Carbon Capture and Storage Development in China

The H. John Heinz III Center For
Science, Economics and the Environment

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Executive Summary

Due to its successful economic development during the past three decades, China has increasingly become a powerful player on the world stage, both politically and economically. At the same time, as climate change gradually becomes a potential global crisis, China finds itself in the spotlight for less positive reasons. The country's rapid urbanization and industrialization have caused significant environmental degradation that not only impacts China domestically, but also affects its neighbors and the world as a whole. Now, as greenhouse gas emissions continue to increase, the world is urging China to address its obligation to reduce emissions.

China has not ignored this call to action, but has, in fact, made significant efforts towards reducing its greenhouse gas emissions. It has developed national targets for energy conservation and energy efficiency improvements; renewable energy technologies are being deployed at full speed; and hydrological and nuclear power generation capacities have been expanded substantially, with more projects in the planning stages. However, current analyses indicate that these efforts will not be sufficient to curb the country's increase in greenhouse gas emissions. As the world's largest carbon emitter, China's actions have a huge impact on the global atmospheric concentration of greenhouse gases. In order to reduce global emissions, China must adopt more aggressive emissions reduction strategies.

One solution that scientists and policy makers are discussing is carbon capture and storage (CCS) technology. Although it is still in the early stages of development, CCS could potentially be used to capture carbon emissions from the atmosphere and inject them into deep geological formations. Since China relies on carbon-intense coal as its primary source of power generation, this solution is vital for China to sustain a strong position in the world economy while cutting emissions.

Currently, however, CCS development is not a priority item on the country's technology advancement agenda. One reason is technological: there remains uncertainty about the safety and permanence of CO_2 storage. Another is economic, given that a full-scale CCS demonstration plant would require a significant initial investment of about $1 billion USD. And finally, pursuing CCS could even have negative environmental effects, not only because the technology itself involves some impacts, but also because it might slow or replace the development of renewable and clean energy sources. Scientists feel relatively optimistic about meeting the technological challenges, but the economic and environmental concerns have so far checked the enthusiasm of the government and industrial investors.

In addition to the barriers associated with the technology itself, China's power sector does not provide a supportive environment for CCS technology placement. This problem mainly stems from the existing electricity pricing structure. Additionally, there is no CCS development plan or roadmap in place. Regulations to reduce the financial and physical risks are lacking as well. Although related clean coal technology developments can provide good deployment and operational experiences for CCS implementation, actual progress will vary based on national development priorities and how much domestic engineering capacity the country develops. China needs technology transfer of several key components of the CCS process. Also, the country's slow progress in developing integrated gasification combined cycle (IGCC) technology suggests that it may not be able to develop domestic engineering capacity for CCS before it needs to be implemented, given the urgency of climate change.

With the need to reduce emissions so pressing, China would need to take several steps to make CCS a short-term development priority. First, it could create a CCS development roadmap and establish regulations to clarify liabilities and minimize risks. Incentives that will foster demonstration projects and private investment could be explored and implemented. Enhancing international collaboration and technology transfer would also be necessary to increase the pace of technology development. At the same time, localizing CCS technologies quickly would substantially lower the overall long-term price, which could ultimately provide the cost effectiveness that the industry requires.

Chapter 1: Introduction

Carbon capture and storage (CCS) technologies, if implemented successfully, could provide an important means for reducing China's carbon emissions. However, CCS has spurred much debate recently within the international community. Ideally, these technologies have the potential to become the most influential climate change mitigation strategy of our time by capturing and storing carbon emissions into geological formations for thousands of years. Based on the International Energy Agency (IEA) report, if it were implemented worldwide, CCS could account for up to one-fifth of the 50% reduction in global greenhouse gas emissions needed from the baseline emissions scenario by 2050[1]. On the other hand, the large initial investment required, and the possibility of leakage of injected carbon dioxide back into the atmosphere, have generated concerns about the cost-effectiveness and feasibility of this new technology. Nevertheless, the huge mitigation potential offered by CCS makes it an attractive solution for China to consider.

China became the world's largest greenhouse gas emitter in 2008. Emissions generated from its rapid industrialization and urbanization activities will continue to grow, with the possibility of doubling the current level of emissions by 2020 in the absence of any intervention[2].

At the same time, the country faces an urgent demand for affordable energy sources to support its rapid industrialization. While other solutions such as energy efficiency and renewable energy are rapidly being deployed, the low cost of conventional energy sources, especially coal, ensures that fossil fuels will remain the dominant energy source in China. Given the greenhouse gas emissions generated from such energy sources, accelerating the development and deployment of advanced CCS technology may be the best option to help China reduce its greenhouse gas emissions.

This report explores the current status of CCS development in China. Special attention has been paid to the technology, economics, and policy implications of large-scale implementation of CCS in China. A discussion of barriers and a list of recommendations that would be required to advance CCS development in China are also included in the last section of this report.

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1. IEA, "Figure 2.1."
2. Buckley, "China report warns of greenhouse gas leap ."

Chapter 2: Current Status of China's Power Sector

During the past three decades, China has undergone rapid industrialization accompanied by economic reform. This enormous growth has come with an ever-increasing energy demand. China is now the world's second largest energy consumer and has become an important player in the world energy market. According to the recently published statistical communiqué from China's National Bureau of Statistics, *2008 National Economic and Social Development*, the country's annual energy consumption reached 2.85 billion tons of coal equivalent, a 4% increase from 2007. As a result, China consumes one-third of the coal burned for energy worldwide[3].

Energy demands

From the 1980s to 2005, China achieved a 9.5% average annual growth of GDP, while its energy demand increased by only 5.7% per year. However, over the same time period, the world's energy demand grew by only 1.6% annually [4]. Furthermore, between 2001 and 2004, China's annual GDP growth rate was 9.9%, while its energy consumption grew by a remarkable 12% annually, making its elastic co-efficiency of energy consumption 1.59 in 2004, four times that of its 2001 figure[5]. Currently, China's per capita installed generation capacity is about one-fifth that of Canada and the US, and less than half that of Japan, France, Russia and Germany[6]. Needless to say, China's energy demand will continue to increase in the near future.

Energy security

As economic development produces higher average incomes, more and more Chinese can afford the attributes of a Western lifestyle, such as owning an automobile. The rising number of cars in China is significantly increasing the country's reliance on petroleum. The large increases in energy consumption related to economic growth have made the Chinese government extremely worried about energy security.

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3. World Bank, "China's energy efficiency the target of three new World Bank projects."
4. Research Center for Sustainable Development, Chinese Academy of Social Science, *Understanding China's Energy Policy: Economic Growth and Energy Use, Fuel Diversity, Energy/Carbon Intensity, and International Cooperation*.
5. National Bureau of Statistics of China, *Data sheet 6-8 Elasticity Ratio of Energy Consumption.*
6. Cai et al., "Sectoral analysis for international technology development and transfer."

Based on the International Energy Agency's definition, energy security refers to "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns."[7] To achieve this level of security, China is actively exploring a range of technology options and has rolled out a host of energy conservation regulations to ensure that increases in energy demand will not jeopardize economic growth.

ENERGY CONSERVATION

China's economic development is directed by five-year plans that include a list of development targets and initiatives created by the government in consultation with the provinces and with approval from the National People's Congress. Presently, the country's emission reduction efforts focus on the development of renewable energy sources and energy efficiency. The emission reduction target is fairly challenging. In its Eleventh Five Year Plan, China's government committed to reducing the country's energy consumption per unit of GDP by 20 percent between 2006 and 2010[8]. On top of the 20% energy conservation target, the Eleventh Five Year Plan also established a goal of doubling China's 2005 GDP per capita by 2010[9]. Based on this plan, China's government intends to increase its share of total consumption from renewable energy to 10 percent by 2010 and 15 percent by 2015[10].

In 2006 and 2007, China achieved only a 1.23%[11] and 3.66%[12] reduction in energy consumption per unit of GDP, missing the annual reduction target of 4%. However, energy consumption per unit of GDP fell 4.59% in 2008, the first year the country met its annual target towards reducing energy intensity 20% by 2010.[13] Figure 1 indicates the energy consumption growth reduction, which was accomplished through an increase in energy efficiency and the change in the energy mix.

COAL-DOMINATED ENERGY SUPPLY

Despite these efforts to reduce consumption and increase the use of renewable energy, coal still accounts for more than 70 percent of China's energy supply. The country has relatively abundant coal reserves, and it remains a cheap way to mitigate the shortage of oil. Thus, many predict that the dominance of coal will not change in the foreseeable future.

7. IEA, "Energy Security."
8. Ma, "The 11th Five-Year Plan: targets, paths and policy orientation."
9. Xinhua News Agency, "China Aims to Double Its Per Capita GDP by 2010 ."
10. Information Office of the State Council of the PRC, *China's Energy Conditions and Policies*.
11. National Bureau of Statistics of China, *Communiqué on Energy Consumption per Unit of GDP by Regions in 2006*.
12. National Bureau of Statistics of China, *Communiqué on Energy Consumption per Unit of GDP by Regions in 2008*
13. National Bureau of Statistics of China, *Statistical Communiqué of the People's Republic of China on the 2008 National Economic and Social Development*.

FIGURE 1 2004-2008 Energy Consumption, Growth Rate and GDP Growth Rate

Source: China National Bureau of Statistics, Statistical Communique of the People's Republic of China on the National Economic and Social Development 2004 -2008

Development in the power sector

China's rapid economic growth is reflected in the vast development of its power sector. In 2008, 91 gigawatts (GW) of new power generation capacity were installed, the equivalent of three new 500 megawatt (MW) power plants per week.[14] More than 97% of newly installed thermal power capacity in 2007 came in the form of coal-fired power plants larger than 100 MW.[15] This rapid capacity addition threatens huge increases in greenhouse gas emissions, but also opens up opportunities for new and cleaner technologies. Continuous installation and operation of low-efficiency power plants not only prevents further efficiency improvements but also creates a "lock in" effect that will keep the high-emission technology in operation for at least another two decades. Thus, decisions made over the next twenty years will be critical in structuring China's future energy blend.

14. Ibid.
15. Chen et al., "Role for carbon capture and storage in China," 4213.

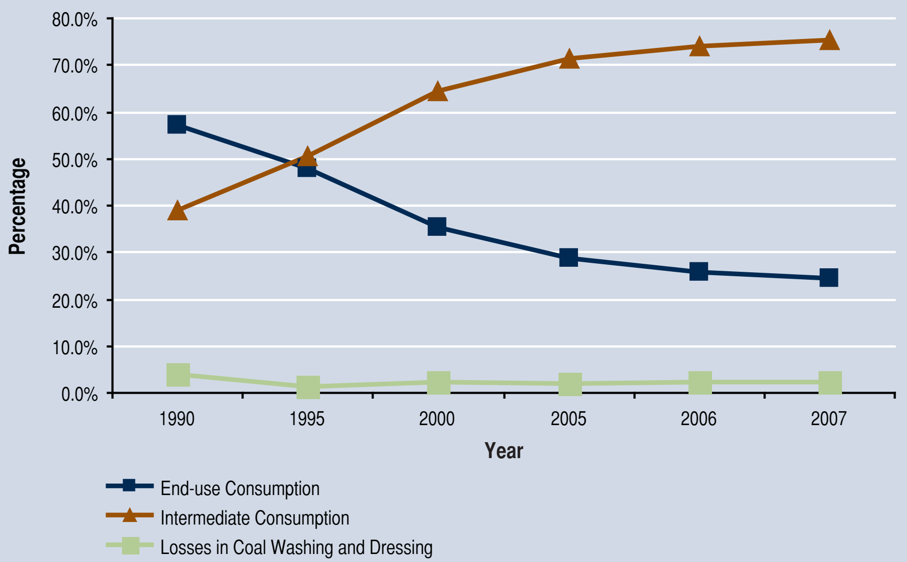
CURRENT COAL CONVERSION

Though the government has recently started to prioritize renewable energy development, these sources still comprise only about 7% of total energy consumption.[16] As the balance sheet of coal consumption shows, China has changed its consumption structure significantly over the past two decades. Figure 2 indicates that China has decreased end-use consumption of coal drastically from 57% in 1990 to 25% in 2007. In 2007, 67% of the intermediate consumption of coal was devoted to power generation, while 21% was used for cooking.[17]

COAL UTILIZATION TECHNOLOGIES

Relatively archaic methods of coal production and consumption have made "dirty coal" a major source of pollution and greenhouse gas emissions. The primary coal utilization technology in China is the pulverized coal plant, although more advanced technologies such as the supercritical and the ultra-supercritical units have also been deployed. While it is expected that the newly installed generating plants will increase energy efficiency, existing plants still show large variations in technology, quality of

FIGURE 2 China Coal Consumption by Usage



Source: China Statistics Year Book 2008. Calculated using data sheet 6-5, Coal Balance Sheet

16. Ibid.
17. National Bureau of Statistics of China, *Data sheet 6-5 Coal Balance Sheet*.

coal used, and environmental performance.[18] According to the State Electricity Regulatory Commssion, current coal comsuption rate for electricity generation is 341 g/kwh[19] while the best available coal fired plant (600 MW level ultra super critical units) can achieve 293 g/kwh[20]. China's power generation sector is also highly fragmented. The five major Chinese power generation companies provide only 42% of the total capacity.[21] The remainder is provided by local or foreign enterprises that are much smaller in size, with significantly less R&D capabilities, and using less advanced and/or outdated technologies. Additionally, the coal used in China is of low quality, primarily consisting of bituminous coal, which has a high carbon content.[22] It is believed that direct combustion of coal results in more than 70% of the soot, sulfur dioxide, nitrogen oxides, carbon dioxide, and other pollutants emitted nation wide.[23] As a result, acid rain and respiratory diseases continue to increase. Moreover, it is especially hard to reduce CO_2 emissions using direct coal combustion technology because of the low concentrations of CO_2 within the flue gas.[24]

18. Hearney Anna, Hester, and Gurney, *New Energy Technologies: Measuring Potential Impacts in APEC*, 3.
19. State Electricity Regulatory Commission, *First eight months coal consumption reduced by 8g/kwh compared to last year*.
20. NDRC. "600 MW level coal fired power plant energy efficiency level comparison result"
21. Cai et al., "Sectoral analysis for international technology development and transfer," 2.
22. Ibid., 4.
23. Mao, Sheng, and Yang, *The True Cost of Coal*, 6, Section 2.1.1.1 Air Pollution: Combustion.
24. Liu et al., "Strategic thinking on IGCC development in China," 2.

Chapter 3: Emission Abatement Potential

China currently does not have a clear emissions reduction target. The most recent official greenhouse gas emissions inventory accounting was done in 1994.[25] Based on IEA statistics, the country's greenhouse gas emissions were about 5.6 Gt CO_{2e} in 2006 (from fuel combustion only).[26] Fuel combustion accounts for 68% of total greenhouse gas emissions.[27] The "business as usual" scenario indicates that this figure will grow to over 12 Gt CO_{2e} by 2030 based on U.S. Energy Information Administration estimates.[28]

Emission abatement pressure from the international community

If a global agreement on emission reductions were to be achieved, China would face significant international pressure to reduce its emissions. Table 1 illustrates China's reduction requirements based on different atmospheric concentrations of carbon dioxide in 2050. As the table shows, China would encounter an emissions reduction requirement of at least 40 Gt of CO_2 if it continues its current emissions level towards 2050. Even in the shorter term, by 2030, China may face large abatement pressure. The McKinsey/Vattenfall "Curbing Climate Change" analysis indicates that as part of a global effort to keep the atmospheric concentrations of carbon dioxide at 450 ppm, China needs to abate 4.6 Gt CO_{2e} /year in 2030.[29]

TABLE 1 China 2050 Emissions Reduction Estimation

CO_2 concentration level	Global total emissions in 2050 under different concentration scenario (Gt CO_2) [a, b]	China max. emission allocation (Gt CO_2) [c]	China BAU emissions in 2050 (Gt CO_2) [a]	Emission Gap (Gt CO_2)
450 ppm	26	7	55	48
550 ppm	31	8	55	47
650 ppm	44	12	55	43
750 ppm	51	14	55	41

[a] Liu, Yanhua. Ge, Quansheng. He, Fanneng. And Cheng, Bangbo. (2008). Countermeasures against international pressure of reducing CO_2 emissions and analysis on China's potential of CO_2 emission reduction. Pg. 677. Table 1. ACTA Geographica Sinica. Vol. 63. No. 7. [b] Wang Weizhong, Chen Bin, Lu Chuanyi et al. (2002) The Kyoto Protocal and allocation of carbon emission permits. Journal of Tsinghua University (Philosophy and Social Sciences), Vol. 17. No.6. Pg. 81-85. [c] Calculated at 26% of global level, the best allocation option China could obtain.

25. CRS, *China's greenhouse gas emissions and mitigation policies*, 5.
26. IEA, "IEA Energy Statistics - Energy Indicators for China, People's Republic of."
27. CRS, *China's greenhouse gas emissions and mitigation policies*, 18.
28. Ibid., 17.
29. Vattenfall, "BAU and reduction potential for China."

Potential gap in proposed strategies

Even with its several strategies for achieving emission reductions, China's current efforts may not be sufficient to meet its reduction needs. One study indicates that even if China met its energy conservation goal, raised its share of renewable energy used to 15% by 2020, fully implemented energy efficiency initiatives, and accounted for all the carbon sequestration potential of its land and ocean, it might still face a 0.17 Gt CO_2 emission reduction gap by 2020.[30] As this emission reduction gap increases over time, the need for CCS is expected to grow as well.

CCS as part of the solution

Currently, there is no clear estimate of China's carbon capture capacity or the potential impact of CCS on emissions reduction. According to an IEA publication, CCS in power generation, industry, and synfuel production can reduce total global emissions 20-28% by 2050.[31] If by 2030 China indeed faces a 4.6 Gt CO_2/year abatement requirement, CCS would need to account for approximately 1 Gt CO_2/year of these reduction needs. A recent study done by scholars from Tsinghua University as part of the Sino-British Near Zero Emission Coal (NZEC) initiative indicates a promising role for CCS in emission reduction in China. The results suggest that to reduce the same amount of emissions, installation of capture-ready integrated gasification combined cycle (IGCC) units in the power sector is more cost-effective than replacing coal-fired power plants by wind and nuclear units without capture.[32]

TABLE 2 Increased Cost Comparison: IGCC vs. Clean Technologies

Year	2020	2030	2050
Emission reduction (Mt CO_2) [a]	357	1240	2188
Increased Cost			
IGCC with capture (US$ Billion) [b]	44	90	63
Wind (US$ Billion)	186	624	978
Nuclear (US$ Billion)	93	300	407

Source: Chen, Wenying. Liu, Jia. Ma, Linwei. D Ulanowsky. And G K Burnard. (2009). Role for carbon capture and storage in China. Pg. 4215. Table 5. Energy Procedia 1. 4209-4216. [a] Calculated by subtracting CO_2 emission after capture from CO_2 before capture and assuming a 90% capture rate. [b] Assuming IGCC units account for 10%, 30% and 50% of coal-fired plants in years 2020, 2030 and 2050.

30. Liu, Yanhua et al., "Countermeasures against international pressure of reducing CO2 emissions and analysis on China's potential of CO2 emission reduction," 679.
31. IEA, *IEA Energy Technology Essentials: Carbon Capture and Storage*, 3.
32. Chen et al., "Role for carbon capture and storage in China."

Table 2 illustrates a cost comparison of IGCC, wind, and nuclear technologies based on this study. Notice that these estimates assume a rather optimal level of development of capture-ready IGCC units. Installed IGCC units reaching a 10% share of coal-fired power plants in 2020 equates to 97.5 GW of generation capacity. Consider that only one IGCC plant is under construction in China, a 250 MW unit. Many more resources and investments would be needed for this strategy to succeed. Interestingly, however, the increased cost requirements fall in 2050 for IGCC units, while those for wind and nuclear will continue to grow due to increased emission reduction requirements.

The importance of CCS

A study done by the Tyndall Center on China's cumulative CO_2 emissions over the 21st century indicates that CCS development will vary radically under different emission scenarios.[33] Table 3 is a summary of the findings from the Tyndall study related to energy and power mix only. The results indicate that aside from energy demand changes, the size of the emissions budget and the year of emissions peak also play very important roles in terms of deciding the priority of energy generation technology developments.

TABLE 3 CCS Development Based on Different Emissions Scenarios [a]

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cumulative Emissions Budget [b]	70 Gtc	111 Gtc	90 Gtc	111 Gtc
Year of Emissions Peak	2020	2030	2020	2030
GDP Growth Rate	2-4%	5-8%	4-6%	2-8%
Pop. Growth [c]	About 0.4% p.a., reaching its peak in 2030 with 2050 population at 1.4 bn			
Energy Demand	Slow growth	Moderate growth	Moderate growth	High growth
Primary Energy Supply Mix (in priority order)	Renewables; fossil fuels or nuclear	Renewables; fossil fuels	Nuclear; fossil fuels; renewables	Fossil fuels; nuclear; renewables
Power Generation (in priority order)	Renewables; coal with CCS or nuclear	Renewables; large hydro; coal and gas with CCS	Nuclear; coal with CCS; renewables	Coal and gas with CCS; nuclear; renewables
Clean Coal and CCS	Moderately important/urgent	Not urgent; gradual diffusion	Very important and urgent	Important but slow diffusion at first

Source: Wang, Tao. And Watson, Jim. (2008). Carbon Emissions Scenarios for China to 2100. Tyndall Center for Climate Change Research. [a.] Table recreated based on data from Table 2 (pg.13) and Table 3 (pg.14). [b.] Emissions budget under each scenario is the cumulative emissions budget for China in 21st century. [c.] Population growth is based on UN 2004 projection.

33. Wang and Watson, *Carbon Emissions Scenarios for China to 2100.*

Chapter 4: CCS Technology Development

Carbon capture and storage technology consists of a three-stage process: 1) capture the CO_2 from the point source such as a power plant, and compress it; 2) transfer the CO_2 through a pipeline or tank; 3) inject the CO_2 into a geological formation and permanently store it. Although technologies related to each stage have been tested and/or implemented, there has never been a CCS plant that integrates all three steps as a means of reducing greenhouse gas emissions.

Carbon Capture

Carbon capture at the power plant can be achieved through three different technologies: post-combustion capture, pre-combustion capture, and oxy-fuel capture. Although not commercially used in the power generation sector, carbon capture technologies are mature applications in industrial processes such as natural gas processing and ammonia production.[34]

Post-combustion capture, as it states, is the method most suitable for use in a conventional power plant where chemical solvents capture CO_2 from the flue gases after combustion. The solvent is reusable after the CO_2 is stripped off. For coal power plants, technologies that can be used for post-combustion capture include subcritical pulverized coal (PC), supercritical pulverized coal (SCPC), ultra-supercritical pulverized coal (USCPC) and circulating fluidized bed (CFB) plants.[35] However, there is a large energy penalty associated with the extra energy required to compress CO_2 from atmospheric pressure to pipeline pressure.[36]

Due to their high energy efficiency, supercritical and ultra-supercritical units are being installed at a very fast pace in China. The country has developed 100% of the domestic engineering capability needed for supercritical units, and 60% of that needed for ultra-supercritical units, making the investment cost cheaper than that in developed countries.[37] Reportedly, more than 150 supercritical and ultra-supercritical units larger than 600 MW have been installed or are on order.[38] China also has significant operational experience with the CFB technology and is now building the world's largest CFB units, at the 600 MW level.[39]

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34. Rubin, Chen, and Rao, "Cost and performance of fossil fuel power plants with CO2 capture and storage," 4444.
35. Forbes and Verma, "Guidelines for Carbon Dioxide Capture, Transport, and Storage ," 26.
36. Philibert, Ellis, and Podkanski, *Carbon Capture and Storage in the CDM*, 9.
37. Liu, Shi, and Jiang, "New power generation technology options under the greenhouse gases mitigation scenario in China," 3.
38. Chen et al., "Role for carbon capture and storage in China," 4214.
39. Ibid.

Pre-combustion capture refers to a series of processes in which coal is first converted into gaseous components. After a "partial oxidation" process, the resulting synthesized gas (syngas) goes through a water-gas shift reactor, which brings the CO_2 concentration level to about 40%, along with 55% H_2 within the syngas.[40] The CO_2 can then be separated and stored, while the H_2 can be used in electricity production. Relatively higher concentrations of CO_2 in the syngas stream makes carbon capture through pre-combustion capture hypothetically easier and thus cheaper than post-combustion capture where the pressure of CO_2 is lower; this process can be applied to the integrated gasification combined cycle (IGCC) or natural gas combined cycle (NGCC). The combined cycle means that the syngas produced from the previously mentioned gasification process is cleaned and then sent to the combustion turbine/generator to produce energy. The heat generated during the combustion process is then utilized by a heat recovery steam generator, and more electricity is generated through a steam turbine. Thus, the combined cycle has a higher efficiency rate because it involves less energy waste.

IGCC is the leading technology for power plants with carbon capture due to its lower cost, according to an MIT study.[41] The advantages of IGCC technology go beyond its linkage with CCS. IGCC systems require less cooling water and have higher flexibility in terms of fuel sources.[42] Current IGCC technology can achieve an efficiency level of 38–43% with a potential efficiency level reaching over 50% with improved gas turbines.[43] IGCC also produces much less pollution, with the desulfurization and denitrification rate at 99% and 90% respectively, while producing only 25 mg/Nm^3, which is 2% of the current Chinese standard.[44] Another very important advantage of IGCC is its ability to produce multiple commercially desirable products such as hydrogen and fertilizer feed stocks.[45] This type of technology is called polygeneration, and its advantages have led the Chinese government to make it a priority in the development of advanced coal utilization technologies. One study suggests that compared to producing heat, power, methanol and syngas separately, the polygeneration system can reduce capital investment, production cost, and raw coal consumption by 38%, 31% and 22.6%[46] respectively. However, IGCC technology development in China went through quite a difficult process. Fact box I (page 16) illustrates that: 1) setting technology advancement goals alone does not necessarily foster actual development and deployment, because

40. NETL, "What is the status of various capture technologies and the timeline for completion of each technology development effort?."
41. MIT, *Executive Summary*, 13.
42. Liu et al., "Strategic thinking on IGCC development in China," 5.
43. Ibid.
44. Ibid., 4.
45. Ibid.
46. Ibid., 9.

economic feasibility and environmental considerations may affect the progress of development significantly; and 2) although China has the ambition to acquire domestic engineering capacity for certain advanced technologies, the urgency of climate change does not leave much time for it to take that path. The lengthy development and demonstration period of IGCC in China provides a good example. Despite their various benefits, IGCC systems are much more expensive to build and less reliable than conventional coal power plants. By contrast, NGCC requires relatively low capital costs and less time to construct than other power generation technologies (i.e., pulverized coal fired power plants), but has higher fuel costs.[47]

Oxy-fuel capture refers to the process of using pure oxygen and recycled flue gas instead of air during the fuel combustion process, which in turn produces a stream of pure CO_2 and H_2O.[48] Compared to conventional power plants, oxyfuel combustion incurs an energy penalty during the oxygen generation and gas compression process.[49]

Among the three capture methods, post-combustion capture is the only viable solution for existing power plants, as it requires minimum modification of the base plant for either new builds or retrofits.[50] Oxy-fuel capture and pre-combustion capture require either partial or complete changes to base power plants. Although carbon capture is relatively easier using oxy-fuel and pre-combustion capture methods, given the speed of China's energy generation capacity installation, post-combustion capture will be the best candidate for CCS, at least during early deployment.

47. Hearney Anna, Hester, and Gurney, *New Energy Technologies: Measuring Potential Impacts in APEC*, 106.
48. Wall et al., "An overview on oxyfuel coal combustion—State of the art research and technology development," 2.
49. Wall et al., "An overview on oxyfuel coal combustion—State of the art research and technology development," 3.
50. Philibert, Ellis, and Podkanski, *Carbon Capture and Storage in the CDM*, 9.

FACT BOX 1 Timeline of IGCC Development in China

Key research projects in the National Plan[51]

Eighth Five-Year Plan (1990 – 1995):

- ❖ National key technologies R&D program, "Feasibility study on the technologies of the IGCC demonstration plan"

Ninth Five-Year Plan (1995 – 2000):

- ❖ National key technologies R&D program, "Study on the key technologies of IGCC"

Tenth Five-Year Plan (2000 – 2005):

- ❖ 863 Project, "Design, Integration and Dynamic characteristics of IGCC"
- ❖ 973 Project, "Basic researches on the polygeneration applications of the syngas from the combination of gasified and pulverized coal gas"

Eleventh Five-Year Plan (2005 – 2010):

- ❖ 863 Project, "Polygeneration demonstration engineering based on coal gasification"

IGCC Development Timeline[52]

- 1970s: IGCC research and development start to receive attention. A 10 MW IGCC demonstration project is planned but eventually terminated.
- 1991-1995: Construction of an IGCC demonstration project included in the Ninth Five-Year Plan, China Energy White Paper, and China's Agenda 21.
- 1993: Ministry of Electric Power conducts preliminary study on IGCC demonstration at Beijing and Yantai.
- 1994: IGCC working group established, consisting of six government agencies, to conduct a feasibility study. Between 1994 and 1995, the working group finishes the IGCC demonstration project's technical feasibility assessment as one of the National Key Science and Technology Breakthrough Projects during the Eighth Five Year Plan Period.
- 1996-2000: Ministry of Electricity selects Yantai as the site of the first IGCC demonstration power plant in 1997. Plan includes two 300-400 MW units. However, this project is never carried out. The "Study on the key technologies of IGCC" is finished as one of the National Key Science and Technology Breakthrough Projects during the Ninth Five Year Plan Period.
- 2001 – 2005: 863 Project, "Design, Integration and Dynamic characteristics of IGCC," successfully concluded. During the Tenth Five-Year Plan period, R&D of medium- and low-heat value (MHV and LHV) syngas turbine technology receives funding from the 863 program and the priority projects in the Knowledge Innovation Program of the China Academy of Sciences.
- 2005: China Huaneng Group joins U.S. FutureGen International Partnership. Da Tang International Power Generation and China Power Investment Corporation is preparing three to five 300 – 400 MW level IGCC power plants.

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51. Liu et al., "Strategic thinking on IGCC development in China," 9.
52. Timeline put together using sources from: [a.] Liu, Hengwei. Ni, Weidou. Li, Zheng. And Ma, Linwei. (2008). Strategic thinking on IGCC development in China. Pg. 7. Energy Policy 36. 1-11.; [b.] http://www.chinaesco.net/PPT/xushisen.pdf Pg. 20. [c.] Nautilius Institute. (1999). IGCC in China. Pg. 12. [online]. Available. http://www.nautilus.org/archives/papers/energy/NIIGCCESENAY3.pdf

Domestic Engineering Capabilities

Key Components	Localized Capacity	Technology Gap
Gasifier [a]	Domestically-developed multi-burner gasification technology and the two-stage oxygen feed gasification technology	
Gas cleaning [b]	Normal temperature syngas cleaning at mature stage	High temperature syngas cleaning technology under development
Air Separation [b]	Manufacturing capacity for units suitable for 400 MW IGCC power plants	
Combined Cycle [b, c]	Domestic engineering capacity for steam turbines, generators and exhaust heat boilers	"Advanced blade of gas turbine, blade passage technologies, advanced sealing techniques in gas turbine, etc. still need to be imported from companies in the Netherlands, the USA and Germany" [c]
System integration and optimization [b]	Can design large scale IGCC power plants independently	Lack operational parameters and experiences

Sources: [a.] Chen, Wenying. Liu, Jia. Ma, Linwei. D Ulanowsky. And G K Burnard. (2009). Role for carbon capture and storage in China. Pg. 4213. Energy Procedia 1. 4209-4216. Liu, Hengwei. Ni, Weidou. [b.] Li, Zheng. And Ma, Linwei. (2008). Strategic thinking on IGCC development in China. Pg. 8. Energy Policy 36. 1-11. [c.] Cai, Wenjia. Wang, Can. Liu, Wenling. Mao, Ziwei. Yu, Huichao. And Chen, Jining. (2009). Sectoral Analysis for international technology development and transfer: case of coal-fired power generation, cement and aluminum in China. Pg. 8. Energy Policy.

COST OF ENERGY PRODUCTION TECHNOLOGIES WITH CARBON CAPTURE

High cost is the main barrier to large-scale operation of carbon capture technologies. Yet, understanding the cost structure and potential benefits will significantly influence the choice of technology and related policies. Several studies have tried to estimate the cost of CCS based on different assumptions, such as fuel cost and efficiency of the capture plant.[53,54] An analysis of these studies suggests that the main candidates for fossil fuel power generation technologies are supercritical coal-fired power generation, ultra-supercritical coal-fired power generation, IGCC and NGCC. The former two technologies are relatively mature tools that China already has significant operational experiences with, while the latter two are relatively new.

53. IPCC, *Chapter 8: Cost and Economic Potential*.
54. Rubin, Chen, and Rao, "Cost and performance of fossil fuel power plants with CO2 capture and storage," 4444.

The investment cost in China is much lower compared to that in developed countries, assuming China acquires significant domestic engineering capacity. Table 4 is based on a study by scholars from the Chinese Academy of Science and Energy Research Institute. The table summarizes the investment costs of the above four technologies in China, both currently and as estimated for 2030. Supercritical and ultra-supercritical units have limited room for cost reductions because they are already fairly mature technologies. China has limited experience with IGCC, leaving room for cost reductions. The estimated learning curve based on international experience is 12%. However, due to variations in the technical maturity of different components of the IGCC unit, the actual cost reductions may vary. Finally, the cost reduction potential of NGCC is also limited because globally it is an established and evolved technology that is not likely to become more efficient without a significant technology breakthrough.[55]

It is important to note that the above costs do not include the cost of capture. Currently, CO_2 capture can increase fossil fuel usage by 35-40%, with efficiency losses at 8-12%.[56] However, with advanced technology and next generation plants in place, the energy increase can be reduced to 10-30%, with significantly less efficiency loss. A few studies have examined CCS costs using different technologies in China. One such study indicates that the capture cost in a Chinese laboratory is 0.19-0.25 RMB/kWh, equivalent to the cost of electricity generation, which is 0.2-0.25 RMB/kWh.[57] This capture cost number needs to be reduced to 0.01-0.1 RMB/kWh in order to be cost-effective.[58]

TABLE 4 Cost of Clean Coal Technologies

Technology	SC with De-Sulfur	USC with De-Sulfur	IGCC	NGCC
Current Investment Cost ($/kW)[a]	515	560	1150	445
Cost in 2030 ($/kW)[b]	515	535	960	400

Source: Liu, Qiang. Shi, Minjun. And Jiang, Kejun. (2009). New power generation technology options under the greenhouse gases mitigation scenario in China. Pg. 3. Energy Policy. doi:10.1016/j.enpol.2009.02.044. [a.] Price and exchange rate at 2007 level. [b.] Estimation based on different rate of learning curves: IGCC at 12% and NGCC at 20%.

55. Liu, Shi, and Jiang, "New power generation technology options under the greenhouse gases mitigation scenario in China," 3-4.
56. IEA, *IEA Energy Technology Essentials: Carbon Capture and Storage*, 2.
57. Dapeng and Weiwei, "Barriers and incentives of CCS deployment in China," 3.
58. Ibid.

Based on a summary of recent studies on CCS cost estimations done by Professor Edward Rubin of Carnegie Mellon University, the total capital requirement for a power plant with CO_2 capture will be \$1894-\$2578 per kWh for pulverized coal units (supercritical units), \$1414-\$2270 per kWh for IGCC, and \$909-\$1261 per kWh for NGCC.[59] These studies also conclude that NGCC units are the most cost-effective technology when considering the cost of electricity and CO_2 emission reduction. However, Professor Rubin states that special attention should be paid to the different assumptions about the price of fuel and the utilization level. Although NGCC represents the lowest capital requirements among all the technology options, the fluctuation in fuel price for natural gas causes significant variation in its operational cost. When natural gas prices increase significantly, causing NGCC units to be underutilized, IGCC with CO_2 capture is estimated to have the lowest cost in terms of both electricity generation and CO_2 emissions reduction.[60] Thus, it is important for policy makers and investors to review all the assumptions carefully when selecting the most cost-effective technologies.

TRANSPORT AND STORAGE

CO_2 can be transported by pipeline or ship. Pipeline transport requires compression of CO_2, while ship transport requires liquefaction. Chinese companies have had sufficient experience with transporting CO_2 over both short and long distances.[61] However, in the case of CCS, CO_2 transport can be a very complicated issue. First, extra pipelines might need to be built to connect the emission sources and the storage sites. Second, if the CO_2 will be used in enhanced oil recovery (EOR), the fact that the demand for CO_2 varies from time to time means the mismatch between constant supply from the power plant and the fluctuating demand must be addressed.

A CO_2 shortage could also be an issue for EOR, which may require CO_2 to be supplied through multiple sources. Substantial amounts of research, design, and planning are needed to ensure the efficiency and effectiveness of CCS.

Three main methods of carbon sequestration can be utilized in carbon storage: geological sequestration, ocean sequestration and mineral sequestration. Carbon geological sequestration has been considered most feasible for power plants. This type of sequestration includes deep saline reservoirs, depleted oil and gas fields,

59. Rubin, Chen, and Rao, "Cost and performance of fossil fuel power plants with CO2 capture and storage," 4445.
60. Rubin, Chen, and Rao, "Cost and performance of fossil fuel power plants with CO2 capture and storage."
61. Dapeng and Weiwei, "Barriers and incentives of CCS deployment in China," 3.

or deep unmineable coal beds.[62] According to a presentation given by Professor Gao Li at the Carbon Sequestration Leadership Forum, China has abundant potential carbon storage sites. The estimate shows that 46 gas and oil reservoirs can store 7.2 billion tons of CO_2; 68 unmineable coal beds with methane recovery technology can store 12 billion tons of CO_2; and 24 saline aquifers can store 1,435 billion tons of CO_2.[63] With 3 to 4 billion tons of CO_2 abatement per year, this capacity can last about 400 years.

An Asia Pacific Economic Cooperation (APEC) study indicates that China has moderate to high prospective undersurface carbon storage. Northern China has a number of good storage sites that may be available for this region's high concentration of carbon emissions.[64] Western China does not have large sources of carbon emissions, while southern China, with a high concentration of emissions, lacks onshore subsurface storage capacity.[65] However, due to the country's limited experience with geological storage, the actual storage capacity may vary drastically from the estimate. A few analyses indicate that China may face a shortage of storage capacity due to the rapid growth in coal consumption.[66] Another study indicates that China's CO_2 storage capacity is 21 billion tons, equivalent to only four years worth of annual emissions--a mere 1% of Professor Gao Li's estimate.[67]

CO_2 can also be used for enhanced hydrocarbon recovery, including the previously-mentioned EOR as well as enhanced gas recovery (EGR) and extraction of coal bed methane (ECBM) through CO_2 injection. China has had operational experience with EOR and ECBM, though not for the purpose of mitigating climate change. Rather, these technologies have been used to enhance fossil fuel production. Nevertheless, storing CO_2 underground permanently is the most important component of the CCS strategy. Therefore, the accumulation of geological data and storage experiences should be stressed in the CCS strategy for China.
The cost of CO_2 transport and storage varies depending on the different kinds of storage sites. The total cost of electricity increases by 4-10 % if CO_2 is stored using an aquifer. The total cost is reduced by 7-18% if CO_2 is used in enhanced oil recovery.[68] The IPCC's CCS report indicates that CO_2 transport costs range from \$1-\$8/t and geological storage costs \$0.5-\$8 for each ton of CO_2 injected, while monitoring and verification will add another \$0.1-\$0.3 for each ton of CO_2 injected .[69]

62. Newlands, Langford, and Causebrook, *Abstract GHGT-8*, 1.
63. Innovation Norway, *International CCS technology survey*, 124.
64. Newlands, Langford, and Causebrook, *Abstract GHGT-8*, 2.
65. Ibid.
66. Vattenfall, *Global Mapping of Greenhouse Gas Abatement Opportunities up to 2030*, 26.
67. Dapeng and Weiwei, "Barriers and incentives of CCS deployment in China," 3.
68. Rubin, Chen, and Rao, "Cost and performance of fossil fuel power plants with CO2 capture and storage," 4446.
69. IPCC, *Summary for policy makers*, 11, Table SPM.5.

Several reports have examined the cost and mitigation potential of CCS based on a bottom-up approach. The carbon emission abatement cost from CCS is quite substantial, reaching \$100/t CO_2 marginal cost according to most assumptions.[70] The high cost of CCS makes it a less attractive technology in the current market. Some have suggested including CCS technology in the Clean Development Mechanism (CDM), a market-based carbon emissions reduction trading scheme developed under the Kyoto Protocol. Although many countries (including China) have received extra funding by selling carbon credits generated from clean energy sources to countries with emission caps, the relatively low carbon price still does not provide the needed financial incentive for CCS development, when compared to other less expensive carbon abatement methods. For example, the estimated destroying cost of HFC23 is only \$0.2/ton of CO_2 equivalent, while the estimated reduction cost for renewable energy is about \$10/ton.[71] Considering the current market price of primary carbon credits is approximately \$17/ton, a steep fall from \$30/ton since August 2008,[72] CCS projects will not be attractive to most companies currently even if such projects qualify for CDM credits.

70. Government of Japan, *Appendix: Overview of studies on mitigation potentials analysis based on a bottom up approach*, 3-4.
71. Carbon Finance, "The Credit for Destruction."
72. Point Carbon, "2009 European-CER Prices," 2.

Chapter 5: CCS Policy and Efforts in China

Policy Related to CCS Development

Science and technology development

Several laws, regulations, and policies have been promulgated in China recently to promote clean energy and environmental protection. Unlike many other countries where efficiency improvements have been driven by environmental policies, the promotion of advanced clean energy technologies in China is largely driven by technical policies.[73] Both the Mid- and Long-Term Science and Technology Development Plan and China's Special Science and Technology Campaign to Cope with Climate Change have listed CCS technology as one of the leading-edge development objectives.[74] Other relevant support projects include the National Key Fundamental Research Project (973 Project), "Green-house gases geological storage and resources utilization in the increasing oil mining and collection," with a ¥1 million RMB (approximately $143,000) budget.[75]

Power plant closure

As energy demand decreases due to the economic downturn, China plans to speed up the closure of some of its most inefficient coal-fired power plants. Table 5 illustrates the ongoing and projected closure of these plants. By late 2008, China had closed 34.2 GW of small coal-fired power plants to reach 68.4% of its Eleventh Five Year Plan listed target.[76] By using more efficient technologies, it was able to decrease the coal consumption of power plants from 370 g/kWh in 2005 to 357 g/kWh in 2007.[77] One study estimated that 420 Mt CO_2 emissions were avoided due to this improvement in generation efficiency.[78] The percentage of 30 MW or larger, high efficiency coal-fired power plants increased from 43.39% in 2003 to 58.9% in 2007.[79] Moreover, the newly installed generation capacity is mainly comprised of plants larger than 600 MW.[80] Since it is more cost effective to capture carbon from a large point source than from less concentrated sources, this policy helps the development of CCS in the sense that reducing the number of small and inefficient power plants and replacing them with large scale, modern power plants will ease future barriers to carbon capture. However, this policy has also caused a surge of concern about unemployment, an over-developed coal-fired power sector, and the loss of the flexibility offered by small power plants.

73. Lu et al., "Policy study on development and utilization of clean coal technology in China," 476.
74. Liu and Gallagher, "Driving Carbon Capture and Storage forward in China," 3881.
75. Basic information about this project (in Chinese) can be accessed at http://7058.973program.org/ProjectInfo.aspx
76. Anonymous, "China will close 31 GW of small coal-fired power plants in three years."
77. Chen et al., "Role for carbon capture and storage in China," 4213.
78. Cai et al., "Sectoral analysis for international technology development and transfer," 6.
79. Anonymous, "Closure of small coal-fired power plant should not be over corrected."
80. Chen et al., "Role for carbon capture and storage in China," 4214.

TABLE 5 Closure of Small and Inefficient Coal Plants

Year	2007	2008	2009	2010	2011
Capacity Shut-down	14.38 GW	16.69 GW	13 GW	10 GW	8 GW

Source: Anonymous (2009). China will close 31 GW of small coal-fired power plants in three years. 02/06/2009. [online]. Available (in Chinese). http://www.chd.com.cn/news.do?cmd=show&id=34982

CURRENT EFFORTS

INTERNATIONAL COLLABORATION

TABLE 6 International Collaboration Projects on CCS

Existing Initiatives	Partnership	Goal [a]	Chinese Participants [a,b]	Chinese Involvement [a,b]
NZEC	UK	Capacity building with possible demonstration project starting between 2010 and 2015	Administrative Center for China's Agenda 21 (ACCA21), Tsinghua University, Zhejiang University and GreenGen	
COACH	EU	Prepare the ground for new energy technology options that employ CCS		Eight out of the twenty partners come from China; EU provides □1.6 million worth of funding
APP	Australia, Canada, China, India, Japan, Korea, and US	Accelerate the development and deployment of clean technologies		China is co-chair with Australia of the Cleaner Fossil Energy Task force; co-chair with US of the power generation and transmission task force
Geo Capacity	EU	Data collection on storage capacity and facilitate technology transfer	China Ministry of Science and Technology, Tsinghua University and Chinese Academy of science	Full project partner
FutureGen	US	Build first of its kind coal-fueled, near zero emissions power plant	China HuaNeng Group	2% of investment from HuaNeng Group
China Japan EOR Project [b]	Japan	Enhance collaboration of CCS technology development and plan to set up projects in Herbin and Daqing oil fields	China National Petroleum Corp. and the China Huadian Corp	The cost of the project will be 20 to 30 billion yen ($220-$320 million). How the cost will be shared is not clear.

Source: Liu, Hengwei and Gallagher, Kelly. (2009). Driving carbon capture and storage forward in China. Section 3.1. International Cooperation. Pg. 3879 – 3880. Energy Procedia 1. 3877-3884. [b] Information collected from http://www.greencarcongress.com/2008/05/report-japan-ch.html and http://www.mofa,go.jp/region/asia-paci/china/pv0805/press.html Item 27.

Demonstration Projects

GreenGen

The GreenGen program is a joint venture between China HuaNeng Group (CHNG) and seven other state-owned energy companies with a registered capital of ¥300 million RMB. The goal is to "design, build and operate the first IGCC power plant in China in 2009 and coal-based, near-zero-emission GreenGen power plant in China with independent intellectual property rights."[81] The plan involves three phases, with an end goal of a completed demonstration project consisting of a 400 MW integrated coal gasification combined cycle (IGCC) plant before 2020, with over 80% of CO_2 separated and treated (See Table 7).[82] The plant will also be operated with H_2 production, fuel cell, and hydrogen power generation capacity, targeting near zero emissions.[83] GreenGen Co., Ltd. joined both the COACH and NZEC[84] projects, which were collaboration programs under EU-China's near zero emissions coal (NZEC) project agreement.[85]

TABLE 7 GreenGen Project Plan

Time Period	Estimated Investment	Tasks [a]
Eleventh Five Year (2006-2009)	¥2 billion RMB	• Build 250 MW IGCC demonstration plant with domestic engineering capacity • Build GreenGen Laboratory • Achieve domestic engineering on 200t/d gasifer
Twelfth Five Year (2010-2015)	¥3 billion RMB	• Improve IGCC and poly-generation technology • Build a 400 MW IGCC plant • Optimize gasification technology • R&D on separation technology of H_2 and CO_2 • Preliminary work of GreenGen demonstration
Thirteenth Five Year (2016-2020)	¥2 billion RMB	• Build a 400 MW GreenGen demonstration plant including H_2 production, fuel cell and H_2 power generation with CCS • Operate the plant with near zero emissions • Prove the economic viability of GreenGen plant • Ready for commercialization

Source: [a.] http://www.greengen.com.cn/en/aboutgreengenproject.htm

81. GreenGen, "GreenGen Profile."
82. Xu and Gao, *Near zero emission coal based power ceneration in China Greengen Project*, 3.
83. GreenGen, *GreenGen Project of China*, 12.
84. NZEC, "What is NZEC?."
85. Webb and Gao, *Near Zero Emission Collaboration in China: China-UK Collaboration*, 4.

Yantai IGCC

The Yantai IGCC project was included in China's Tenth Five Year Plan as an important demonstration of China's commitment to developing clean coal technologies. Currently under construction, the project received support from both the EU and Japan. The estimated cost is about $420 million USD, funded through equities, loans, and Global Environment Facility (GEF) grants from the World Bank.[86]

PCC Demo Project

In August 2008, China HuaNeng Group and the Australian-based Commonwealth Scientific and Industrial Research Organization (CSIRO) launched a post combustion capture (PCC) pilot plant in Beijing designed to capture 3,000 tons of CO_2 per year. This project is a collaborative effort between the Chinese and Australian governments, which provided $4 million for this project.[87]

86. World Bank, *Project Information Document: China –Yantai IGCC Project*, 3.
87. Science Daily, "Carbon Capture Milestone In China."

Chapter 6: Challenges to CCS Development in China

Lack of emission reduction requirements

As a non-Annex I country, China does not face a cap on greenhouse gas emissions. While a lot of effort has been focused on pushing China to accept hard emission reduction targets, most scientists and industrial experts believe this will not occur until a post-2020 regime and more importantly, until the U.S. actively participates. As a consequence, China has no internal incentives to promote emission reductions. The majority of government efforts focus on renewable energy and energy efficiency as a means of increasing energy independence. Emission reduction efforts are not the government's first priority. Furthermore, the industrial sector is not enthusiastic about CCS and is reluctant to invest in CCS technologies.[88] The lack of any major commitment towards CCS is also reflected in China's recent stimulus package. China dedicated ¥200 billion RMB to low-carbon spending, which is equivalent to 37% of its entire stimulus package, a much higher commitment compared to developed countries.[89] However, no funding was committed to CCS projects, while the U.S., EU, and Canada all appropriated funding for CCS demonstration projects and infrastructure building.[90]

Limited demonstration of CCS technologies

Without internal motivation from government and industry, CCS development in China will not see significant progress in the foreseeable future. According to Dr. Chen Hongbo from the Research Center for Sustainable Development at the Chinese Academy of Social Sciences, current CCS development in China will be limited to small-scale projects and will focus on research rather than actual implementation, as the Chinese government takes a "wait and see" approach.[91] Current Chinese research and development focuses heavily on carbon capture using pre- and post-combustion capture technologies with few operational experiences. Likewise, one survey indicates that China lacks "integrated technologies for transportation, injection, monitoring and risk control" for successful CCS deployment.[92] The same evaluation also found that research priority is directed towards clean coal technologies. Accordingly, only nine studies related to CCS (all on CO_2 capture) were proposed to China's Natural Science Foundation during 2002 to 2007, while 46 clean coal projects were proposed during the same time period.[93]

88. Dapeng and Weiwei, "Barriers and incentives of CCS deployment in China," 5.
89. Mabey, *Delivering a Sustainable Low Carbon Recovery*, 13.
90. Ibid., 23.
91. Chen, "China's emission trading."
92. Ibid., 3.
93. Ibid.

Effectiveness of and risks associated with CCS

There are several unresolved concerns about both the potential risks and the actual effectiveness of CCS in emissions reduction. The risks from a wide deployment of CCS include: environmental concerns such as CO_2 leakage; damage to the marine ecosystem and geological systems; operational risks such as accidents associated with new technology; energy system risks such as additional energy requirements (energy penalty) and the threat to energy efficiency improvements; and commercial risks like the shortage of CO_2 as a commodity or a shortage of proper storage sites.[94]

China is not alone in having these concerns. Many environmentalists around the world are campaigning against CCS because of its "pro-coal" approach and potential negative environmental consequences. These concerns seem to have significantly hindered enthusiasm for CCS development in China, as many experts question the effectiveness of CCS and the role it will play in changing the country's energy blend. Uncertainties related to CCS can only be fully understood and addressed, however, through further research and demonstration projects.

Lack of clear regulatory framework

If China were to create and maintain a stable and clear regulatory system, it would give investors confidence in making long-term investments in CCS technology. It could also provide guidelines to minimize risks and mistakes during technological deployment. The drafting process for standards and regulations could also identify potential issues that might foster further research and development efforts. However, thus far China has not made any attempt to create such a regulatory framework for CCS development, other than establishing research and development targets. Regulations relating to carbon storage safety are especially important since there are numerous liabilities and uncertainties associated with secure CCS development.

Financing Challenges

As mentioned previously, an integrated CCS system will require a significant level of start-up investment. The question of who will finance this large investment project, and how, remains a major barrier that constrains CCS development in China, as it does worldwide. The Chinese power generators themselves are running a deficit. Electricity prices are directly linked to coal prices; but while the price of coal fluctuates based on market conditions, the price of electricity is under state control. The central government plans to adjust the price of electricity if the price of coal rises 5% or more over a half-year period.[95] Thirty percent of such an increase will be borne by the electricity companies (100% if coal prices rise less than 5%),

94. Ibid., 4.
95. Mao, Sheng, and Yang, *The True Cost of Coal*, 30.

while the remaining increase will be passed on to consumers.[96] Coal purchased for electricity accounts for 70% of the generation costs. For that reason, the power generation companies are under a good deal of pressure as downstream entities.[97] This inconsistency between the coal price and the electricity price caused the five major power generators a loss of ¥16.8 billion RMB ($2.4 billion) between January and August of 2008,[98] while the entire power generation sector lost ¥70 billion RMB ($10 billion) over 2008.[99] Under such circumstances, it would be unreasonable to expect these companies to shoulder the large capital investment costs of CCS, despite their interest in increasing their generation capacity to gain a competitive advantage. The 250 MW pilot IGCC plant built by China HuaNeng Group cost the company ¥2.2 billion RMB ($300 million) in 2006, equivalent to 47% of HuaNeng's 2005 net profit.[100] Support from the central government is given mainly for research and development of key technologies. Yet, for China to adequately weigh the pros and cons of CCS development, it is critical not only to acquire the core technologies but also to gain equal operational experience with the different CCS technologies available.

Dr. Hongbo indicates that the Chinese government is concerned CCS investment would undermine its recent efforts to promote renewable energy.[101] On the other hand, the government understands the necessity of pursuing all available CO_2 abatement methods to keep China ahead of the game. Reducing the costs of CCS technologies requires further diffusion of the technology and more investment in research and demonstration. Thus, despite the high cost of CCS, the Chinese industrial sector should start looking into this technology more closely since it holds the potential to become one of the more viable solutions among the range of low-carbon strategies.[102]

Another investment stream is the carbon market. If CCS projects can qualify for Clean Development Mechanism (CDM) credit, the extra funding may provide part of the investment cost. However, there is an ongoing debate about whether implementation and storage of CO_2 can permanently remove greenhouse gases from the atmosphere, which would be required for CDM credit. Also, with the current market price of carbon facing a steep fall, the offsetting potential from CDM will be discounted as well.

96. Ibid.
97. Xinhua News Agency, "With rising coal price, power generation companies seeking imported coal."
98. Cai et al., "Sectoral analysis for international technology development and transfer," 9.
99. China.com, "Over development of coal-fired power plant and worsened power mix is the main cause of China's coal-electricity conflict."
100. Cai et al., "Sectoral analysis for international technology development and transfer," 8.
101. Ibid.
102. Dapeng and Weiwei, "Barriers and incentives of CCS deployment in China," 5.

Social Implications

On top of the large capital investment associated with CCS plants, there is a potential social cost involved as well. Although the "greening" of the economy is widely expected to create more jobs, the newly generated job opportunities may not be enough to compensate for unemployment resulting from the closure of small coal-fired power plants. One study indicates that a large, advanced power plant requires only 10% of the employees currently needed for a small plant in China, so the closure of small power plants will impact at least 30% of the workers in the power generation sector.[103] How to relocate workers laid-off due to power sector reform could be a large issue, especially considering that 58% of the country's generation capacity comes from small, local enterprises.

103. Cai et al., "Sectoral analysis for international technology development and transfer," 7.

Chapter 7: Recommendations

CCS technologies face a number of technical, economic, and environmental concerns, but none of them are insurmountable. Despite the technical challenges, the biggest problem may lie in making a rational business case for CCS because, eventually, most of the investment will have to come from the business sector. To develop CCS, China would need to explore the following action steps required to advance CCS technology.

Create a CCS roadmap and regulatory framework

Current CCS developments are largely driven by technology policies. More attention should be paid to emissions reduction rather than technology development. Because CCS is a capital-intensive technology, the first several demonstration projects will require heavy government involvement. Without supporting activities such as market incentives, regulation and standards, the further diffusion of CCS technology will be limited. The urgency of climate change requires that the country establish a clear roadmap for CCS development that enables commercialization to happen within a recommended timeframe.

The CCS technology roadmap and program plan published by U.S. Department of Energy and National Energy Technology Laboratory provides a good example. The first step is to identify a designated office in charge of the design, planning, and monitoring of the development progress. The second step is to choose a list of initiatives aimed at closing the technology, policy, and financial gaps. Creating and enhancing a collaborative network globally should also be a critical component, as it plays an important role in facilitating technology transfer.

Since several CCS demonstration projects are already planned, creating a clear regulatory framework while demonstrating different technologies is imperative. Regulations that could foster CCS development include a carbon tax, higher electricity prices from clean energy sources, and mandatory carbon emission caps. Various laws and regulations have been made on the international, regional and national level around the globe. They provide a good starting point for China to consider and develop similar frameworks. Table 8 provides a summary of existing CCS related regulations. Note that several policy proposals focus on safe storage of CO_2 since it is one of the main barriers to investment in full-scale development of CCS. China now has a few demonstration sites using EOR and ECBM technologies to utilize CO_2. The related guidelines and regulations should be designed to encourage more private investment, as both of these are economically feasible technologies.

TABLE 8 CCS Regulations Developed by Different Nations/Regions

Scope	EU[a,b]	UK[c,d,e]
Regulations	Directive on the geological storage of carbon dioxide	Energy Act 2008 and consultation documents related to CCS demonstration and development framework
Key Points	❖ Main focus on safe storage of CO_2 providing clear guidelines for storage permits, liability and penalties ❖ Intent to require all new coal-fired power plants above 300 MW to be "capture-ready" when technically and economically feasible to store CO_2 and retrofit the power plants	❖ Creates regulatory framework to enable private investment in CCS ❖ Government intends to require all new fossil fuel power stations to be capture ready, "no new coal without CCS demonstration from day one"
Other Activities	Removed legal barriers to CCS storage from EU Water Law and EU Waste Law	❖ New regulations are under consideration requiring full capture by 2020 once CCS has been technically and economically proven ❖ A CO_2 emissions performance standard (EPS) is also considered in case CCS is not proven by 2025

a. http://register.consilium.europa.eu/pdf/en/08/st03/st03739.en08.pdf
b. http://www.ucl.ac.uk/cclp/ccsdedlegstorage.php
c. http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/ccs/ccs.aspx
d. http://www.ucl.ac.uk/cclp/ccsdedlegnatoverview.php
e. http://www.decc.gov.uk/en/content/cms/news/pn050/pn050.aspx
f. http://www.epa.gov/fedrgstr/EPA-WATER/2008/July/Day-25/w16626.pdf

Consider a Carbon Tax

Levying a carbon tax is considered the most important incentive for the wide deployment of CCS technology. Clearly, reducing carbon emissions will not be taken seriously unless companies face penalties for not doing so. Taking into consideration costs associated with negative externalities resulting from different types of technologies, then internalizing these into total production costs, would make a significant difference in restructuring the power generation combination. One review suggests that once local externalities such as air pollution is monetized, advanced coal-power plants and IGCC will replace conventional coal-fired power plants, while NGCC and renewable sources will increase their share of the power mix.[104] If costs associated with local and global externalities were to be internalized into the total cost of production, the same review projects that in 2050 IGCC with carbon capture would become the second largest coal based power producing method globally, while NGCC would also become highly competitive.[105]

104. Rafaj and Kypreos, "Internalisation of external cost in the power generation sector," 840.
105. Ibid., 835.

US[f,g,h]	Australia[i,j]	Canada[k,l]
EPA proposal on federal requirements under the Underground Injection Control (UIC) Program for carbon dioxide geological sequestration wells	The Offshore Petroleum Amendment (Greenhouse Gas Storage) Bill 2008 currently being debated	Alberta Province proposed 2009 Bill 14: Carbon capture and storage funding act
❖ EPA proposes to "create a new category of injection well under the existing Underground Injection Control Program" to allow CO_2 injection for geological sequestration	❖ Aims to provide confidence to project developers to commit to low emission energy projects involving CCS ❖ Ensure projects meet health, safety and environmental requirements	❖ Aims "to encourage and expedite the design, construction and operation of carbon capture and storage projects in Alberta" ❖ Requesting no more than $2 billion of funding
❖ Interstate Oil and Gas Compact Commission published "CO_2 Storage: A legal and regulatory guide for states" ❖ 12 States have passed various rules regarding CCS	❖ Published "Carbon capture and storage: Australian Regulatory Guiding Principals" ❖ Queensland, Victoria and Western Australia all mandated different requirements related to CCS, focusing on geological sequestration	❖ Developed "Canada's CO_2 capture and storage technology roadmap" (CCSTRM) to identify near-term CCS R&D, marketing and investment strategies.

g. http://iogcc.publishpath.com/Websites/iogcc/pdfs/Road-to-a-Greener-Energy-Future.pdf
h. http://www.ucl.ac.uk/cclp/ccsdedlegnatoverview.php
i. http://www.ret.gov.au/resources/Documents/ccs/CCS_Aust_Regulatory_Guiding_Principles.pdf
j. http://www.ret.gov.au/resources/Documents/ccs/os_Petroleum_Amendment_Bill_2008.pdf
k. http://www.assembly.ab.ca/bills/2009/pdf/bill-014.pdf
l. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier/78713/ccstrm_e_lowres.pdf

The debate in China concerns when to impose this type of tax. At the center of the debate is whether to give high emitters seven to ten years to prepare for the actual implementation of a carbon tax. In order to make the costs of CCS technology attractive, the carbon tax should be around ¥120 - ¥200 RMB/t CO_2, making the tax paid by small-scale power plants equal to half of their annual profit.[106] China's current price structure within the power sector is also problematic. To ensure the profitability of power companies after levying the carbon tax, the price of electricity would have to increase. The extra costs would be transferred to the end customer, a result that would impact economic growth.

Prioritize technology options

CCS is still a relatively new technology, and one that many observers estimate will not be commercially available until 2030. The EU, however, has a goal of making CCS readily available by 2020. Research shows that in order to achieve this very

106. Dapeng and Weiwei, "Barriers and incentives of CCS deployment in China," 6.

ambitious goal, demonstration projects must be operational by 2011.[107] Under such a constrained timeframe, it is important to select the right demonstration technology in order to shorten the learning curve while still achieving successful implementation.

One option is to prioritize post-combustion capture, since it is a mature technology and requires minimal modifications to existing base plants. One study shows that retrofitting existing plants with post-combustion capture can reduce the length of the deployment cycle of CCS by about two years compared to IGCC or Oxy-fuel plants.[108] Significant investment and demonstration efforts for transportation and storage are still needed, but these can be done with a higher confidence of success. Scholars believe that if IGCC and oxy-fuel capture research are conducted parallel to the implementation of post-combustion capture, "no significant social disadvantage [is] likely to occur if CCS is adopted with only post-combustion capture available initially".[109]

Another viable option to prevent the carbon "lock-in" for new power plants in the pipeline is to make them capture ready. Based on empirical analysis, this alternative is economically sound for three reasons: 1) capture ready plants have a higher probability of later retrofitting; 2) capture ready plants provide a more secure electricity supply and less chance of early closure; and 3) the extra investment to make plants capture ready has a positive net present value.[110]

Develop a Regional Approach

Selecting the right region is also a critical component during the early deployment of CCS. While China is actively promoting renewable energy developments such as solar, wind, and hydro power plants nationwide, natural conditions play an important role in determining actual deployment within each region. Figure 3 compares the carbon emissions of each province and the distribution of clean energy power plants in China. It clearly illustrates that clean energies have a larger presence in the central and southern region of China. Wind energy has great potential in Southeast China, Xinjiang, and Inner Mongolia.[111] Hydro power plants are concentrated in central China, where hydro resources are abundant. Nuclear power plant development is limited to the relatively wealthy regions along the east coast.

107. Gibbins and Chalmers, "Preparing for global rollout," 505.
108. Ibid., 507.
109. Ibid., 506.
110. Liang et al., "Assessing the value of CO2 capture ready in new-build coal-fired power plants in China."
111. Chen, "Saving Energy and Decreasing Consumption Has a Long Way to Go," 314.

Ideally, large point sources of carbon emission would be matched with nearby storage sites. Current geological sequestration capacity assessments indicate that the northeast region, especially the Bohai basin, has great storage potential. A GIS analysis (Figure 4) of China's power plant distribution also shows large clusters of thermal power plants located in the same region, while the presence of clean energy sources is limited. Thus, the northeast region would be a good candidate for early deployment of CCS technology.

Enhance international collaboration

Advanced low emission technologies have been developed largely in the industrialized countries. Nonetheless, emission reduction efforts are most urgently needed in emerging economies such as China's. International collaboration and technology transfer will need to play a significant role to accelerate the diffusion of technologies. An assessment of climate-friendly patents reveals a strong Chinese performance in several industrial sectors such as cement, geothermal, solar, hydro, and methane.[112]

Today, the majority of CCS-related patents are owned by industrialized countries such as Japan and the U.S. Industrialized countries have also accumulated more operational experiences with clean coal technologies such as IGCC. In order to accelerate its technology development, China must close some of the technology gaps as soon as possible. While the country is actively seeking technology transfer from developed nations, concerns exist in the international community about the protection of intellectual property. Although China has put laws and regulations in place to protect intellectual property rights, the fears of technology providers may remain until these laws and regulations are consistently enforced.

One possible solution to narrow the technology gap is to foster collaboration between both developed and developing nations. In theory, if countries develop technologies together, they can all benefit and share ownership of the technology. However, the success of this strategy would still rely on detailed agreements that outline how technology would be transferred and who would own the intellectual property rights.

Regardless of the technology China chooses to pursue internally, it could benefit from strengthening its collaboration with developed countries in science and technology development. At the same time, China could evaluate more stringent measures to protect the intellectual property rights in order to address lingering international concerns.

112. Dechezlepretre et al., *Invention and Transfer of Climate Change Mitigation Technologies on a Global scale: A Study Drawing on Patent Data*, 20.

FIGURE 3 2007 China Carbon Emissions by Region and Location of Clean Energy Sources

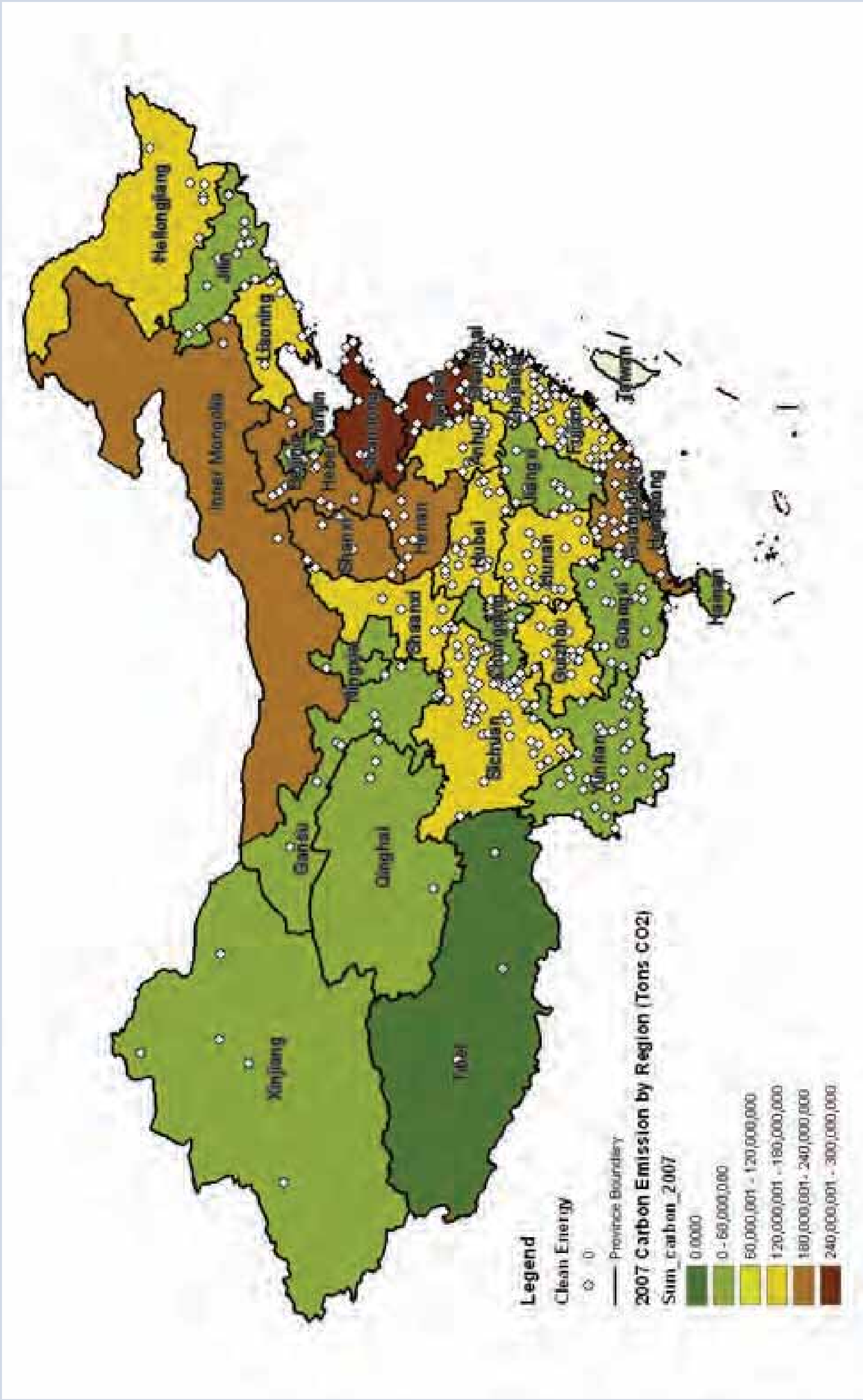
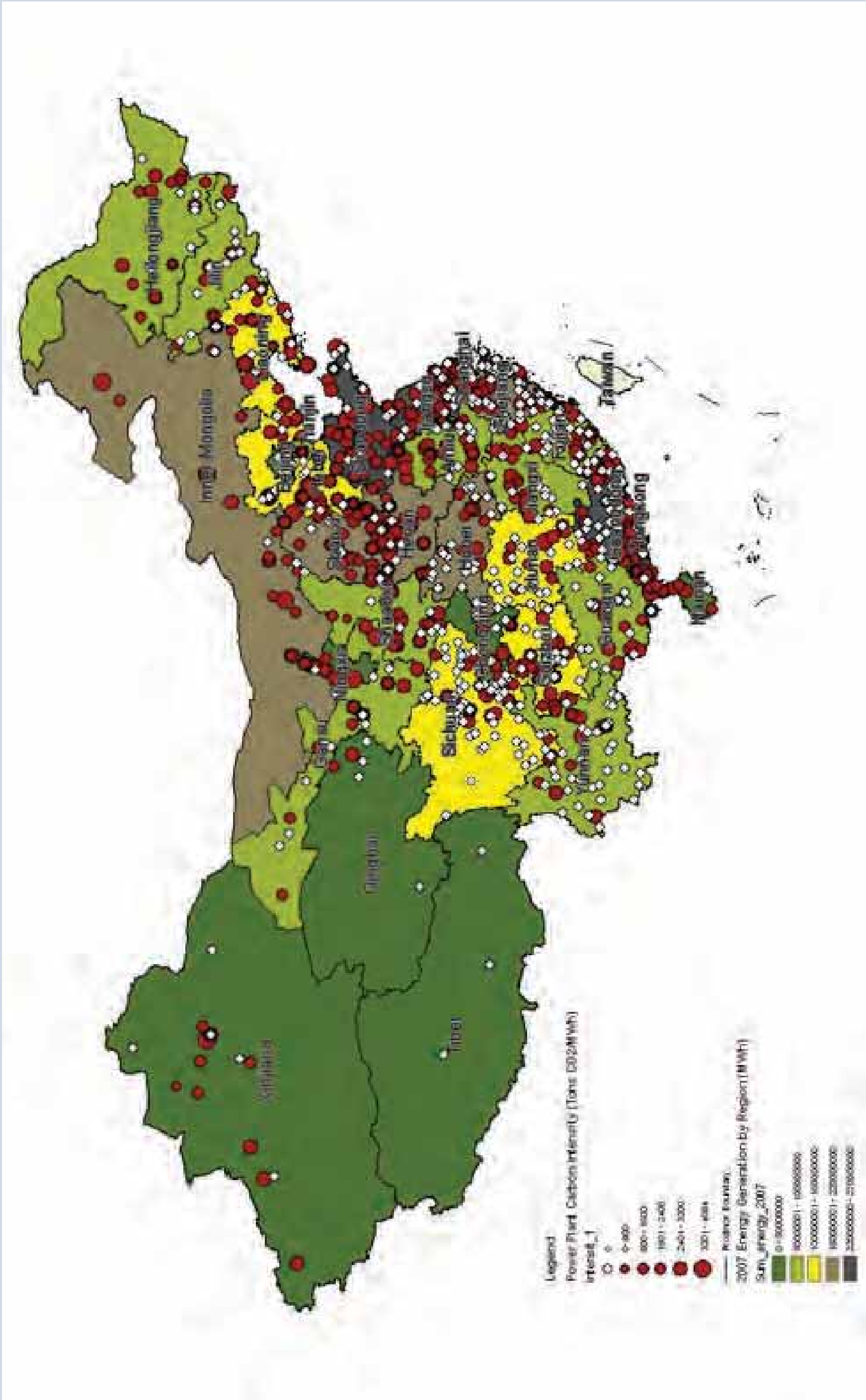


FIGURE 4 China Energy Generation vs. Power Plant Carbon Intensity by Region



Chapter 8: Conclusion

As a relatively new technology, CCS still presents many uncertainties, both technological and economic. Risks associated with CCS technology make decision-makers around the world hesitant to commit to large-scale deployment. The considerable preliminary investment requirements further cool their enthusiasm. China is not alone in moving carefully when making technology development decisions. However, these decisions are currently based on limited knowledge and experience with CCS technology. A full examination of the feasibility and actual effectiveness of CCS for emissions reduction is needed, including demonstration projects to study the associated benefits and risks. At the same time, regulations and guidelines should be put in place to minimize risks and clarify liabilities. It is also crucial to remove some of the policy and market barriers uniquely associated with China's power industry to provide more incentives for enterprises willing to participate in CCS development. International collaboration is also important to close the immediate technology gap. Conversely, localizing these technologies would quickly and substantially lower overall long-term costs, which can ultimately provide the much-needed cost effectiveness required within the industry to develop CCS technology in China.

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