China's drive for cleaner air and lower carbon intensity: the use of high efficiency low emissions clean coal technology and CCS

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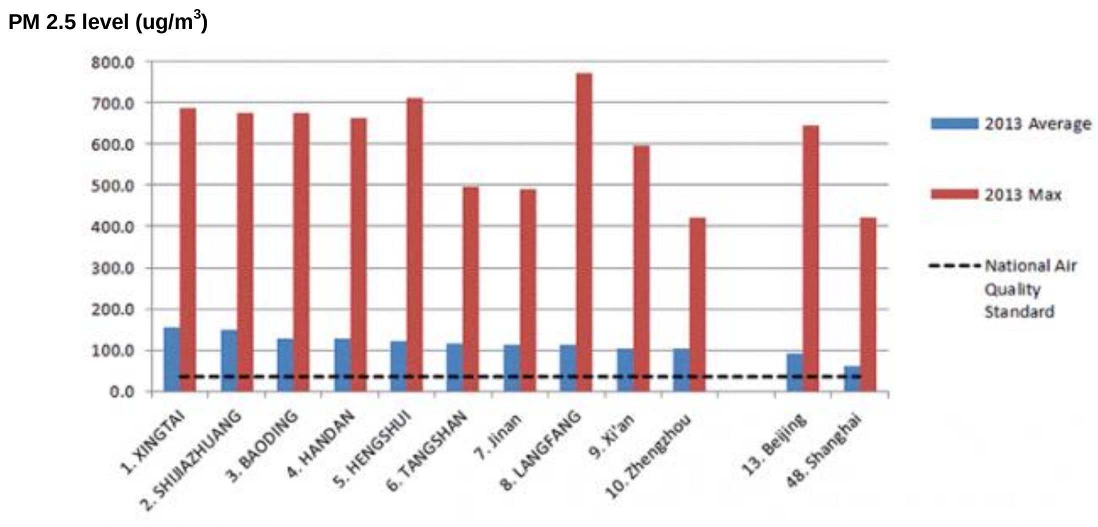
1 Introduction

China is the second largest economy and the biggest energy-using nation in the world. It 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 has been underpinned by significant increases in coal use especially for power generation, resulting in major emissions both of greenhouse gases, such as CO_2, and of SO_2, NOx and fine particulates. Even with the Government's ambitious plans to move to a less carbon intensive economy, coal will continue to dominate the energy mix and will continue to drive economic growth for the foreseeable future. These significant and continuing increases in coal use have caused severe air pollution problems, especially in urban areas. There are acid rain problems 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.

A major study between the State Environmental Protection Administration, now part of the Ministry of Environmental Protection (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 over $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.



Source: MEP

Figure 1 $PM_{2.5}$ emissions data for the ten worst major cities in China

To put this in context, The MEP recently released 2013 pollutant information for 74 cities in China, of which only 5 met the national air quality standard of 35ug/m^3. The emissions data for the ten cities with the highest average $PM_{2.5}$ level in 2013 are given in Figure 1.

Much of the problem is caused by coal use in non-power sectors such as coking, cement production, coal to chemicals and industrial boilers for the production of process steam and heat, which show poor energy and environmental performance.

There is also a major concern about the high carbon intensity arising from the burning large quantities of coal in power plants and in other industrial processes, with the high level of anthropogenic CO_2 emissions contributing to climate change. In short, the cost of that coal-based economic development may well be too high, given the environmental issues arising.

2 China's policy and regulatory initiatives to address coal related environmental issues

Climate change has been increasingly highlighted within China and its government has emerged as a global leader in strengthening mitigation efforts. It has taken some very significant steps to address coal related energy issues by introducing lower carbon and zero carbon options into the energy mix, as well as tightening air quality regulations and setting strict limits on emissions of conventional pollutants.

In 2009, the government pledged to reduce CO_2 emissions per unit of gross domestic product (GDP) by 40-45% from 2005 levels and to achieve a share of non-fossil energy of 15%, both by 2020. By 2013, the carbon emission intensity had decreased by over 28.9% and the share of non-fossil fuels in primary energy consumption accounted for 9.8%. In November 2014, the Chinese government announced that it had set a target for 2030 of reaching peak CO_2 emissions and achieving a share of 20% non-fossil energy in the total primary energy supply. Given the size of the Chinese power sector, which has already become the largest solar and wind market in the world, this represents a major structural change.

In June 2014, as part of the lead to the November announcements, the NDRC issued two policy documents, the 'Action Plan of Energy Development Strategy (2014-2020)' and the 'Action Plan of Upgrade and Renovation of Coal Power for Energy Conservation and Emission Reduction (2014-2020)', the latter being jointly issued with the MEP and the NEA. These policies focus on the near term optimization of the energy structure, to include:

- Reduce the share of coal consumption from 65.7% in 2013 to 62% by 2020 and to increase the share of coal used for high efficiency power generation
- Increase the share of natural gas consumption to over 10%
- Safely develop nuclear power
- Rapidly develop renewable energy, with a 2030 target of achieving a share of 20% non-fossil energy in the total primary energy supply subsequently set in November 2014.

That said, in order to satisfy electricity demand growth until 2030, total power generation capacity will have to increase to about 2,300 GW, which means that even with a very strong growth in non-fossil energy, there will be increases in coal and, to some extent, natural gas use. While in percentage terms coal power capacity will decrease, this will be within a still rapidly growing power generation sector, with coal-fired power plant capacity projected to rise from about 860 GW to 1,200 GW. Most of this additional capacity will be built in the next 5 to 10 years. Consequently, in absolute terms, coal use for power generation will increase through to about 2030.

This gives China some major challenges, which need to be addressed in a pragmatic manner since it cannot simply cease to use coal. The Chinese government has stepped up its efforts to address the comprehensive need for clean coal technology across many sectors in order to improve energy and environmental performance. This covers the essential need to achieve lower carbon intensity and to address air quality issues.

The means to decrease carbon intensity includes the further extensive deployment of high efficiency low emissions (HELE) coal power plant, which in itself results in a significant reduction in carbon emissions per unit output while also providing a precursor to the addition of CCS technology as a means to make coal based technology a very low carbon option. With regard to air quality issues, this requires a focus on how to meet the tightening emissions standards in the various coal industrial sectors while avoiding significant adverse impact on local GDP.

3 Early steps to address reduce carbon intensity and improve air quality

From 2006 onwards, China established a strong policy and regulatory framework to reduce emissions from coal power plants. This has required the power plant companies to make major improvements not only in terms of overall energy efficiency, which will lead to CO_2 emissions reduction, but also in the absolute reduction of pollutant emissions, namely SO_2, NOx and particulates. Thus, there has been a major policy to only build high efficiency coal power plants based on supercritical (SC) and more recently ultra-supercritical (USC) steam cycles. Such plants are over 20% more efficient than the older units, with a corresponding reduction in CO_2 emissions, Figure 2. In addition, almost all small, old and obsolete power station boilers below 300MW unit capacity have been closed.

Figure 2 Waigaoqiao No.3 2x1000MW coal power plant: a modern high efficiency low emissions plant constructed in China

In 2011, the MEP put in place some of the strictest emissions performance standards in the world for coal power plant, as shown in Table 1.

Table 1 Emission limit values for air pollutants from coal-fired thermal power generating boilers [GB13223-2011]

Pollutant		ELV, mg/m^3	
		Nine key regions	Rest of the country
Particulates	all	20	30
SO_2	all	50	
	New boilers		100 200a
	Existing boilers		200 400a
NOx (as NO_2)	all	100	100 200b
Mercury and mercury compounds	all		0.03

Notes:
a. ELVs apply to plants in Guangxi Zhuang Autonomous Region, Chongqing Municipality, Sichuan Province and Guizhou Province.
b. ELV applies to arch fired furnaces, existing CFB power generating boilers, and power generating boilers commissioned or received approval for construction before 31 December 2003.

The primary focus is on nine key regions, which are facing very significant air quality challenges, Figure 3. These 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.

Figure 3 Provinces of China, showing priority regions for enhanced emissions control in the coal power sector

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 have to achieve particulate, SO_2 and NOx emissions limits of 20, 50 and 100 mg/m^3 respectively, with new plants meeting the standards from 1 January 2012 and existing plants by 1 July 2014.

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. Thus the particulates and NOx emissions limits for all plants are 30 and 100 mg/m^3 while for SO_2 it is either 100 or 200 mg/m^3 depending on whether the plant is new or already in operation. 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. 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. It has been suggested that levels could be reduced to particulates 5 mg/m^3, SO_2 30 mg/m^3 and NOx 50 mg/m^3. In addition, from 2012, the Chinese government has limited coal consumption for power generation in China's nine key regions.

In order to meet these very tight emissions standards for non-CO_2 pollutant emissions, the power plant owners have had to install and use state of the art control systems for the specific removal of SO_2 and NOx. The other initiative has been 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 addition, China is seeking to address the need for structural changes for the power sector where sectoral reform and pricing liberalisation are central to all of the proposed energy reforms.

Notwithstanding these various initiatives, the air quality in many major cities has remained poor, due primarily to continued high levels of coal use in the smaller and relatively less efficient non-power sectors. The Chinese Government has now made addressing these ongoing 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.

4 Further initiatives to address air quality problems

This includes devolution of powers from State to Provincial Government together with a further series of regulatory requirements. For example, the MEP has declared that it plans to clearly divide powers between itself and the provincial Environmental Protection Bureaux, and to increase funds to prevent pollution at the local level. At the same time, it has indicated that the local level officials will have to be more rigorous in tackling environmental problems.

4.1 Power sector issues

A key requirement is the intention to increase the impact of high efficiency low emissions HELE) coal power generation, since this offers a major opportunity to limit the disproportionate pollution caused by ineffective coal use within some of the non-power sectors. By 2020， for each power company, the average specific coal consumption for its existing pulverised coal power plants must be lower than 310gce/kWh (grams of standard coal equivalent) after retrofit, in which average specific coal consumption for 600MWe units and above must be lower than 300gce/kWh. For the new coal power projects, unit capacity must be at least 600MWe USC and mostly 1000MWe USC, with net coal consumption lower than 285gce/kWh and 282gce/kWh respectively. In the developed eastern part of China, the emissions of new coal power projects must meet the emission limits for natural gas fired combined cycle power plant of 10, 35 and 50 mg/Nm^3 for dust, SO_2 and NOx, respectively, which can be achieved using the latest Chinese technology. There will also be a drive to introduce supercritical steam parameters for combined heat and power plants of $\geq$ 300MWe capacity.

For CFB units with capacity of 300MWe and above, supercritical steam parameters should be adopted, while for such units burning low grade coal, the design specific coal consumption must be not higher than 310gce/kWh, while for units of 600MWe CFB and above, a limit of 303gce/kWh applies

4.2 Non-power sector issues

For the non-power sectors, which produce a disproportionate amount of pollutants, these give China some major challenges, which need to be addressed in a pragmatic manner since it cannot simply cease to use coal in some of these sectors immediately. The Chinese polices will dictate a drive to using more coal for power generation and less in the other sectors. However, the ability to make such a change will vary with each province, depending on local conditions.

In September 2013, the State Council released the ‘Air Pollution Prevention and Control Action Plan’ (APPCAP), to address the national air quality problems within all provinces of China, especially in the northern urban areas. The aim is to ensure that within the next five years there will be a significant improvement in air quality within the nation's 338 cities, taking into account pollution and economic development in different areas, with the aim of reducing $PM_{2.5}$ levels in the Beijing-Tianjin-Hebei, Yangtze Delta and Pearl River Delta regions, and PM_{10} levels in the other cities. There is an expectation of further improvements nationwide during the subsequent five year period. It is noted that the emphasis on PM_{10} in cities outside the three key regions does not imply that controlling $PM_{2.5}$ is less important, since $PM_{2.5}$ particles account for 50 to 60% of PM_{10} particles.

Specific targets are as follows: PM_{10} emissions in cities at prefecture level or above need to decline by over 10% in 2017 compared with 2012 levels while $PM_{2.5}$ emissions in the Beijing-Tianjin-Hebei, Yangtze Delta and Pearl River Delta areas need to drop by about 25%, 20% and 15% respectively. In recognition that the Beijing-Tianjin-Hebei region is to be the most stringently targeted, the annual $PM_{2.5}$ in Beijing is to be controlled to within a 60ug/m^3 upper limit. While this will be challenging, this target is still higher than the 35ug/m^3 limit established in the National Ambient Air Quality Standard (GB3095-2012) for average $PM_{2.5}$ concentration, which was issued in 2012 and is to be implemented in 2016.

The National Development and Reform Commission (NDRC) has established a coal cap strategy, in order to add a critically important lever to existing climate and energy policies. By 2020, it aims to cap both national coal production and consumption at around 4.2 Gt, compared to about 3.6 Gt in 2013, with the introduction of regional production targets and individual provincial consumption caps.

It has been mandated in China’s Energy Conservation and Emission Reduction Program for the 12th 5 year Plan Period (2011-2015) that energy efficiency enhancements and dust removal retrofits shall be conducted on emission intensive industries such as iron, steel and cement making. However, as yet there are no standards in place to determine the levels of reduction required. Even so, closure programmes for older plants are already underway. In contrast for the industrial boiler sector, emissions performance standards are already in place as shown in Tables 2 and 3.

Table 2 Emission limits for an existing industrial boiler (mg/Nm^3）
[PRC- GB 13271-2014 to replace GB 13271-2001]

Items of pollutants	Emission limits（mg/Nm^3）			Location for monitoring pollutants
	Coal fired	Oil fired	Gas fired	
PM (particulate matter)	80	60	30	Stack or flue
SO_2	400 550[(1)]	300	100	
NOx	400	400	400	
Mercury and its compounds	0.05	-	-	
Blackness	< = 1			Outlet of stack
（1）This limit is used for Guangxi, Chongqing, Sichuan and Guizhou Industrial boilers with greater than 10 tonnes/hour steam capacity and hot water boilers above 7 MWth will need to meet emission limits from October 2015. For other boilers, the standards need to be met from July 2016				

Table 3 Emission limits for a new industrial boiler (mg/Nm^3）
[PRC- GB 13271-2014 to replace GB 13271-2001]

Items of pollutants	Emission limits（mg/Nm^3）			Location for monitoring pollutants
	Coal fired	Oil fired	Gas fired	
PM (particulate matter)	30	30	20	Stack or flue
SO_2	200	100	50	
NOx	200	200	150	
Mercury and its compounds	0.05	-	-	
Blackness	< = 1			Outlet of stack
Emission limits for new industrial boilers will need to be met from July 2014 onwards				

The options available to operators of existing boilers (and in due course the other non-power sectors) are threefold. They can:

- Meet the new standards by the due date;
- Convert to gas firing, this being subject to adequate supplies of gas being available at an economically acceptable price; or
- Close down, with potential adverse impact on the local economy.

4.3 Strategic issues requiring State Government input

These top down edicts will require considerable action from the provincial governments and there will be consequences for non-compliance. For example, the $PM_{2.5}$ and PM_{10} emission limits will be considered as compulsory targets in the social and economic development objectives for provinces, and be part of the performance evaluation indicators for provincial leaders. While there are broad policies in place, in many cases there is a lack of an implementation approach, combined with a lack of awareness of the better technology options to apply.

There is a potential strategic conflict that will need to be addressed. Much of the air quality problem is caused by the inefficient burning of often poor quality coal in industrial appliances with inadequate pollutant control systems. In some cases the introduction of alternative appliances and much better control of coal quality might be sufficient to achieve the necessary significant improvement.

However, the alternative and proven approach, as practiced in most OECD countries has been to increase coal use for power generation with associated Combined Heat and Power (CHP) applications, providing power, process steam and heat to industry, thereby either reducing or eliminating direct coal use in non-power systems. China has a proven track record in establishing large scale power plants and high quality CHP schemes.

For example, the team based at Waigaoqiao No.3 power plant has a very good track record in applying innovative improvements, both to achieve higher efficiency and to ensure lower pollutant emissions, which in the case of NOx is lower than can be achieved by gas fired combined cycle power plants. The specific coal consumption at this plant has already been reduced to 276gce/kWh, way below the new standards. That team is already beginning to engage with other power plant operators to replicate such improvements either through retrofit or new power plant applications.

However, the overall urgency to deal with the air quality problems may mean that in the near term the increased application of HELE coal power/CHP plants will not be the better way forward. While the coal power/CHP option is likely to be the more effective overall approach, it would require additional power/CHP units to be built and so most likely would be more expensive than other options. It would also require a longer schedule for implementation that will be inconsistent with the timescales being set by the environmental bureaux.

As such, recognising that the overall energy mix for the various industrial sectors needs to be changed quite quickly, it would appear that the selection of alternative non-power technologies that will meet national energy efficiency and environmental standards, and which are economically attractive, may have to be chosen. It is likely that many of these technologies will be innovative and not tested at industrial scale. Consequently, there is a need to establish a financial framework that will enable the demonstration of such technologies. It is also essential to consider how best to then set up a robust deployment programme. This suggests an urgent need to develop a pragmatic roadmap to select the more cost effective clean coal options for the non-coal power sectors, which can be trialled and subsequently rolled out to establish rapid deployment within each province. These are issues where dialogue at State level input would be expected since such a change would represent a fundamental modification to the current energy infrastructure.

In overall terms, any programme to address the problems is likely to include:

- Introduction of a change in philosophy towards a transparent and sustainable coal based system
- Reduction in carbon intensity and conventional pollutants for large scale applications
- Introduction of alternative and in many cases as yet unproven technologies for industrial boilers, metallurgical applications and other non-power sectors where it is technically viable and economically sensible to do so
- Addressing the fall-out from fundamental changes in the provincial energy structure

5 Looking to the not so distant future

While China is taking important steps to diversify its energy mix with nuclear, gas and renewables to reduce its national carbon intensity, the scale of this task is too large to have the required impact in the timescales suggested by climate scientists. As noted above, introducing HELE cleaner coal technology results in less coal being burned and reduces the emissions of CO_2 per unit output. The impact since 2006 is enormous, representing close to 2 Gt CO_2 saved through the introduction of HELE coal power plants compared to a business as usual scenario. However, on its own, this too is not enough and it is essential to look towards the application of CCS. This includes technology to capture most of the CO_2 emitted and, in order to ensure that this doesn't later escape to atmosphere, the captured CO_2 is liquefied then transported and stored in a geological formation such as a depleted oil well or a saline aquifer, for very long term containment. This is currently the only available technology that can cut up to 90% of CO_2 emissions from coal based processes. Any delay in its widespread commercial application may decrease the maximum abatement potential and, without CCS, the cost of meeting the country's anticipated climate change mitigation objectives will be at least 25% higher. CCS will also allow cost-effective deeper reductions in CO_2 emissions in many carbon-intensive and process industries in the coal chemical, power, steel, cement, and refinery sectors thereby reducing the projected peak of the CO_2 emissions in 2030.

Currently, the cost of avoided CO_2 for CCS is comparable with other low-emission technologies like solar photovoltaic and offshore wind. There is considerable potential that early-stage CCS demonstration will drive down costs in the future. However, while none of the individual CCS components is complicated, their integration in the entire project chain is complex. Each CCS project is highly capital intensive and faces major policy, technical, financial, and commercial challenges. In some parts of the world, large-scale carbon storage projects have met significant public opposition. For early-demonstration projects in the power sector, the Chinese government could establish a support program consisting of revenue support, such as large-scale feed-in tariff, and relief from resource taxes.

5 Scope for international cooperation

China has established numerous international cooperation agreements covering all aspects of clean energy. These offer significant opportunities for joint technology development and knowledge transfer, together with the introduction of advanced equipment in various sectors. CCS is a major focal point but it is important to recognise from a Chinese perspective that improving coal efficiency and environmental performance across all industrial sectors is also critical. Such work not only helps China achieve their domestic objectives for low carbon development, but also helps the global development of low carbon policy, technology and expertise.

7 Final thoughts

Since China is such a major user of coal, it is essential that it is fully engaged with ensuring that this fuel is burned as efficiently as possible with minimal emission of pollutants across all industrial sectors. At the same time, the development, demonstration and deployment of CCS technology is critical to limit CO_2 emissions from coal power plants and other large process units. China already is a world leader in establishing modern very high efficiency coal power plants, and these are the most effective units on which CCS can be included. As such, the basis for CCS implementation is already in place. International cooperation for such actions is essential to advance this and other energy issues of global significance.

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