for the period to 2015 (China Daily, 2011b,c; RAP, 2011) with:

- energy consumption per unit of GDP to be cut by 16% from 2010 levels;

Figure 1 Map of the provinces of China (Muztagh, 2011)

- carbon dioxide (CO_2) emissions per unit of GDP to be cut by 17% from 2010 levels;
- non-fossil fuel use to account for 11.4% of primary energy consumption, with a target of 15% for 2020;
- SO_2 emissions and chemical oxygen demand (a measure of water quality) both to be cut by 8% from 2010 levels;
- NOx and ammoniac nitrogen emissions both to be cut by 10% from 2010 levels;
- heavy metals pollution (mercury, lead, chromium, cadmium, and arsenic) to be reduced by either 15% compared to 2007 levels for priority regions or to 2007 levels for other regions;
- water consumption per unit of value-added industrial output to be cut by 30%;
- research and development expenditure to account for 2.2% of GDP, with an emphasis on scientific and technological innovation leading to Chinese intellectual property rights.

It is also expected that the NDRC will introduce new environmental taxes covering SO_2 and wastewater in the near future, with the possibility of subsequently including CO_2 (China Daily, 2010). Other new market mechanisms such as tiered energy pricing and pilot carbon emissions trading programmes will also be explored, with selected provinces and specific sectors being the focus of the initial experiments in cap-and-trade (China-US Focus, 2011).

With regard to both the energy and environment targets, the overall savings requirements amongst the provinces and the sectors where the savings will be made (iron & steel, non-ferrous metals, cement, petrochemicals and power) will be allocated in a predominantly top-down process, as was undertaken during the 11th FYP period (Chinadialogue, 2011a; China FAQs, 2011). Thus the intended 16%

overall cut in energy intensity (energy consumed per unit of GDP) is the national target. At the provincial level, there are some variations, depending on local circumstances, especially the level of development. Figure 1 provides geographical information on the provinces. The eastern and central provinces have been allocated targets in the range 16–18%. In contrast, the western provinces, Qinghai, Xinjiang and Tibet, which are relatively undeveloped and have large ethnic minority populations, have been given energy-intensity targets of 10%, while Ningxia and Gansu, also in the west, have been given targets of 15%.

Similarly, the environmental targets will be allocated to provinces, based roughly on comparative emission volumes and levels of economic development. The key priority regions where accelerated air quality management is intended (*see below*) will be expected to achieve 13–15% reductions in SO_2 and 14–17% reductions in NOx emissions. In contrast, the central regions will have 5% targets both for SO_2 and NOx emissions while the western regions will have reduction targets of between 0% and 5% for both pollutants. Performance against these will be reviewed at the mid-point of the Plan and can be adjusted by the NDRC and the MEP, depending on progress to date and the scope for improvement.

2.5 Environmental regulations and standards

During the period of the 12th FYP, the Chinese Government is taking steps to tighten emissions from the power, steel, non-ferrous metals, petroleum, chemical and cement sectors, as part of the overall intention of achieving more stringent air quality standards. The initial focus is on power plants, for which a new emission standard has been developed following an extensive analysis of industrial emissions, air quality issues, regional variations in industrial activity and environmental problems (MEP, 2009b).

This new standard, which came into effect at the start of January 2012, is applicable to any coal-fired boilers (other than some types of stoker-fired boilers almost all of which have now been closed as part of the energy efficiency initiative) with unit steam rating greater than 65 t/h, pulverised coal boilers of any capacity, oil- and gas-fired boilers with capacities greater than 65 t/h, all gas turbine combined cycle (GTCC) power plants, as well as all boilers with capacities greater than 65 t/h that fire waste coal, biomass, oil shale, petcoke and other such materials. The permitted emission levels for GTCC power plants will also be applicable to the gas turbine island of an IGCC power plant. However, the new standard is not applicable to power plants that fire municipal wastes and/or hazardous wastes. The new standard also sets out the requirements for sampling and monitoring pollutants.

For coal-fired power plants, the NDRC target for 2020 is to reduce absolute emissions of SO_2, NOx and particulates from coal-fired power plants to the levels achieved in 2000. To put that in context, coal-fired power capacity in 2000 was 235 GWe and by the end of 2010 had reached 687 GWe, an almost three-fold increase in ten years.

2.5.1 Coal-fired power plant emission limits to the end of 2011

The coal-fired power plant emission standards, as given in the Emission Standard of Air Pollutants for Thermal Power Plants [GB13223-2003], were implemented from 1 January 2004 (Wang and Zeng, 2008), as shown in Table 3.

These 2004 standards were within World Bank guidelines and at that time equivalent to the OECD average. There were variations in the emissions limits depending on the age of the plant, the location and the types of coal being burnt, together with a further tightening of the emissions limits for some categories with effect from the start of 2010. For big international cities and scenic areas such as Beijing, Shanghai, Guangzhou, Hangzhou and Guilin, the local Environmental Protection

Administration (now part of the MEP) could set local air pollutant emission limits that were far stricter than the national emission standards.

Table 3 Previous emission limits for coal-fired power plants in China [GB13223-2003] (CEC, 2004)

Power plant construction date	Time period 1 (before end 1996)		Time period 2 (start 1997 to end 2003)		Time period 3 (from start 2004)
Date of implementation	1 January 2005	1 January 2010	1 January 2005	1 January 2010	1 January 2004
Dust, mg/m³	300* 600†	200	200* 500†	50 100‡ 200§	50 100‡ 200§
SO_2, mg/m³	2100*	1200*	2100 1200†	400 1200†	400 800‡ 1200§
NOx, mg/m³	1500 anthracite		1300 anthracite		1100 anthracite
	1100 lean coal		650 lean coal		650 lean coal
					450 bituminous coal

* applicable to thermal power plants located in urban areas
† applicable to thermal power plants located in rural areas
‡ applicable either to thermal power plants for which the environmental impact report of the project had been approved before this standard was implemented, or to coal minemouth power plants burning extra low sulphur coals (S<0.5%) located in the western region of China and outside of the Two Control Zones areas
§ applicable to thermal power plants for which the dominant fuel is coalmine waste (heating value of the coal should be less than 12.55 MJ/kg)

2.5.2 Coal-fired power plant emission limits from the start of 2012

Table 4 New emission limits for coal-fired power plants in the priority regions of China [GB13223-2011] (MEP, 2011c)

Pollutant	Conditions for application	Permitted emission levels, mg/m³	Location for monitoring emissions
Particulates	all	20	Stack or flue duct
SO_2	all	50	
NOx (as NO_2)	all	100	
Hg and compounds	all	0.03	
Stack opacity (Lingeman blackness)	all	1	Exit of stack

In 2011, the Chinese Government introduced the Emission Standard of Air Pollutants for Thermal Power Plants [GB13223-2011], which from 1 January 2012 replaced [GB13223-2003]. The new regulation has significantly tightened the emissions control requirements, as set out in Tables 4 and 5 (MEP, 2010, 2011a,b,c).

The MEP has identified nine key regions, facing very significant air quality challenges, where there is the need for advanced air quality management. These are the three major economic zones around the cities of Beijing, Shanghai (Yangtze River Delta) and Guangzhou (Pearl River Delta), and six areas around the cities of Shenyang, Changsha, Wuhan, Chengdu-Chongqing, the Shandong peninsula, and the coastal area west of the Taiwan strait. These regions comprise the

Table 5 New emission limits for coal-fired power plants in the remainder of China [GB13223-2011] (MEP, 2011c)

Pollutant	Conditions for application	Permitted emission levels, mg/m^3	Location for monitoring emissions
Particulates	all	30	Stack or flue duct
SO_2	new unit	100 200*	
	existing unit	200 400*	
NOx (as NO_2)	all	100 200†	
Hg and compounds	all	0.03	
Stack Opacity (Lingeman blackness)	all	1	Exit of stack

* Applicable to thermal power boilers located in Guangxi Zhuang autonomous region, Sichuan province, Guizhou province and Chongqing municipality

† Applicable to thermal power boilers that employ the 'W-shape' furnace, existing CFBC boilers, and thermal power boilers that came online or were granted approval for the environmental impact reports before 31 December 2011

population and economic centres of the country, responsible for 64% of national GDP, 43% of total energy use, and representing 39% of the population. Table 4 shows that the new emissions limits for dust, SO_2 and NOx are very strict in these regions, with no allowance made for whether the plant is either new or already in operation. In addition, as is discussed in the next subsection, as part of the overall drive to improve air quality, the provincial governments will be able to stipulate local standards to regulate additional pollutants not covered by the new Standard and they can also stipulate more stringent standards for pollutants covered by the new Standard. As noted previously, there will also be an increasing emphasis on limiting any new coal-fired power plants in these regions.

For the rest of the country, the standards are not quite so strict as for the priority regions and the SO_2/NOx limits for existing plants are less severe than for new plants, as shown in Table 5. In addition, in several provinces which are not so developed and which are dependent on the use of local higher sulphur coal, the SO_2 limits are further relaxed. On a national basis, but excluding the nine priority regions, there is also a pragmatic acceptance that certain types of existing power plants and those burning very low volatile content coals will not be able to achieve the NOx levels expected elsewhere. Consequently, these levels have been relaxed; however, this will not apply to new plants and so there will most likely be a future shift in power plant design.

All new plants (those that receive their environmental impact approval after the end of December 2011) will need to achieve the new standards from start of operation. Existing plants, and those approved before the end of December 2011, will have until the start of July 2014 to comply.

The new pollutant that will be regulated on coal-fired power plants is mercury and its compounds, for which the limit has been set at a level that represents a core control. This means that providing the power plant operator improves the particulate, SO_2 and NOx removal systems such that the new standards are achieved, then the mercury standard should be met without the need to introduce an additional capture device (He, 2011). This limit is in line with that agreed by the UNECE, which has also noted that a coal-fired power plant fitted with either an ESP or fabric filter, FGD and SCR should actually be able to meet an emissions limit value of 0.003 mg/m^3 (Weem, 2011). The emissions level will have to be measured on a regular basis and the chosen technique is based on that used in the USA, namely on a molecular absorption basis. Currently, the five major power generating companies are undertaking demonstration projects to determine if this approach is technically and scientifically viable. Subject to these demonstrations being successful, mercury monitoring on all coal-fired power plants will need to begin from the start of January 2015.

2.5.3 Ambient Air Quality Standards & Air Quality Index

The reduction in pollutant emission limits for coal-fired power plants is a significant part of the drive to improve the ambient air quality, with the intention to tighten the standards and to extend the air quality index. However, there is also a need to achieve a balance between economic, industrial and social stability and overall environmental quality.

Recently, the MEP proposed further revisions to the National Ambient Air Quality Standards which were last updated in 1996 (Standards Administration of China, 2010). The amendments, which should be implemented during 2012, cover legally-binding standards for seven pollutants, namely SO_2, NO_2, PM_{10}/TSP, CO, O_3, Pb, BaP. These set two grades for each pollutant. Grade I applies to natural conservation areas while Grade II applies to urban and residential areas with the former being more stringent. Although the general intention is to tighten such standards in line with WHO guidelines, the PM_{10} standards are likely to remain well above internationally-recognised levels at three times the WHO recommended daily limit of 50 mg/m^3. At the same time, the introduction of a secondary set of aspirational health-based standards, which include internationally recognised $PM_{2.5}$ standards as well as standards for NOx, mercury and other heavy metals, is under consideration.

China has a daily Air Quality Index, which uses the 24-hour average concentrations of SO_2, NO_2, and PM_{10}, to determine the air quality level according to the pollutant with the greatest 24-hour average concentration. However, it does not include O_3, $PM_{2.5}$ and other contributors to regional haze. Consequently the index does not readily align with public perception of air quality (RAP, 2011; Clean Biz Asia, 2011). The system is currently under revision although, while the MEP has proposed to incorporate O_3, it has not, as yet, included fine particulates (MEP, 2011a).

In addition, in 2010, the MEP began hourly, real-time reporting of air quality data for 113 cities across China. An online web application provides hourly averaged data from individual monitoring stations for concentrations of SO_2, NOx, and PM_{10}, which represents greater data transparency compared to the existing Air Quality Index.

2.5.4 The Regional Air Quality Management Rule

In recognition of the scale of the environmental problems, the State Council established the Regional Air Quality Management Rule in 2010 (China FAQs, 2011). This identified the nine key regions described previously that are facing particular air quality challenges with the need for advanced air quality management. It also gave the provincial governments the authority to set local standards according to the more acute regional needs.

The provincial officials in these key regions are required to:
- amend the ambient air quality standards and the air quality index to include fine particulates ($PM_{2.5}$) and O_3 to the list of pollutants to be measured;
- seek to increase deployment of low- and zero-carbon energy resources, including natural gas and renewable electricity, while improving energy efficiency, in urban areas;
- strictly limit the construction of new coal-fired power plants and other energy-intensive industrial facilities;
- set air pollution emissions standards for these energy-intensive industries that are significantly tighter than the national standards;
- set up regional NOx emissions caps and require all new coal-fired power plants to include the introduction of de-NOx systems;
- phase out small coal-fired boilers;
- seek to apply a regional cap on coal-consumption.

The development and approval of these regional plans is ongoing, with the expectation that the final versions will be agreed by the MEP and approved by the State Council by early 2012. In its current form, the planning scheme is a top-down approach, without the means for joint planning between neighbouring provinces and municipalities. Any preparation and implementation of plans that cut across jurisdictional lines will be done by the MEP. The plans will have a lifetime of five years and there will be an annual progress assessment, with the career prospects of the officials tied to their successful implementation.

In addition, in 2010, under this rule, the State Council also targeted 113 major cities. Should these cities not meet China's National Grade II ambient air quality standards, they will be required to submit air quality remediation plans to the MEP. However, the exact procedures and planning guidance for the cities have yet to be finalised.

2.6 Implications for the coal power generation sector

In the near to medium term, the Chinese Government is dependent on coal use to drive economic growth while it aims to improve general standards of living. As such, it is seeking to maintain a balance between establishing regulations to enable cleaner production and use of energy while maintaining the affordability and ready availability of coal (China Greentech Initiative, 2011). Within the context of the 12th FYP and the new environmental standards for the power sector, the drivers are to improve efficiency of coal use while significantly reducing pollutant emissions.

2.6.1 Improved energy efficiency initiatives

Over the 11th FYP period, the average thermal efficiency of China's coal fleet improved from 370 gce/kWh to 335 gce/kWh. The target for 2020 is 320 gce/kWh (Mao, 2011). The intention within the 12th FYP is to build 270 GWe of coal-based capacity, which will all be either 600, 660 or 1000 MWe high efficiency supercritical and ultra-supercritical units, except for CHP schemes where the power plants will be smaller in scale with lower grade steam conditions. The Government will continue with the closure of outdated power plant capacity, with a target of some further 50 GWe by end 2015. The focus will be on the remaining 100 GWe of inefficient small/medium capacity (about 12% of total capacity), mostly in the range 100–200 MWe (Yue, 2011).

It is understood that the Government is considering capping total energy use at 4.1–4.2 Gt coal equivalent although how this might be achieved in practice has not been made clear (KPMG, 2011). In terms of overall coal use, which was 3.2 Gt in 2010, there have been public statements from officials suggesting that the Government will set an upper annual limit on total raw coal use within the duration of the 12th FYP at 3.6 to 3.8 Gt for the period 2011-15 (China Daily, 2010; China.org, 2011; Sxcoal, 2010a). If this is correct and it requires a cutback in currently projected coal use then it is assumed that this will be through the closure of either more of the inefficient small/medium power plant capacity or units from the non-power industrial sectors.

2.6.2 Improved environmental performance

The revised, significantly tighter pollutant emissions standards for coal-fired power plants, covering dust, SO_2, and NOx emissions, will require major changes to the current control technologies.

For fine particulates (dust), the ESP collection efficiency will need to be improved and, if that is not enough, there will be a need for a combination ESP plus part bag filter. For coals that have difficult ash characteristics there will be a need to introduce full bag filter systems. This will require a major retrofit activity for most existing coal-fired power plants together with the immediate introduction of these more effective systems on any new coal-fired power plants.

Since 2003, all new coal-fired power plants have been equipped with low NOx burners and, in some cases, air staging in order to meet the emissions standards introduced at the start of 2004 (Wang and Zeng, 2008). However, there will now be a need to introduce additional NOx reduction systems. To an extent, this need has been expected for some while, since, for the last five years, the designs of all new coal-fired plants have had to include space for the subsequent installation of SCR/SNCR equipment (Minchener, 2010; istockAnalyst, 2011a).

According to China's 2007 pollution survey (MEP, 2008), the power sector is the largest source of NOx emissions, accounting for over 40% of total emissions, with the transport and industrial sectors accounting for 30% and 25% respectively. The MEP has set out the policy framework for NOx reduction actions at fossil fuel fired power plants to be undertaken during the 12th FYP (Business Wire, 2010). The Notice of Fossil-Fired Power Plant NOx Emission Prevention and Treatment Policy applies nationwide to all coal-fired power plants and cogeneration units that are 200 MWe or larger, except in the designated priority regions where it applies to all units regardless of size.

In principle, the first option technologies to be installed are Low NOx Combustion Technologies (such as low NOx burners and over-fire air systems), which are the technologies that have been introduced previously. However, if this approach should not prove adequate, flue gas de-NOx technology should be installed, such as elective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and SNCR-SCR systems. For the SCR and SNCR options, the policy recommends that SCR should be installed on units of 600 MWe capacity or greater. For units of less than 600 MWe capacity, the preferred technologies are SCR and SNCR-SCR. For systems which require ammonia as a reducing agent for SCR, SNCR-SCR and SNCR, there are special policy guidelines depending on the unit location. For all units within the priority regions, the preferred reducing agent is urea.

To reduce the energy penalty disincentive for the generating companies, it is expected that a price premium for operating NOx control systems will be introduced, as is done currently for desulphurisation. This is likely to be set at 0.015 RMB/kWh (0.0023 US$/kWh).

2.7 Future requirements

There is expected to be pressure to further tighten the 'National Ambient Air Quality Standards', especially for PM_{10}. It is also likely that the intention to introduce internationally recognised $PM_{2.5}$ standards, as well as standards for NOx, mercury and other heavy metals, will be approved. If this is the case, the provincial governments will be given authority to set local standards according to these references. There is also scope to improve the daily Air Quality Index, to include $PM_{2.5}$ and other contributors to regional haze.

Consequently, while the new standards for the coal power sector represent a very significant tightening of the emissions limits, there is an expectation that further changes could be applied prior to 2020. At present, there are no limits on $PM_{2.5}$ and should this be introduced, there would need to be a rethink of the approach in the coal power sector to controlling dust emissions, with a need to retrofit either full bag filter systems or electro-bag filters (ESP plus part bag filter) on almost all plants (He, 2011). At the same time, it needs to be recognised that SO_2 and NOx are precursors to $PM_{2.5}$ and so, in principle, emission limits for these pollutants could be tightened yet further.

It is also possible that the mercury emissions limit could be changed such that specific control systems would need to be introduced. However, measurements of mercury will not be introduced until 2015, and there would need to be a period of time during which such measurements are taken and the results analysed. Consequently, if it was decided that any tightening of such standards should be necessary, it would be unlikely to take place until close to 2020,

3 Overview of coal-fired power generation in China

This chapter provides information on the current coal-fired power plant capacity in China, the expected growth of such capacity, the likely technology mix and the associated size of the units, together with a broad estimate of future changes beyond 2020.

3.1 Recent historical overview

Table 6 Annual power plant capacity and growth rate in China (NEA, 2009; Mao, 2011)

	Installed net capacity, GWe	Annual increase in net capacity, GWe	Annual growth rate, %
2000	315	–	–
2001	338	23	7.3
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
2009	874	81*	10.2
2010	963	89*	10.2

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

The power sector is very large and the overall generation capacity has grown very rapidly – over 200% in the ten years to the end of 2010 (*see* Table 6). It also shows that year-on-year increases in capacity growth rate peaked at the end of 2006, with the subsequent yearly increases, although massive in absolute terms, representing a decline from that peak value.

Table 7 provides information on that capacity on a technology basis for the period from the end of 2003 to the end of 2010. This indicates the dominance of coal-fired power generation within the sector. Firstly, the great majority of that annual increase in capacity is due to the construction of coal-fired plants. 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 small but steady increase in nuclear power and the new and rapid introduction of wind power. Within this total, some 5% was for CHP applications (Mi, 2010).

Table 7 Total installed capacity 2003-10, GWe (NEA, 2009; Zhu and others, 2010; Mao, 2011)

	2003	2004	2005	2006	2007	2008	2009	2010
Total installed net capacity	385	442	508	622	713	793	874	963
Hydropower	92 (24%)	105 (24%)	117 (23%)	129 (21%)	145 (20%)	170 (21%)	197 (22%)	213 (22%)
Thermal power* (coal and gas)	286 (74%)	330 (75%)	384 (76%)	483 (78%)	554 (78%)	601 (76%)	652 (75%)	707 (73%)
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%)	9.1 (1.0%)	11 (1.1%)
Renewable power†				0.7 (0.1%)	4.7 (0.7%)	12.2 (1.6%)	16.1 (1.9%)	32 (3.3%)

* The level of gas- and oil-fired power generation at the end of 2010 was ~20 GWe, which is negligible compared to the amount of coal-fired capacity

† This comprises wind power plus a tiny proportion of biomass-fired units

3.2 Current and future coal power capacity

A very preliminary forecast of the relative proportion of coal-fired power plant out to 2050 is given in Table 8. This provides firm data on the situation at the end of 2010, the official plan for the 12th FYP (2011-15) together with some indicative estimates of likely coal power capacity for 2020 and 2050.

The proportion of thermal power in China's electricity output should fall by about six percentage points by the end of 2015, to be in line with the plan of the NEA. On the same timescale, non-fossil energy is expected to comprise 33% of the total installed power plant capacity, up nearly nine percentage points over the 2005 level. However, because of the continuing growth in overall capacity, although coal's share of the total will be lower, in absolute terms, it will increase significantly (Sxcoal, 2010b). The projections also suggest that coal power capacity could double over the period 2010–50.

It is stressed that projections for 2020 onwards are very flexible, with some variation both on the total capacity and the relative proportions of fossil and non-fossil technologies. For example, Table 8 suggests that the total capacity in 2020 will be some 1730 GWe with 41% based on non-fossil fuel technology. There are other projections, also from the CEC, that suggest the total capacity might be 1885 GWe, with about 365 based on non-fossil fuel technology (Sxcoal, 2010b). In absolute terms, the level of non-fossil technology is almost the same although there is a significant difference in possible coal-based capacity.

In terms of China's power consumption, by 2015 this is likely be in the range 5.4–6.3 trillion kWh, with an annual growth rate of 6.0–8.8%. By 2020, electricity consumption may grow further, to 6.6–8.5 trillion kWh, with an annual growth rate of 4.0–6.1%. At that time, it is projected that, in absolute terms, coal consumption for China's power generation sector could be about 35% higher than 2010 levels (istockAnalyst, 2011b).

Table 8 Projection for China's total installed net power generation capacity for 2015-50 (Mao, 2011)

		2010	2015	2020	2050
Total installed net power plant capacity, GWe		963	1437	1730	2900
Coal, GWe (%)		687 (71.4)	933 (65.3)	960 (55.5)	1400 (48.3)
Natural gas, GWe (%)		20 (2.0)	40 (2.7)	60 (3.5)	100 (3.5)
Hydro, GWe (%)		213 (22.1)	324 (22.0)	350 (20.3)	400 (13.8)
Nuclear, GWe (%)		11 (1.1)	43 (2.9)	70 (4.0)	300 (10.3)
Renewables	Wind, GWe (%)	30 (3.1)	70 (4.8)	250 (14.4)	400 (13.8)
	Biomass, GWe (%)	2 (0.2)	27 (1.8)	20 (1.1)	100 (3.5)
	Solar, GWe (%)			20 (1.1)	200 (6.8)

Note:
(1) The projection of China's total installed power capacity is based on information collected from representatives of the China Electricity Council (CEC), the National Development & Reform Commission and Tsinghua University
(2) The data for 2010 were issued officially by the CEC, early in 2011
(3) The data for 2015 are the official goal of 12th Five-Year Plan (2011-15)
(4) The projections of China's total installed power capacity for both the medium term (2020) and the long term (2050) are at best indicative with many assumed conditions. As such they should not be in any way considered as official projections by the Chinese Government

3.3 Possible technology options

At present, the very great majority of coal-fired power plants are pulverised coal (PC) units with the remainder comprising CFBC units, which are used for lower grade, variable quality coals. For the PC plant, the great majority of the newer units have either supercritical (SC) or ultra-supercritical (USC) steam conditions, while the older, smaller units operate with subcritical steam conditions, as shown in Table 9. For the CFBC units, these currently all have subcritical steam conditions although a 600 MWe supercritical design is close to demonstration (Minchener, 2010).

In the future, all new coal-fired PC plants will incorporate either SC or USC steam conditions, except those used for CHP applications. There will also be significant improvements in overall plant efficiencies for such plants (Luan, 2011), as suggested in Table 10. CFBC will show a similar deployment trend, with larger (>300 MWe) subcritical units being introduced to be followed by 600 MWe SC units.

Table 9 Technology variations for coal-fired power plants at the end of 2010 (Mao, 2011; Yue, 2011)

	Number, %	Capacity, GWe	Proportion, %
1000 MWe USC	33	33	5
660 MWe USC	10	7	1
600 MWe SC	261	157	23
600 MWe sub-critical	100	60	9
300–600 MWe sub-critical	700	210	30
<300 MWe sub-critical	–	220	32

Subcritical includes CFBC units and CHP plants

In addition, there may be an introduction of commercial-scale IGCC units. This technology is seen as a high technological priority by the Ministry of Science and Technology (MOST) although the NDRC is yet to be convinced that it can be competitive, given the ongoing doubts about component reliability and system availability together with the much higher capital investment costs compared to PC plant. At present, China is proceeding with an initial trial of a 250 MWe demonstration unit at Tianjin, which may be followed with a 400 MWe unit incorporating CCS (Minchener, 2011). Should the IGCC core technology prove successful, then it could be introduced at that unit size. However, it will still lack economies of scale. If introduced at a larger scale then the questions of reliability and availability will most likely only be resolved through further demonstration activities. Consequently, it is difficult to envisage IGCC having a meaningful impact on the technology mix prior to 2030.

Table 10 Projected performance improvement for Chinese USC designs (Mao, 2011)

	Typical 1000 MWe USC	WCQ No 3 unit 1000 MWe USC optimisation	Projected first generation 1350 MWe USC	Optimised 1350 MWe USC
Heat rate, kJ/kWh	7320	7140	6947	6765
Power consumption rate, %	4.5	3.5	4.0	3.0
Boiler efficiency, %	93.6	95.5	94.0	95.5
Plant net efficiency, %	43.4	46.0	46.3	48.8

Information based on designs undertaken at Shanghai WGQ No 3 Power Plant
Maximum superheater steam temperature 600°C

4 Current and likely future emissions of non-GHG emissions from coal-fired power plants in China

On the basis of the information provided in the previous two chapters, the emissions of conventional (non-GHG) pollutants from coal-fired plant in China are presented against a background of the coal power generation technologies in use today. This is followed by projections for how these emissions might change over time, given the MEP targets and the likely future use of coal in the power sector.

It is stressed that, while there is consistency in the historical trends of pollutant emissions, there are considerable variations in the absolute levels depending on the source material. Consequently, while the data presented have been drawn from official government sources and while every effort has been made to confirm the validity of the information presented, there may be errors. Any interpretation of the data should be made with caution.

4.1 Historical review of particulate emissions

Table 11 Dust emissions from coal-fired power plants in China (Zhao and others, 2008; Zhu and others, 2010; Lu and others, 2010)

Year	Dust, Mt
2000	3.0
2001	2.9
2002	2.7
2003	–
2004	–
2005	2.8
2006	3.7
2007	3.5
2008	3.3
2009	–
2010	2.5*

* estimate

Since the late twentieth century and especially since the implementation of the Emission Standard of Air Pollutants for Thermal Power Plants (GB13223-2003) from 2004 onwards, there was an upturn in the introduction of air pollutant control equipment especially into the coal-fired power sector. With regard to fine particulates (the dust that contains unburnt carbon), the increased introduction of ESP has helped to reduce emissions from coal-fired power plants. The total dust emissions from this sector initially showed a decrease as ESP and, in a few cases, bag filters were retrofitted to plants that had previously utilised lower grade collection devices. From 2003 onwards, as coal-fired power generation capacity increased rapidly, the dust emissions initially also increased until 2006-07, reflecting the massive upturn in capacity even though the new plants included good quality ESP systems, Table 11. From 2007 onwards, the total dust emissions declined, as the significant introduction of wet FGD to control SO_2 emissions had a beneficial side effect for dust removal (Zhao and others, 2008).

4.2 Historical review of SO_2 emissions

During the 11th FYP period, there was a rapid introduction of FGD systems. All new power plants were required to include FGD while the MEP continued its extensive programme of retrofit introduction on existing units, especially but not exclusively (some 82%) on those with capacity of 300 MWe and above (MEP, 2011b). By the end of 2010, the proportion with FGD had reached about 86% of total coal-fired power plant capacity as shown in Figure 2 (CEC, 2011). National emissions of SO_2 were reduced by about 14% compared to 2005 levels, even though the total coal-fired power plant

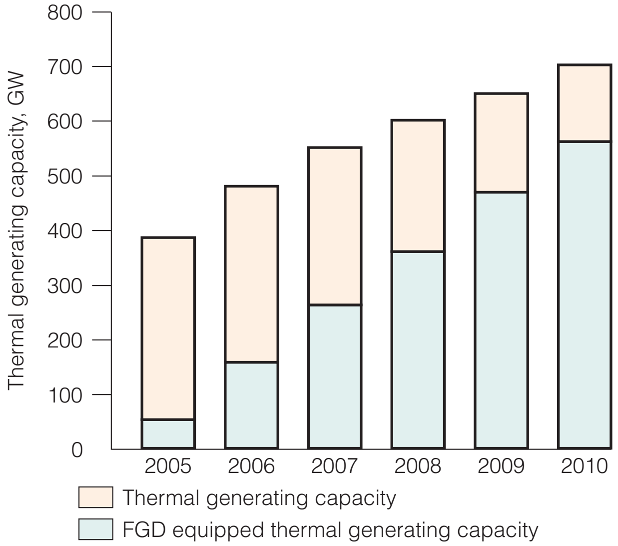

Figure 2 Relative proportion of coal power plant with FGD installed (CEC, 2011)

Table 12 SO_2 emissions in China (MEP, 2009a; Lu and others 2009, 2010; China Daily, 2011a)

	Total emissions of SO_2, Mt	Emissions from thermal power plants	
		SO_2, Mt	Proportion of total, %
2000	20.0	6.5	32.5
2001	19.5	6.5	33.3
2002	19.3	6.7	34.7
2003	21.6	8.3	38.4
2004	22.5	9.3	41.3
2005	25.5	11.1	43.5
2006	25.7	11.6	45.1
2007	24.7	10.9	44.1
2008	23.2	9.3*	40.1*
2009	22.1		
2010	22.9	10.0*	43.7*

* estimate

capacity had increased from 384 GWe to 687 GWe over the same time period (Minchener, 2011; China Daily, 2011c).

FGD has been installed on all new coal-fired power plant since about 2006, which increasingly has comprised the larger (⩾600 MWe) units. 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.

Table 12 shows that the total SO_2 emissions increased from 20.0 Mt in 2000 to 25.7Mt in 2006, close to a 30% increase during five years with a very large proportion of this arising from the increase in coal-fired power generation. However, despite an even greater increase in coal-fired power generation in subsequent years, from 2007 onwards the total emissions of SO_2 began to fall, which was primarily a result of the significant and continued introduction of FGD (China Business News, 2009; Lu and Streets, 2011). That said, there is a clear suggestion that there has been a subsequent upturn in coal power SO_2 emissions, which could reflect the sheer impact of yet more plants being operated, despite the increasing installation of FGD.

4.3 Historical review of NOx emissions

For NOx emission control, based on the previous emission limit (*see* Table 3 on page 14), the use of low NOx combustion technologies has ensured 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. However, now that the limit is to be tightened to 200 mg/m^3 or below, catalytic de-NOx systems are having to be introduced.

The installed capacity of such systems at the end of 2010 was 58 GWe, up from 30 GWe at the end of 2008, with some further 100 GWe of systems at the planning and/or construction stage (Zhu and others, 2009, 2010). In line with the guidance provided by the MEP, the technology adopted most widely (97.4%) is SCR with the remainder being SNCR. The equipment has been installed mainly in Beijing, Shanghai and in the eastern provinces, namely Fujian, Zhejiang, Guangdong and Jiangsu.

As yet, NOx hasn't been included in the list of environment statistics for China, due to the lack of comprehensive standards for data collection. There have been some estimates undertaken, based on measurements at power plants, comprehensive analysis on coal consumption, consideration of size and types of thermal power plants, as given in Table 13. This shows that NOx emissions from the coal power sector have increased significantly with the increased installation of new power plants and that the impact of low NOx burners has not been sufficient to halt this rising trend.

Table 13 Estimated NOx emissions from coal-fired power plants (Zhao and others, 2008; Zhu and others 2009, 2010; 21 Tradenet, 2011a,b)

Year	Estimated NOx emissions, Mt
2000	4.7
2001	–
2002	5.4
2003	6.0
2004	6.5
2005	7.0
2006	8.5
2007	8.4
2008	8.4
2009	–
2010	9.7

4.4 Mercury emission issues

A major source of mercury emissions to the atmosphere is from the combustion of coal (Kuang and others, 2008). It is very difficult to obtain consistent measurements of such emissions from coal-fired power plant and other industrial sources, which makes determination of the mercury concentrations in the various off-takes from such plants problematical. That said, it is known that ESP, wet FGD and de-NOx control systems all contribute to removing mercury in solid form. Consequently, on a qualitative basis, total mercury emissions should have been reduced significantly as the extensive introduction of emissions control systems has been applied in China. From 2015, all operators will be required to undertake measurements of mercury emissions from the stack of coal-fired power plants and it is hoped that at that time a much better, practical assessment of this pollutant can be obtained.

4.5 Projections of future non-GHG emissions

Future emissions of non-GHG emissions from coal-fired power plants will depend on many factors, including:

- emissions limits for each pollutant that will be applied by the MEP;
- future power demand;
- the mix of fossil and non-fossil fuel technologies in the total power plant capacity, and how that mix will be utilised;
- type of coal power plant available for operation, with differing levels of efficiency and pollutant emissions, and the likely operational load in each case;
- impact of changes in coal preparation procedures (for example coal washing to lower ash and sulphur contents);
- speed at which the power generation companies will uprate their pollutant control systems in order to meet the new national standards;
- impact of other legislation that can alter the performance of coal plant, such as a need for CCS.

With this number of variables, it is difficult to make meaningful predictions of future emission trends. Even so, in 2009, as part of the consultation process prior to the introduction of the new standards, the MEP made some broad estimates for 2020 of the impact of the new emissions standards on non-GHG emissions (MEP, 2009b). In taking into account the likely power plant mix, there is some uncertainty as to exactly how much and when the new coal-fired power capacity will be introduced. The assumed 2010 baseline levels for the three key pollutants are not in line with the actual power plant data, due to there being an unexpected surge in FGD introduction while some power plants have fitted SCR de-NOx systems earlier than was legally required in anticipation of the new standards being applied. Also the implementation of the new emissions standards did not apply until January 2012 with a further two and a half years being allowed for compliance on existing plants while the MEP had assumed that implementation would commence at the start of 2010. Nevertheless, these projections do at least provide an insight into how the non-GHG emissions might change over the period to 2020.

These MEP provisional projections, made in 2009, suggest that dust emissions would have risen by some 70% from 2010 values if new standards had not been introduced to compel the power companies to upgrade the collection efficiency of their dust removal systems, as shown in Table 14. With such improvements, the emissions would be reduced by about 15% in 2015 although in 2020 they would be back up to the 2010 levels. This reflects the fact that the collection efficiency of ESP is essentially at the maximum and as such there is little scope to reduce dust emissions in this way. Consequently, the improvement to 2015 reflects the small benefit gained by using uprated ESP on existing plants while beyond that point such benefit is wholly counteracted by the large number of coal plants to be introduced within the power sector. This suggest that at some point the MEP will need to proactively implement policies for the power sector to introduce either bag filters or ESP-filter hybrid systems in order to ensure that PM_{10} and indeed $PM_{2.5}$ levels can be significantly and consistently reduced.

Table 14 Predicted impact of the new standards on dust emissions from coal-fired power plants in China (MEP, 2009b)

Predicted dust emissions from coal-fired power plants, Mt	2010	2015	2020
Without new emission standards being implemented	3.8	5.4	6.4
With new emission standards being implemented in 2010	3.7	3.3	3.9

Table 15 Predicted impact of the new standards on SO_2 emissions from coal-fired power plants in China (MEP, 2009b)

Predicted SO_2 emissions from coal-fired power plants, Mt	2010	2015	2020
Without new emission standards being implemented	8.8	10.5	10.1
With new emission standards being implemented in 2010	6.3	5.2	5.1

Table 16 Predicted impact of the new standards on NOx emissions from coal-fired power plants in China (MEP 2009b)

Predicted NOx emissions from coal-fired power plants, Mt	2010	2015	2020
Without new emission standards being implemented	10.4	13.1	14.5
With new emission standards being implemented in 2010	10.4	8.0	9.5

For SO_2 emissions, the MEP projections are more encouraging, as shown in Table 15. These suggest that by 2020, SO_2 emissions should be at least 50% lower than would be the case if the new standards had not been introduced. This would be due to a considerable improvement in SO_2 removal efficiency on a proportion of the existing FGD plants, since many of the early units have relatively poor performance (Zhao, 2006).

For NOx, Table 16 suggests that there will be a very significant drop initially as SCR is introduced but that much of the benefit will gradually be lost as newer power plants are continually introduced through to 2020.

It is stressed that these projections are at best very uncertain and are not entirely consistent with subsequent public pronouncements from the MEP (MEP, 2011b). However, they do suggest that, while pollutant levels for dust, SO_2 and NOx will be reduced significantly, it will be very challenging to maintain those lower emission levels over and beyond the next decade.

5 Monitoring, verification and control

It is evident that during the 11th FYP period China made significant progress in reducing fine particulate and SO_2 emissions, particularly from the coal-fired power sector while at the same time reducing energy intensity with the implementation of some very significant initiatives. However, there were many issues with standards and regulations not being implemented, which necessitated the MEP and others to establish new organisational approaches to address such problems. For the 12th FYP period, the MEP is taking the various initiatives further, to ensure effective monitoring and verification, such that acceptable implementation and compliance can be achieved within the coal power and other energy-intensive sectors.

5.1 Resourcing issues

The MEP does not yet have adequate staff in place and lacks a significant technical capacity, especially at the local levels. Consequently, it has drafted in technical experts for advice and assistance from the National Environmental Protection Institute, and other national centres of excellence such as Tsinghua University, Beijing University, Chinese Academy of Environmental Planning, and the Chinese Research Academy of Environmental Science. Such organisations undertake scientific data collection and evaluation, technology assessment, development of emissions inventories, provision of environmental impact assessments, and the recommendation of changes to industrial emissions standards and regulations. They are also working with the provincial and regional authorities in developing air quality plans in line with the MEP guidance (MEP, 2010).

5.2 Operating approach of the MEP

With regard to meeting the specific 12th FYP national targets for water and air (SO_2 and NOx) pollution, this will be administered by the Total Emission Control (TEC) Department of the MEP, which will issue specific subsector control measures. The key to effective implementation will be to ensure that the provincial and local targets within the various subsectors are met. This is the responsibility of the Environmental Supervision Bureau of the MEP, for which the State Government has established regional offices to provide administrative and enforcement support. Currently there are six Regional Environmental Supervision Centres, which cover East, South, North, Northwest, Southwest and Northeast China (RAP, 2011). These centres have eight key functions (MEP, 2010) to:

- supervise implementation of local regulations and standards;
- investigate major pollution and ecological destruction cases;
- serve as an information node between governmental levels;
- handle major environmental disputes across provinces and basins;
- participate in supervision on major environmental emergency responses;
- undertake or participate in law enforcement supervision;
- supervise major pollution sources and MEP project approval for pollution abatement;
- supervise law enforcement in nature reserves.

These regional offices are critical to the MEP achieving its targets since the local and provincial Environmental Protection Bureaus (EPB), which are the primary entities responsible for implementation, are under the authority of the provincial governments. As such, the EPB have strong links to local enterprises, which may compromise enforcement (He, 2011). Indeed the MEP Department of Total Pollution Control relied heavily on the regional offices for monitoring and evaluating incremental progress towards the achievement of China's 11th FYP SO_2 reduction target (RAP, 2011).

5.3 Interactions at provincial and enterprise levels

The 12th FYP includes provision for a continuation of the previous approach to monitoring and verification. Thus career advancement for provincial officials and leaders of state-owned enterprises will be dependent, in part, on them meeting their binding environmental and energy targets. The pollutant emissions and water environmental targets will need to be met while also ensuring carbon intensity is reduced, which will be challenging. At the same time, a priority will be the development of the seven SEI, many of which will help China to achieve its energy and environmental targets. There will be government incentives to initiate and expand both production and energy efficiency initiatives. Although there will be closures of excess manufacturing capacity and curbs on energy-intensive industrial growth, there will be investment in higher efficiency power plant and technological improvements to other industrial processes that should deliver cost-effective economic and environmental benefits within many provinces.

5.4 Controlling and monitoring emissions from the coal-fired power sector

Prior to 2006, the government had limited success in controlling SO_2 emissions, in part due to an evolving approach to control and accountability within the coal power sector. For example, the government offered an enhanced electricity purchase price to those plants that installed FGD. However, this incentive did not fully offset increased operational costs nor did it offset the capital investment. This led to major problems with some power companies not generally operating these units, except when inspections from the MEP were due, and so not meeting emissions standards although they were receiving an enhanced power price (Yale Environment 360, 2010).

During the 11th FYP period, with the [GB13223-2003] standards in place, this control was fine tuned to provide a viable way forward. It included the application of a pollution levy that made it worthwhile to apply FGD (Chen and Xu, 2010), together with the introduction of Continuous Emissions Monitoring Systems (CEMS) and the compulsory transfer of such data to the MEP's regional bureau to allow supervision and auditing (Chen, 2008). These CEM systems provide data on real-time SO_2 emissions so that the MEP can check that the FGD is operating correctly (Li and others, 2010). In addition, a national registry has been created, which lists those plants that have certified FGD equipment in place. These control approaches were complemented with an enhanced pricing mechanism for electricity from FGD-equipped power plants, together with financial assistance by the government in the form of interest-free loan payments for FGD financing. The MEP and NDRC also negotiated agreements with the major power companies and provincial leaders that identified their respective emission targets, obligations for controlling emissions, and the consequences for failure to achieve the targets. Thus by 2007:

- the pollution levy, which applied to total SO_2 emissions while still requiring the power plant owner to meet the emissions limits, reached 1.26 RMB/kg (0.198 US$/kg). This is higher than the estimated average cost of controlling SO_2 emissions from coal-fired power plants (MEP, 2008);
- the price premium of 0.015 RMB/kWh (0.0023 US$/kWh) was introduced for power plants that operated FGD for 90% or more of total electricity generated. At the same time, penalties were introduced of 0.015 RMB/kWh (0.0023 US$/kWh) for plants operating FGD between 80% and 90% of total generation, and 0.075 RMB/kWh (0.0117 US$/kWh) for plants operating FGD less than 80% of the time (Xu, 2011).

In 2007, the MEP and NDRC also introduced a franchising mechanism for desulphurisation, which allowed the power plants to subcontract the installation, operation, and management of the FGD system to specialist companies in exchange for either all or a portion of the price premium (Li and others, 2011).

This co-ordinated approach was quite successful for SO_2 control, as described in Chapter 4.

For the 12th FYP period, the MEP's regional independent inspection centres are now linked to the great majority of power plants that have had CEMs installed to monitor their SO_2/NOx emissions. In addition, these bureaux have access to satellite data that will indicate any significant changes in pollutant levels on a 10 km^2 grid basis. This allows them to check the effectiveness of China's SO_2 emission control measures, by pinpointing large changes in SO_2 emissions from major point sources such as power plants and other energy-intensive industries (Li and others, 2010). With improved technical capacity being established, this combination of CEM and remote monitoring is expected to be extended to NOx emissions on coal-fired power plant.

In order to implement these reforms, the Chinese Government received loans from the Asian Development Bank together with expert assistance from the US Environmental Protection Agency (US EPA), including advice on SO_2 controls, installing and maintaining equipment, and training personnel in monitoring and managing data (Yale Environment 360, 2010).

5.5 Implications of non-compliance

For the 11th FYP period, it is not clear whether the MEP applied severe penalties for non-compliance with meeting the standards and regulations. For example, it is known that in 2010, the MEP fined eight power plants for fraudulent FGD operational reports and, although the level of fines is not public information, it is understood that this is not thought to be a significant deterrent (He, 2011).

However, there is now a strong culture of monitoring, verification and compliance being established. The regional centres have the right to undertake their own monitoring activities at any plant where they suspect any failure to control the emissions. The Department of Total Emissions Control now has the legal right to close the power plant if it cannot meet the new standards and ultimately it can prevent any applications by that operator to receive environmental impact approval for new plant applications. This is seen as a very serious deterrent, especially since any default of the approvals process would provide an opportunity for an alternative company to take over the planning option.

6 Market opportunities to 2020

The new thermal power plant emission regulations and standards will further create a rapidly growing and large market demand in China for improved pollutant control devices on coal-fired units, both for retrofit and new applications. This includes particulates, SO_2, and NOx emissions control, mercury monitoring devices, plus continuous emissions monitoring systems for supervision and verification. From the start of January 2012, when the new standards came in to force, the generating companies will have 30 months to complete the upgrading process while all new plants will require the advanced systems from the start of operations. Although mercury monitoring is expected to be required from the start of 2015, this will require only the installation of equipment plus training in its operation. Consequently, this is not considered further in this chapter, not least since the Chinese stakeholders are focusing on the more pressing needs to address the more comprehensive emissions control and monitoring requirements.

At the start of 2011, the coal-fired power plant capacity was some 687 GWe (21 Tradenet, 2011a), which ranges from small (100–200 MWe), old and inefficient units with limited environmental controls to very large (1000 MWe), modern units with full emission control systems for the removal of particulates, SO_2, and NOx. Discounting the 50 GWe of small capacity intended for closure during the period of the 12th FYP, some 94% of the remainder will require their ESP systems to be upgraded, some 80% will require the FGD system to be upgraded while 92% will need SCR/SNCR to be installed (istockAnalyst, 2011a).

For the long term, should CO_2 capture be introduced, there will be a need at that time to consider how best to integrate the capture process with the existing emission control devices. If the capture process should be based on amine post-combustion scrubbing, then the need to achieve the currently defined very low SO_2 and NOx levels in order to limit amine degradation should be achievable without further upgrading.

There have been numerous provisional capital and operational cost estimates from industry and the MEP, covering both the necessary upgrades to existing plants and the need to ensure all new plants are compliant with the new standards. Some of these estimates are quoted and referenced in the subsequent sections. However, at this stage, there are no definitive estimates, in part due to the sheer scale of what is required and the lack of any firm assessments of the impact this will have on the global market in terms of supply of equipment, materials and services. Consequently, all such information in this chapter must be treated with extreme caution.

6.1 Particulates/fly ash removal and utilisation

The removal of particulates from coal-fired power plants is an area where China already has some market dominance. Equally, due to the sheer scale of operations, China also has the greatest challenge both in terms of fly ash utilisation and disposal.

6.1.1 ESP and bag filters

In China, most ESP are either three-stage or four-stage systems with particulate collection efficiencies of 99.2% and 99.5% respectively. The use of a five-stage system would give a collection efficiency of about 99.7% but the reliability is not assured. It has been suggested that, for existing power plants, the coal power sector will introduce a part bag filter arrangement to top up the collection efficiency of the existing systems to 99.9–99.95%, which has the benefit of improving the collection of particles of less than ten microns in size (for example $PM_{2.5}$). For new plants, the use of a full bag filter arrangement is being considered although this is likely to be an expensive option compared to the alternatives. In any case, where the coal ash characteristics make effective ESP operation difficult, there will also be a need to also install bag filters (Feng, 2010). Certainly, the MEP would like to see bag filters become the norm for fine particulates removal. However, it may well need either additional persuasion or direct command to ensure that the power companies take that step.

China has a very strong domestic ESP production capability and the expectation is that it can handle the necessary improvements, including the possible use of supplementary or full bag filters, using its own technologies and domestic production systems. There should also be scope to maintain and expand its export opportunities.

The major domestic suppliers of ESP, which between them contribute over half of the gross output value of this sector in China, include the Zhejiang Feida Environmental Protection Technology Co Ltd, Fujian Longking Co Ltd, Shanghai and Mining Machinery Manufacturing Factory, China Tianjie Group Co Ltd, and the Lanzhou Electric Power Building And Repairing Factory (Pollution Engineering, 2010). With regard to bag filters, some 80% of the suppliers are small domestic enterprises. The major suppliers for power plants are the Jiangsu Xinzhong Environmental Protection Co Ltd, Zhejiang Feida Environmental Protection Technology Co Ltd, Fujian Longking Co Ltd, and the Wuhan Kaidi Electric Power Environmental Co Ltd. Some of these larger Chinese companies are co-operating with international companies and many of the international suppliers of filter media and bags have invested in manufacturing facilities in China for export applications (Pollution Engineering, 2010).

6.1.2 Particulates/fly ash utilisation

In China, combustion of one tonne of coal produces about 0.3 tonnes of particulates/fly ash, most of which is captured in the ESP and/or bag filters. The annual collection rate reached 380 Mt in 2010, making it China's single largest source of industrial solid residue. While there are standards in place covering the choice of storage location and of measures to be taken to prevent wind dispersal, leakage and run-off, these are not rigorously enforced to limit air, water, and soil pollution (Reuters, 2010).

At the same time, safe and effective utilisation of the ash would be the preferred way forward and the drive is to determine cost effective means of utilisation for added value applications. Development of the potential market for recycling was encouraged in 2008 with the introduction of a new Circular Economy Law. However, this potential has not been adequately realised due to inconsistent standards and utilisation requirements, lack of strong government incentives, and limited encouragement for international companies to become involved.

Currently recycling of fly ash is focused on its use for building applications, road construction and agricultural uses, with as much as possible of the ESP particulates directed to cement manufacturing plants. Government statistics suggest that the proportion used is up to 67%, although such numbers have not been verified. Work is under way to develop processes for achieving better added value through the extraction of metals from the ash. There are several emerging technologies for the extraction of alumina, cenospheres and carbon from recovered fly ash. One demonstration project in Inner Mongolia aims to extract up to 600,000 tonnes of alumina, which can then be used to produce aluminium (Northeastern University, 2010). Should such processes prove financially viable, which is questionable under the current conditions, this should encourage a more comprehensive approach to fly ash use.

6.2 FGD

At the end of 2010, about 86% of the coal-fired plants available for operation included SO_2 removal systems (MEP, 2011b). The overwhelming majority of systems installed to date are the wet limestone-gypsum FGD process (Wang, 2010), accounting for some 90% of that capacity, the remainder mostly comprising seawater desulphurisation (3%) for those coastal plants where the coal sulphur content is less than 1%, dry FGD for use on units smaller than 200 MWe (2%) where the coal sulphur content is less than 1%, ammonia desulphurisation (2%), and a CFB scrubber system (1%). The new emission limits will require SO_2 removal levels up to 95–97% and so, apart from for plants in coastal locations and those where very low sulphur coal use (for example at plants that use imported coal) can be guaranteed, wet limestone FGD will be the favoured system both for new and retrofit units. Because of the water availability concerns in Northern China, measures will have to be taken to minimise water usage through recycling.

6.2.1 Likely opportunities

With the continuing introduction of new coal-fired plants through to 2020, all will have to include FGD. There will also need to be FGD fitted on any remaining existing plants that are not scheduled to be closed. At the same time, some 80% of existing FGD units will need to be upgraded in order to meet the new SO_2 emissions control requirements (Market Research, 2010). This suggests that there will be a need for FGD to be installed on some 275–380 GWe new plants, retrofitted on about 70 GWe of existing plants plus upgraded on approximately 470 GWe of existing plants. In the latter case, this will not only be to meet the tighter emissions limits but also to improve the quality and reliability of early installations where the equipment does not meet current standards (Wang, 2010).

For completeness, it should be noted that while the current focus of opportunities is in the coal-fired power sector, in 2010 this was widened by the government with their declared intention to limit emissions from other large, energy-intensive coal processes together with metal processing and manufacturing systems (China Greentech Initiative, 2011).

On the basis of past experience, Chinese equipment and service suppliers are likely to capture the great majority of sales opportunities. At the same time over half of the market will be controlled by state-owned enterprises (SOE), namely the big five power companies and other major energy groups such as the Shenhua Corporation (Minchener, 2010). These SOE have subsidiary companies in these markets and so can determine who will supply the various products to their particular power plants.

Chinese production costs are lower than international suppliers, in part because of the lower domestic manufacturing costs base. Since 2000, capital costs for adding FGD in China have fallen from 800–1200 RMB/kW (126–189 US$/kW) to 200–250 RMB/kW (31–39 US$/kW) (Yue, 2011). This reflects the benefits of economy of scale, with some 550 GWe of power plant capacity fitted with FGD in that time period. The other major factor that has contributed to this fall in costs is that most Chinese designs now use more synthetics and less metal alloys than European or USA alternatives. The use of fibre reinforced plastics for large-scale piping and containment vessels is preferred because it is lower cost and more readily available than high alloy stainless steels, which must be imported (Reinforced Plastics, 2009, 2010).

The other point to note is that these average costs will have been distorted to some extent since some Chinese services companies have won contracts by bidding below true cost, with attempts to then supply inferior and inadequate quality products. Subsequently, this results in higher retrofit component costs due to system failures and lack of reliability.

6.2.2 Likely technology suppliers

The introduction of FGD to China has mirrored that of introducing advanced coal-fired plants (Minchener, 2010). Thus the NDRC supported the introduction of international technologies, the

Table 17 Major Chinese FGD suppliers at the end of 2008 (Mao, 2009; Reinforced Plastics, 2009, 2010)

Company	Contracted FGD capacity, GWe	FGD capacity in operation, GWe	Product range as a percentage of company FGD sales
Beijing Guodian Longyuan Environmental Engineering Co Ltd	68.8	39.7	Limestone scrubber (89.9) Sea water FGD (9.9) CFB-FGD (0.2)
Beijing Boqi Electric Power Science & Technology Co Ltd	52.5	32.9	Limestone scrubber (100)
Wuhan Kaidi Electric Power Environmental Protection Co Ltd	49.7	34.3	Limestone scrubber (90) CFB-FGD (10)
Fujian Longking Environmental Protection Co Ltd	42.4	18.0	Limestone scrubber (72) CFB-FGD (28)
CPI Yuanda Environmental Protection Engineering Co Ltd	41.8	20.7	Limestone scrubber (99) CFB-FGD (1)
Zhejiang University Insigma Mechanical Engineering Co Ltd	39.3	22.2	Limestone scrubber (100)
Tsinghua Tongfang Environment Co Ltd	26.9	16.1	Limestone scrubber (100)
Shangdong Sanrong Environmental Protection Engineering Co Ltd	26.4	19.1	Limestone scrubber (95) CFB-FGD (5)
China Huadian Engineering Co Ltd	23.7	14.3	Limestone scrubber (100)
Zhejiang Tiandi Environmental Protection Engineering Co Ltd	19.1	16.4	Limestone scrubber (99) Sea water FGD (1)
Jiangsu Suyuan Environmental Protection Engineering Co Ltd	18.9	13.7	Limestone scrubber (100)
China Datang Technologies & Engineering Co Ltd	18.3	12.1	Limestone scrubber (100)
Beijing SPC Environmental Protection Tech Co Ltd	12.0	10.8	Limestone scrubber (100)
Guizhou Xingyun Environmental Protection Co Ltd	8.4	8.4	Limestone scrubber (100)
Zhejiang Feida Environmental Protection Technology Co Ltd	7.2	5.1	Limestone scrubber (76) NID FGD (24)
Beijing Langxinming Environmental Protection Technology Co Ltd	6.9	5.5	Limestone scrubber (100)
Guangzhou Tianci Sanhe Environmental Protection Engineering Co Ltd	6.7	4.4	Limestone scrubber (67) Double alkali FGD (17) Spray dry FGD (16)
Zhenjiang Atmosphere Environmental Protection Group Co Ltd	6.6	4.0	Limestone scrubber (95) CFB-FGD (5)
Shandong Electric Power Engineering Consulting Co Ltd	4.8	4.0	Limestone scrubber (96) CFB-FGD (4)

Table 17– Continued			
Company	Contracted FGD capacity, GWe	FGD capacity in operation, GWe	Product range as a percentage of company FGD sales
Shandong Electric Power Engineering Consulting Co Ltd	4.8	4.0	Limestone scrubber (96) CFB-FGD (4)
Hunan Yonker Desulfurization Co Ltd	4.6	4.0	Limestone scrubber (100)
Wuhan Jingyuan Environment Engineering Co Ltd	3.9	3.9	Sea water FGD (100)
China Lantian Env Environmental Engineering Co Ltd	3.2	2.2	CFB-FGD (100)
Sichuan Hengtai Environmental Technology Co Ltd	3.2	1.3	Limestone scrubber (92) Double alkali FGD (8)
Jiangsu Century Jiangnan Environmental Protection Co Ltd	3.2	1.9	Ammonia FGD (100)
Zhangjiagang Xinzhong Environmental Protection Equipment Co Ltd	2.8		Limestone scrubber (100)
Shandong Shanda Energy & Environment Co Ltd	2.5	2.1	CFB-FGD (69) Limestone scrubber (31)
State Power Environmental Protection Research Institute	2.5	2.5	Limestone scrubber (100)
Dongfang Boiler Group Co Ltd	2.2		Limestone scrubber (100)

suppliers of which have established co-operation agreements and licensing arrangements with Chinese manufacturers, to ensure market share and to take advantage of lower manufacturing costs. The majority of licensors are from Japan, Europe and the USA and include Alstom, Babcock & Wilcox, Babcock Power, Mitsubishi, Hitachi, Marsulex, Fisia Babcock, Austrian Energy & Environment, and Chiyoda. These companies also supply critical components to Chinese companies in some cases.

In the period 2005-10, Chinese companies secured the majority of FGD applications within China to dominate the market and are now expanding activities into overseas markets. Table 17 lists those FGD suppliers in 2008 that had each achieved a total contracted capacity in excess of 2 GWe equivalent, together with information on their total capacity in operation and their product ranges.

6.3 NOx control

The new emission standards have created a potentially enormous market for de-NOx equipment and service providers, which will offer significant opportunities for Chinese companies in collaboration with international technology suppliers.

6.3.1 Likely opportunities

All coal-fired power station boilers that have been installed since 2003 are equipped with low NOx burners while the installed capacity of catalytic de-NOx systems at the end of 2010 was 58 GWe, which is about 8% of the total coal-fired capacity (21 Tradenet, 2011a). All but two percentage points of this comprised SCR rather than the less efficient but cheaper SNCR. Consequently, the drive will be to install SCR as the required technology option (21 Tradenet, 2011a). Because there are so many existing power plants without NOx control systems and because China continues to lead the world in construction of new power plants, this will become the largest NOx control market over the next decade.

For the period to 2020, the MEP has predicted that:
- by end 2015 some 817 GWe of existing and new capacity will have to add SCR/SNCR de-NOx equipment;
- by 2020 with capacity increasing possibly to 1065 GWe, a further 190-200 GWe of new capacity will also require such equipment.

There is also the expectation that, in time, strict NOx emission standards will be applied to the iron and steel, non-ferrous metals, chemicals, and building materials industries, which will represent a substantial expansion of the market.

As part of the projection to 2020 (istockAnalyst, 2011a), the MEP estimated that:
- the market potential to 2015 for design, production, supply and installation of de-NOx systems on existing and new coal power capacity will be some RMB195 billion (US$31 billion) with annual operating costs of RMB61 billion (US$9.6 billion); and
- by 2020 this cumulative market potential will be RMB 233 billion (US$37 billion) with annual operating costs of RMB80–90 billion (US$12.6–14.2 billion).

These estimates are, at best, tentative and are assuming the majority of the costs are incurred within China, which may not be viable, as discussed below.

6.3.2 Likely technology suppliers

Initially all the technology came from international suppliers but now there are several experienced Chinese system companies that can provide core equipment and technical support. Examples of such international suppliers and established Chinese counterparts are given in Table 18. The majority of the latter companies are already active in the FGD market and they have been joined by the three major power plant engineering companies as all see opportunities for complementary expansion of their business activities.

Babcock and Wilcox (USA) and IHI (Japan) have already established joint ventures with their partners to provide local manufacturing facilities together with NOx control support services (Wang, 2010). LLB (Germany) and Cormetech (USA) have established local operations with Dongfang and CPI Yuanda respectively.

There is also a rapidly growing Chinese catalyst manufacturing capability, with the major suppliers including Chengdu Dongfang KIWH Environmental Protection Catalysts Co Ltd and the Sino-Environment Technology Group Ltd (FECC, 2010).

It has been estimated that for the period to 2015, the annual NOx catalyst market demand will be close to 60,000–80,000 m^3. At the end of 2010, the domestic production capacity (including joint ventures) was below 50,000 m^3. While Chinese manufacturing capacity will increase rapidly, there would appear to be a need for some direct import of catalyst to provide the balance. However, beyond 2015,

Table 18 Examples of international suppliers and Chinese counterparts for NOx control equipment and services (ChinaGreentech Initiative, 2011; Pollution Solutions, 2011a)

International suppliers	Chinese service provider partners
FBE, Germany	Guodian Longyuan
BHK, Japan	Datang Technologies
Babcock & Wilcox, USA	Zhejiang Tiandi
Cormetech, USA	CPI Yuanda
Topsoe, Denmark	Fujian Longking
TKC, Italy	Tongfang Environment
Mitsubishi, Japan	Huadian Engineering and Harbin Boiler
LLB, Germany	Dongfang Electric
IHI, Japan	Shanghai Electric Corporation

demand for catalyst for new applications will decline as the number of new coal-fired plants is expected to decrease and that potential for direct import is then expected to diminish.

The markets for catalyst regeneration and replacement are presently very small in China because the few installations already in place are less than five years old. However, in the longer term, 2020 onwards, China will represent the largest regeneration and replacement market.

At the same time, it should be noted that while SCR is a mature technology that achieves a high NOx removal rate, it uses an expensive catalyst (currently RMB50,000 (US$7700) per cubic metre). Consequently, China is actively seeking to develop integrated de-SOx and de-NOx technologies, in order to reduce upfront investment costs, increase removal rates and streamline operational management (Pollution Solutions, 2011b). There are also ongoing activities to incorporate mercury capture into such systems (Ma, 2011).

6.4 Monitoring and verification equipment

Ultimately, once emission limits have been set and the necessary control equipment has been installed, meeting any operational implementation challenges becomes the critical requirement. In that regard, there will be a continuing demand for CEM to be installed both on new plant and the existing plant not scheduled for closure where such equipment has not yet been included.

6.4.1 Likely opportunities and market value

In the period through to 2020, CEM will be needed on at least some 275–380 GWe new and some 280 GWe existing coal-fired power plants. In terms of value, the 2012 global estimate for stack gas CEMs, including the analysers, software and accompanying service revenues, is about RMB6.4 billion (US$1 billion), with the projection that the market in China will be greater than that for the EU and the USA combined (Environmental Expert, 2011).

6.4.2 Likely equipment suppliers

There is a wide range of international and Chinese equipment suppliers, with the Chinese-built products offered at 15–20% less than the average global price (Altprofits, 2011).

6.5 Global considerations

From a global perspective, in the period to 2020, investment in emissions control and monitoring equipment for coal-fired power plants will account for more than all other coal-based industries combined, and the market will be dominated by China and to a lesser extent India (Market Research, 2010). For ESP, FGD and de-NOx SCR systems for coal-fired power plants, China will represent 90%, 53% and 90% of the total market respectively. For CEM, it will also be a major purchaser of equipment (Pollution Engineering, 2010).

Consequently, this major Chinese environmental initiative will lead to a fundamental shift in the market for power plant air pollution control systems. In particular, Chinese coal power capacity in 2010 was just under 700 GWe. By 2020, it will be at least 960 GWe, possibly 1065 GWe as there is inevitably some uncertainty in the future growth of this sector, as indicated in previous chapters. Thus, on a conservative basis, for FGD systems in the decade up to end 2010, China had installed FGD on close to 590 GWe coal-fired power capacity and so by 2020 this could rise to at least 960 GWe. For the rest of the world, the total installed capacity is some 380 GWe on coal-fired power plants since 1980. China also expects to install SCR on all that coal-fired power plant capacity by end 2020. The rest of the world has installed about 300 GWe of SCR systems since 1980 (Environmental Expert, 2009).

Such a demand will totally overload existing international suppliers, which has already led to Chinese companies establishing co-operation agreements with international organisations in order to set up domestic manufacturing capacity.

In these situations, China's demand will dominate the global markets. Costs over the next decade will most likely rise due to Chinese demand for resources outstripping global supply, leading to overall shortages in materials for components (for example catalysts for de-NOx and a wide range of components for FGD). However, in the longer term when the enormous need for advanced pollution control systems on the Chinese coal fleet has been met, there will be some major Chinese suppliers entering the global market, which will decrease prices (Environmental Expert, 2009). Chinese companies are already the world's leading suppliers of ESP, while ten of their companies are among the twenty largest FGD suppliers (Pollution Solutions, 2011b).

7 Comparison with the EU and the USA

An overview is provided of the recent coal power emissions legislation and standards in the EU and the USA, and comparison made with the new requirements in China.

7.1 EU legislation and standards

There are two main directives and one impending directive which are relevant to coal-fired utilities in the EU member states. The Integrated Pollution Prevention and Control (IPPC) Directive and the Large Combustion Plant Directive (LCPD) will both continue to apply until the new Industrial Emissions Directive (IED) comes into force in 2016. However, in terms of the emissions limits for coal-fired plant, the IED encompasses the key aspects of the two current directives and so the focus in this report will be on that particular piece of legislation.

7.1.1 Integrated Pollution Prevention and Control

The EU IPPC Directive (2008/1/EC) provides an integrated environmental regulatory approach that applies to some 45,000 industrial facilities, including large combustion plants. It is based on a plant-specific permit which details the requirements relevant to each individual facility and can therefore take into account not only any international and national requirements but also regional and local considerations such as the preservation of sensitive watershed areas. Each installation must obtain a permit that contains emission limit values (ELV) and other conditions based on the application of best available techniques (BAT) to minimise emissions of pollutants likely to be emitted in significant quantities to air, water or land. There is also a need to address energy efficiency, waste minimisation, prevention of accidental emissions and site restoration (DEFRA, 2011).

In general, for plants with a capacity greater than 500 MWth, the minimum BAT requirements under IPCC are as follows (Adams, 2006):

Table 19 BAT requirements under the IPPC Directive (Adams, 2006)

Requirement	Existing plant	New plant
Efficiency, % net, LHV basis	36–40	43–47
Particulates, mg/m^3	5–20	5–10
SO_2, mg/m^3	20–200	20–150
NOx, mg/m^3	90–200	90–150

With regard to technologies, the BAT options comprise:

- Particulates: either ESP (99.5% efficiency) in combination with wet FGD, or baghouses (fabric filters) (99.95% efficiency) in combination with wet FGD;
- SO_2: either low sulphur fuel, wet FGD spray dry FGD, seawater FGD or a combined SO_2 and NOx control system;
- NOx: either primary measures (air/fuel staging, low NOx burners, reburn) in combination with SCR (or SNCR in some cases), or a combined SO_2 and NOx system.

From a practical perspective most, if not all, large units in Europe will install some form of FGD system. For NOx, the situation is less clear cut since NOx emissions are not directly related to the nitrogen content of the coal, in the same way that SO_2 emissions are related to its sulphur content, due to some NOx being formed from N_2 in the combustion air. New technologies for NOx control such as dry-low NOx systems or new combustion controls are still being developed which means that the market place for NOx systems is more volatile than that for SO_2 control systems (Robinson, 2007).

The listings above are also overly simplistic. The actual selection of which technology to retrofit to each plant is based on a study of the IPPC directive to determine how it applies to each unit individually. The definition of BAT is open to interpretation and therefore the European Commission (EC) has published BREF – BAT reference documents. These are large and detailed documents, which provide a selective review of the many techniques and technologies that could be considered as BAT. They may not be representative as they concentrate on 'best ever' levels of emissions from isolated cases rather than analyses of the wide range of feasible performance characteristics over different plants in different situations (Tsadari, 2006).

The problems with the IPPC directive were evident even before its launch and by March 2006, in the 18 member states involved, only 43% of the installations covered by the directive had completed the application process and been granted permits (Tsadari, 2006).

7.1.2 Large Combustion Plant Directive

The revised Large Combustion Plant Directive (LCPD 2001/80/EC) applies to combustion plants with a thermal output of greater than 50 MW. The requirements vary depending on whether it is either a new or existing plant, the definition of which is that (Sloss, 2003):

- existing plants are those licensed before 1 July 1987;
- new plants are those licensed after 1 July 1987 but before 27 November 2002 (and operational before 27 November 2003); while
- new-new plants are those licensed after 27 November 2003.

According to the directive, owners of all large combustion plants in Europe had to opt for one of the following compliance options by 1 January 2008, to:

- meet ELV for particulates, SO_2 and NOx;
- sign up to lower SO_2 and NOx 'bubbles' that are equivalent to the ELV reductions (*see below*) and which are part of a National Emission Reduction Plan (NERP); or
- opt out of ELV and NERP and commit to close by 2015 while operating for no more than 20,000 hours over that period.

In order to meet the LCPD emission requirements, in practice, it means that a coal-fired power plant would need to have FGD installed with combustion modifications to reduce NOx.

Within Europe as a whole, almost 25 GWe of coal units and 10 GWe of lignite units will not be fitted with FGD, particularly in Western Europe because the owners chose to opt-out of the LCPD (Kramarchuk and Brunetti, 2008). Such plants were deemed to have been opted-out and would have been limited to a total operation of 20,000 hours before the end of 2015 after which the owners would have had the choice of (Adams, 2006):

- closure;
- refurbishment to extend life and to meet LCPD requirements by retrofitting required technologies;
- installing supercritical or advanced supercritical pulverised coal plant;
- installing supercritical FBC (fluidised bed combustion) plant;
- installing IGCC (integrated gasification combined cycle) plant.

The last three options would require either the installation of a new plant at the old site or an upgrading of the existing plant. These requirements have now been superseded by the IED and the timeline extended (*see below*).

7.1.3 Industrial Emissions Directive

In 2007, in recognition that the EU legislation was both piecemeal and confusing, the EC merged seven different directives into the Industrial Emissions Directive (IED) which was published in December 2010. These were (DEFRA, 2011):

- the LCPD;
- the IPPC;
- the Waste Incineration Directive;
- the Solvent Emissions Directive; and
- the three existing directives on titanium dioxide covering disposal (78/176/EEC), monitoring and surveillance (82/883/EEC) and programmes for the reduction of pollution (92/112/EEC).

For coal-fired plants, the IED is effectively a combination of the IPPC and LCPD with a specific permit for performance based on a combination of BAT and ELV. As with the original LCPD, the IED allows the same three options for compliance, namely the ELV, the NERP (now referred to as the National Action Plan) and opt-out.

For the ELV option, the limits for coal-fired power plants, which have to be met by 1 January 2016, are set out in Tables 20 and 21.

Table 20 Dust emission limits for coal, lignite and other solid fuel fired power plants (Sloss, 2009)

Plant size	Dust emission limit, mg/m^3	
	Permit issued before end 2012	Permit issued from start 2013
50–100 MWth	30	20
100–300 MWth	25	20
>300 MWth	20	10
Stack standard conditions: 273.15 K, 101.3 kPa, 6% O_2		

Table 21 SO_2 emission limits for coal, lignite and other solid fuel fired power plants (Sloss, 2009)

Plant size	Dust emission limit, mg/m^3	
	Permit issued before end 2012	Permit issued from start 2013
50–100 MWth	400	400
100–300 MWth	250	200
>300 MWth	200	150
Stack standard conditions: 273.15 K, 101.3 kPa, 6% O_2		

For those plants granted a permit before 2003 and operating for less than 1500 hours per year (rolling average over five years), the emission limit is 800 mg/m^3.

For those plants, which cannot meet the prescribed ELV due to specific fuel characteristics, there is still the option of meeting a minimum rate of desulphurisation (*see* Table 22).

For those plants firing for less than 1500 hours per year (rolling average over five years; 'opted-out' plants), the emission limit is 450 mg/m^3 (*see* Table 23).

Under the National Action Plan option, during the period from 1 January 2016 to 30 June 2020, Member States may draw up and implement a transitional national action plan which allows flexibility

Table 22 Desulphurisation rate for plants firing a challenging fuel (Sloss, 2009)			
Plant size	Required desulphurisation rate, %		
	Permit issued before 27 November 2012	Permit issued before end 2012	Permit issued from start 2013
50–100 MWth	80	92	93
100–300 MWth	90	92	93
>300 MWth	96	96	97

Table 23 NOx emission limits for coal, lignite and other solid fuel fired power plants (Sloss, 2009)				
Plant size	NOx emission limit, mg/m^3			
	Permit issued before end 2012		Permit issued from start 2013	
	Coal	Lignite	Coal	Lignite
50–100 MWth	300	450	300	400
100–300 MWth	200	200	200	200
>300 MWth	200	200	150	200
Stack standard conditions: 273.15 K, 101.3 kPa, 6% O_2				

and co-operation between several plants to maintain emissions below the prescribed combined limit. This is the same as the NERP option under the LCPD but with a longer time schedule allowed.

Under the opt-out scheme, plants may be exempt from the ELV and National Action Plan requirements if they agree to:
- operate for no more than 17,500 hours between 1 January 2016 and 31 December 2023 (a more relaxed timescale than the LCPD);
- report hours of operation on an annual basis;
- maintain ELV prescribed in the plant permit on 31 January 2015 for the remaining operation period of the plant.

The IED carries with it requirements for continuous emission monitoring of particulates/dust, SO_2 and NOx. Although the IED does not set an ELV for mercury from coal-fired utilities, it does introduce a requirement for annual monitoring of mercury emissions.

In summary, the timescale for compliance with the IED is much longer and therefore more lenient than that of the original LCPD and will mean that many countries in the EU will have less compliance issues than they had previously. However, the IED is still a major challenge to many utilities as it is setting requirements and limits that will result in the application of FGD and de-NOx technologies across most plants by 2016 and across the complete fleet of coal-fired power plants in the EU beyond 2023, when all opted-out plants must close.

7.2 USA legislation and standards

Legislation in the USA has evolved over time in a piecemeal fashion, which has resulted in a combination of emission limits, reduction targets and trading allowances. There are often significant differences from region to region, which mean that the permits for plants in the USA are likely to be significantly more varied and site-specific than those in the EU. For individual plant operators the decision on whether to retrofit flue gas control technologies has not been as clear cut as it is in the EU. The use of trading in the past has meant that the rate of adoption of FGD and SCR systems in the USA is not as high as it is in Europe.

Where the EU has BAT, the USA has BACT (best available control technology) and MACT (maximum achievable control technology) requirements for pollution control. The term BACT is used in attainment zones when dealing with major pollutants (for example particulates, SO_2 and NOx) while MACT is used when dealing with hazardous air pollutants. In a non-attainment zone where the air quality standards are not being met, the term LAER (lowest achievable emission rate) applies since plants must still minimise their emissions even though they cannot comply with the standards (Sloss, 2003).

7.2.1 CAAA, NAAQS and NSPS

The US Clean Air Act Amendments (CAAA) of 1990 set emission limits for particulates, SO_2 and NOx for certain plants and revised existing limits for others. Individual states within the USA adopted these emission standards under a State Implementation Plan (SIP). Individual utilities could comply with the rule by meeting annual emission limitations at each facility or on average for a group of facilities, or by applying for a less stringent alternative emission limit if the required control technology did not adequately reduce the emission level (Swisher and McAlpine, 2006).

In the past, the USA has favoured the use of emissions trading to control emissions of SO_2 and NOx. SO_2 trading was first included under the 1990 CAAA whereas NOx trading was introduced later. Phase 1 allowed plant operators to choose between either installing FGD or switching to a low sulphur fuel. At that time, the deregulation of the railway industry lowered the cost of transportation significantly and this meant that the use of, for example, Powder River Basin low sulphur coals was a significantly more economic option than the installation of FGD. However, now that the emission legislation has tightened further under Phase II, fuel switching is no longer the best option on many plants since few coals have a sulphur content low enough to ensure compliance with the new standards (Lewandowski and others, 2004). Consequently, since the early 2000s, there has been a move towards increased installation of FGD, either as part of the CAAA or as a result of regional requirements.

Table 24 Overview of NSPS emission requirements for a pulverised coal fired power plant (Krause and Rosenquist. 2001)

Pollutant	NSPS	Probable BACT/LAER emission limit	Typical BACT/LAER control technology	Typical BACT/LAER control efficiency
TSP or PM_{10}	99% removal and 13 mg/MJ (TSP)	4–7 mg/MJ (PM_{10})	fabric filter/ESP	>99.5% (PM_{10})
SOx	70–90% removal and 260–4420 mg/MJ	52–87 mg/MJ	medium-low sulphur coal	90–95% FGD
NOx	65 mg/MJ	22–44 mg/MJ	SCR with LNB	50–90%
CO	–	44–65 mg/MJ	combustion control	n/a
VOC	–	13–22 mg/MJ	combustion control	n/a

Emission limits are based on recent BACT determinations for coal-fired units and on the known capabilities of currently available emission control technologies

For NOx control, while the trading approach has been broadly similar, the NOx allowance scheme varies not only from state to state but also from season to season with the amount of allowances being reduced during those periods where seasonal ground level ozone is a problem. The market is therefore complex and volatile (Environmental Finance, 2005).

The national air quality standards (NAAQS) are set by the US EPA for the control of particulates, SO_2, NOx, ozone and CO (Krause and Rosenquist, 2001). States that exceed the NAAQS for one or more pollutant are required to include in their SIP details of how they will meet the standards within three years, which can mean the need to take action over and above that which would be required by the national legislation (Schultz, 2008).

The requirements under the NSPS are not as stringent as BACT in most cases. The standards have no incentives for modifications and technology improvements (Li, 2002). If NSPS is applicable to a unit then it must apply BACT to reduce emissions. However, if the unit is located in a non-attainment area, the unit must comply with LAER instead of BACT (Krause and Rosenquist, 2001). LAER is defined as either the most stringent emissions limitation contained in the state rules for such class or category of source or the most stringent limitation achieved in practice by such class or category of source anywhere (Daves, 2002). Since BACT includes an economic factor, permitting agencies have some discretion to adjust emission limits. However, economic factors are not considered when determining LAER so emission limits would generally be at the lower end of the range of emission limits summarised in Table 24.

7.2.2 CAIR and CAMR (now vacated)

Two new rules proposed by the US EPA, have been abandoned (vacated) leaving those plants which had opted to make an early move towards compliance with the decision as to whether to continue to retrofit control technologies on the assumption that they will comply with subsequent new legislation, or to wait until further rules are approved. These are the Clean Air Mercury Rule (CAMR), which was designed to reduce mercury emissions from coal combustion significantly within the next decade, and the Clean Air Interstate Rule (CAIR), which aimed at further reducing emissions of SO_2 and NOx, via trading. Both have been replaced by the new Air Toxics Rule, which is considered below.

7.2.3 The new Air Toxics Rule

The new Air Toxics Rule was proposed in March 2011 with the final rule published on 21 December 2011, and a compliance period that will run for three years from that publication date. This is based on MACT and the US EPA must set ELV that are at least as stringent as the emission reductions achieved by the average of the top 12% best controlled sources for the relevant source categories.

The rule concentrates on several air toxics: mercury, acid gases (HCl surrogate for all acid gases, with an alternate surrogate of SO_2), non-mercury metallic toxic pollutants (such as arsenic and chromium, with either total metals or total particulate matter as surrogates), and organic air toxics (including dioxins) (US EPA, 2011). The limits are challenging and, for example, the emission reduction rate for mercury will mean the requirement for investment in specific, and potentially costly, mercury control technologies at many plants. It is likely that construction of many new plants will be put on hold until further advancements in control technologies are achieved.

7.2.4 Regional legislation

In addition to national legislation, individual states may elect to set their own standards and targets, provided it is either as strict or stricter than the national legislation. Like all major sources, coal-fired units are subject to restrictions arising from the local ambient air quality standards, as well as the NAAQS.

7.3 Implications

It is evident that China has learned extensively from interaction with OECD environmental regulators, and this has assisted the State Government in establishing their own approach. However, unlike in the EU and the USA where coal use is either stagnant or in decline, China has to continue to develop this regulatory system since coal use is expected to show significant increases in the period to 2020 and probably beyond, and as such there will be continuing environmental issues arising. This was indicated in the MEP's forward projections, which show that implementation of the new standards will result in near term absolute reductions in the key non-GHG emissions but that in about ten years some of the benefits will be eroded due to ongoing introduction of additional coal-fired capacity.

It is interesting to note that in many aspects, such as SO_2 and NOx, the Chinese emissions standards from coal-fired plant are tighter than those in, say, the EU and the USA, both in terms of emission levels and in the timescale for implementation. In contrast, in the EU and the USA, the rigour for ensuring the standards are met and the penalties for non-compliance are tougher, at least compared to those applied in China during the period of the 11th FYP. However, as has been considered in Chapter 5, China has taken advice from the USA and others to establish a much stronger monitoring, verification and control approach to be applied during the period of the 12th FYP.

8 Conclusions

It is important to recognise that the tightening of emissions standards in the power sector, although it will have major ramifications for industry over the next decade, is only one part of a bigger and longer-term effort by the State Government to establish energy-efficient and environmentally-friendly industries across all the traditional energy-intensive sectors, while creating self-reliant and innovation driven growth, and encouraging more balanced regional development. This requires a co-ordinated approach between the various commissions, administrations and ministries together with adjustments to the command and control policies for emissions limitation.

8.1 Rationale and guiding principles

While China has established the world's second largest economy, this has been achieved in part through the rapidly increasing use of coal to underpin growth in GDP and, as a consequence it has become both the biggest energy-using nation in the world and a major emitter both of greenhouse gases and fine particulates, SO_2 and NOx (IEA, 2010). The non-GHG emissions have resulted in severe air pollution problems, with acid rain across large regions of Southern China, while, in cities throughout the country, the air pollution levels are high, with 90% of those assessed failing to meet WHO health-based standards. Such problems have a major impact on the overall economy, with various estimates suggesting that the annual cost of pollution to the economy is in excess of 3% of GDP (Bloomberg News, 2010). There is also an increasing concern being voiced in the national media, which notes that quality of life is an important factor to be considered and that growth at all costs should no longer be considered an acceptable way forward (China Daily, 2011e). As a consequence, the government has put in motion a series of initiatives that are based on various guiding principles to ensure full implementation of the energy and environmental objectives, which were initiated during the 11th FYP and will be taken forward during the 12th FYP and beyond.

Thus, as discussed in Chapter 2, there are strategic targets to achieve much better air quality standards throughout China, but particularly in the cities and key developed regions. This requires both the reduction of emissions of concern from large energy-intensive processes together with a better understanding and better assessment of air quality via the national indices. In order to address these issues, the MEP, in conjunction with the NDRC and others, has reviewed the validity of the current approach to emissions control.

In China, the environmental regulatory structure is pollutant-specific, with enforcement of environmental-performance standards (for example command-and-control) for the discharge of pollutants rather than their creation. Thus, water, air, solid and hazardous wastes and noise pollution are each addressed by separate laws, each with their own standards including concentration-based discharge limits for air and water pollution (Chinadialogue, 2011b). This approach can be relatively effective at reducing pollutant loads if the requirement is either constant or growing at a slow pace. However, for China, where the coal-fired power capacity has tripled since 2000, as part of the economic expansion, the levels of non-GHG emissions have either risen strongly (for example NOx) or at best been contained through a massive introduction of FGD for SO_2 control with add-on benefits in terms of particulates control. Consequently, in order to combat these problems, while China is tightening the individual emissions limits as part of the continuing command and control policy, it is also continuing to adjust its regulatory structure by introducing national caps on the total discharge of certain pollutants, for example SO_2 as seen in the 11th and SO_2 and NOx in the 12th FYP (Chinadialogue, 2011b) as well as pursuing a rigorous energy efficiency improvement programme.

For the future, China has indicated that it may well introduce the basis for either large regional or national markets to be created by a cap-and-trade system on both conventional non-GHG pollutants and CO_2 emissions (Minchener, 2010). So far, there have been some pilot projects to test market-based variations on the traditional command-and-control models, including experimental SO_2 trading programmes that have involved power plants with emissions-monitoring devices sophisticated enough to support the creation of such a scheme.

There is also considerable effort being applied to methods to:
- ensure central and local co-ordination of all the initiatives, including the introduction of incentives for local governments and firms to embrace clean energy;
- implement realistic levies, taxation and pricing to ensure appropriate use of emissions control devices;
- introduce effective supervision mechanisms;
- demonstrate that targets are a State Government leadership priority;
- work co-operatively between ministries to alleviate conflicting priorities of economic growth and environmental protection;
- adapt policies over time to integrate lessons from policy experiments.

As an example of the latter point, China has learned a lot from its programme to have FGD fitted and properly used on coal-fired power plants during the period of the 11th FYP. The interaction between external advice, policy, regulations, institutions, and technology provided many encouraging ideas for China's future environmental policy and management (Yale Environment 360, 2010). These have been developed further in order that the MEP will be ready to undertake effective monitoring, verification and control during the 12th FYP.

It is now a government priority to combine environmental protection with economic development, for which the latter will be achieved with regional targets to enhance economic development in the central and less developed western regions. By 2015, this is expected to lead to a joint prevention and control system for atmospheric pollution, as a means to better air quality in line with the strategic targets.

Linked in to emissions control will be the prevention of emissions in the first place, through much stronger environmental impact assessments being established for regional industrial development planning, to avoid overcapacity in energy-intensive sectors, especially in the key developed regions, including the compulsory closure of outdated production capacity.

Alongside these actions, the government is beginning to address the need to establish more meaningful ambient air quality indices, including the need to include further pollutants of concern. A key issue is the release of $PM_{2.5}$, and the improvement of the indices is almost certainly going to lead to a further tightening of the emission standards for the coal-fired power and other energy-intensive industries.

Alongside these policies, there will be further emphasis on increasing the use of low-sulphur and low-ash coal, with an emphasis on greater proportion of the coal being washed, while pushing forward the development of multi-pollutant control technologies such as combined control of SO_2, NOx, particulates and mercury for coal-fired power plants.

8.2 Implementation within the Twelfth Five-Year Plan

The government approach to reducing coal-related emissions in the coal-fired power sector includes command-and-control policies such as emission standards and limits (*see above*), compulsory introduction of certain technologies (for example SC and USC), and compulsory closures of small inefficient units. This is complemented by the use of economic incentives such as pollution levies, lower prices for electricity from small, less-efficient power plants, and higher prices for electricity from power plants with satisfactory FGD operation. Implementation of the plans within the 12th FYP to reduce coal-based non-GHG emissions, implementation will be very challenging. While there are extensive energy efficiency initiatives under way, together with the introduction of low- and zero-carbon alternative technologies that have an added benefit in limiting the release of the major pollutants, fine particulates, SO_2, and NOx coal will continue to dominate the energy mix and will continue to drive economic growth for the foreseeable future. The China Electricity Council has made several projections of future power capacity and use (China-wire, 2010). In terms of total power generation capacity, this is expected to rise towards 1885 GWe by 2020, with about 64% based on fossil fuel technology, predominantly coal.

Consequently, the action by the Chinese Government, to address such problems as a key environmental priority, can be regarded as very necessary. The intention to accelerate the development of systems, institutions and a technical knowledge base for sustained air quality improvement, which is being supported with significant investments to meet the enormous national needs for cleaner energy, air and water, suggests an ongoing developmental approach.

The inter-relationship between the emissions from coal-fired power plants, and other energy-intensive industries, and the need to improve air quality levels is critical in order to establish a more acceptable environment. In the near term, the new emission standards for the coal power sector represent a step change to what has previously been deemed acceptable, particularly in the nine key developed regions where measures are also in place to limit any new coal-fired power plants. This provides an impetus for increasing economic activity in the as yet relatively undeveloped central and western provinces, since these regions will see new industries established together with large advanced coal-fired power plants, for which, at present, the emissions standards will not be so strict.

For all regions, the new pollutant that will be regulated on coal-fired power plants is mercury and its compounds, for which the limit has been set at a level that represents a core control. This means that providing the power plant operator meets the new particulate, SO_2 and NOx standards then the mercury standard should be met without the need to introduce an additional capture device, although the emissions level will have to be measured on a regular basis.

The declared timescales for the power plants to upgrade particulate and SO_2 removal systems and introduce SCR for NOx control, are really quite short, given the overall number of coal-based units. The power sector is arguing that the schedule is unrealistic while the environmental advisors to the MEP are stating that there is little time to lose if the poor air quality and associated environmental problems on land and water are to be reversed.

8.3 Final thoughts

China is battling with the need to balance medium- to longer-term strategic environmental objectives with finding solutions to short-term difficulties. Its approach is a pragmatic but ambitious one, with the need to address various interrelated challenges within the coal sector. The MEP has undertaken some studies to ascertain the benefits to the national economy of improving air quality through tighter emissions standards and related measures within the various energy-intensive sectors. Although the detailed results are not available, it is understood that the cost benefit ratio is significant (He, 2011). However, it is the power companies that will have to make these very significant investments to improve the environmental performance of their various coal-fired power plants. These companies are already registering operational losses due to distortions from a market-based coal price and a power price that is capped by the government (istockAnalyst, 2010). This investment programme will represent a major dislocation within the national economy, both in terms of investment requirements and increased operating costs for the power sector.

Thus, for the medium to longer term, it is evident that the government must pursue its comprehensive programme to improve ambient air quality within the nation as a whole. However, in the short term, it needs to achieve an important breakthrough within the coal power sector and it remains to be seen whether it can achieve such ambitious strategic environmental objectives, while maintaining overall economic competitiveness, through the reduction and control of non-GHG emissions from the coal-fired power plants to levels lower than most other major coal using nations.

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