WWS 402: Energy for Sustainable Development

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STRENGTHENING SECURITY, HEALTH, AND ENVIRONMENT
Towards a Sustainable Coal-based Development Strategy for China

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This paper represents my own work in accordance with University regulations.

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EXECUTIVE SUMMARY

Background and Basis

In the next 30 years, 1400 GW of new electricity generation capacity is expected to be constructed worldwide. If all of this new generation capacity utilized coal, it would produce over its lifetime emissions of carbon dioxide 40% greater than total fossil carbon emissions from 1750 to the present. To avoid these emissions and the resulting impacts, it is imperative to develop new sources of decarbonized electricity. Integrated coal gasification and carbon capture and storage offers one of the most promising routes to decarbonized fossil fuel resources, since coal is abundant and secure and gasification is commercially viable. As such, coal gasification could play a significant role in increasing global supplies of decarbonized energy in the near and long term. However, several obstacles to implementation remain, especially in China and India where the most significant electricity growth will occur. China holds a position of special importance due to its extensive coal reserves and massive energy requirements, which together could transform China into the largest carbon emitter within the next two decades. Both China and the world have much to gain by avoiding this scenario and instead developing China's energy system along an alternative trajectory based on advanced coal technologies This paper will outline the fundamentals of China's coal dependent energy system, describe a coal gasification based alternative, identify the principal barriers to its implementation, and propose a set of policies to stimulate its development. Emphasis will be placed on minimizing carbon dioxide emissions while providing a long term supply of decarbonized energy from coal. Several categories of barriers to the implementation of coal gasification-based power plants have been identified and are followed by associated policy suggestions:

- **Environmental Policy:** Environmental regulations are poorly enforced and often inadequate to justify investment in clean technology.

- **Institutional Capabilities:** The innovation system is weak and fragmented and many companies lack commercial skills and neglect training.

- **Intellectual Property Rights Protection:** Intellectual property rights protection for advanced coal gasification technology is inadequate, hindering acquisition and diffusion of the technology.

- **Investment and Trade Rules:** Foreign ownership restrictions and complex approval processes for investments restrict foreign investor access to the potentially large Chinese market for advanced coal technologies, hindering the development of technology transfer relationships.

- **Finance and Economics:** Coal gasification-based power schemes rely on expensive imported technology and incomplete internalization of environmental and energy security externalities artificially reduce the financial incentive for such projects. Additionally, informational barriers arise from the unfamiliarity of the power generation sector with coal gasification technology.

Policy Recommendations

Recommendation I: Environmental Policy

- Enforce existing environmental regulations to reward clean technologies.
- Install monitoring equipment more widely to enable enforcement and develop domestic monitoring equipment manufacturing capacity.
- Introduce new pollution standards more gradually to give industry time to adjust.

Recommendation II: Institutional Capabilities

- Reform the innovation process to allow coordinated research, development, demonstration, and commercialization of advanced technologies such as coal gasification.

Recommendation III: Intellectual Property Rights Protection

- Strengthen intellectual property rights protection for advanced coal technologies.

Recommendation IV: Investment and Trade Rules

- Continue liberalizing foreign investment to allow greater foreign ownership and control of firms operating in China.
- Streamline the approval process for large foreign investments, particularly those related to coal gasification development.
- Encourage the OECD to develop an information clearinghouse to provide detailed information on the Chinese energy sector tailored for use by smaller firms considering investment in China.
- Actively develop new channels for technology transfer, beginning with the acquisition of clean coal technology through the Clean Development Mechanism (CDM).
- Define priority channels for technology transfer, favoring technology acquisition through foreign direct investment (FDI) and licensing (with appropriate IPR protection) over simple equipment imports.
- Develop administrative and economic measures to support the adoption of already imported technologies to allow the absorption of imported technology. Such measures could include subsidies for goal gasification demonstration projects and risk sharing (such as through loan guarantees) for the early adopters of transferred technology.
- Adopt measures to integrate technology transfer with domestic research and development to support the establishment of an integrated innovation system.

Recommendation V: Finance and Economics

- Environmental policies that accurately reflect the costs of pollution must be implemented and enforced to create the appropriate economic incentives for clean coal financing.
- Technology transfer and absorption is also crucial to allow not only the acquisition of clean coal technologies but also the domestic manufacturing of such hardware at much lower costs than for imported equipment.
- Demonstration projects should be developed to increase familiarity with the technology and address the information barriers to gasification-based power generation. Such projects would benefit from the establishment of avenues to public finance such as loan guarantees, capital subsidies, and grants.

1 INTRODUCTION

1.1 Coal and the Global Environment: Coal is an abundant, cheap, and inherently dirty resource that has historically provided energy via its combustion to produce electricity and heat. Out of all fossil fuels, the use of coal is most damaging to both the environment and human health, adversely affecting landscapes, rivers, ecosystems, water quality, air quality, and global climate. Though environmental impacts are associated with all phases of coal use, including both extraction and transportation, this paper concentrates on issues surrounding the combustion of coal, particularly the globally significant issues of air quality and carbon emissions.

Conventional coal combustion results in emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, mercury, and other metals greatly exceeding those emissions arising from oil or natural gas combustion, aggravating local and regional pollution problems such as acid rain and ground-level ozone. Coal combustion also generates relatively high emissions of carbon dioxide, since both its hydrogen to carbon ratio and power generation efficiency are unfavorable compared to other fossil fuels (Philibert & Podkanski, 2005).

Coal is used primarily for electricity generation, although it also plays a role producing process heat for industry and comfort heat for the residential and commercial sectors. Coal has an additional small role in the transport sector, either through direct use in antiquated steam railways or through conversion to liquid fuels. Coking coal also plays a role in the steel industry (Hongtao, Zheng, Weidou, Larson, & Tingjin, 2003).

Coal currently provides 23 percent of the global total primary energy supply, resulting in 38 percent of global energy related carbon dioxide emissions. Oil is responsible for a similar percentage of carbon dioxide emissions, though it accounts for about 36 percent of total primary energy supply (Jefferson, 2006). Considering existing energy policies in both the industrialized and developing world, the International Energy Agency (IEA) projects that the contribution of coal to global total primary energy supply will decline to 22 percent as natural gas capacity increases in the next 30 years, though absolute consumption of coal will continue to increase during this period (Philibert & Podkanski, 2005). However, this global fuel switching to natural gas, stimulated by policies favoring energy efficiency improvements and cleaner energy sources, will become limited by resource availability. In the long run, while the cleaner fossil fuels (oil and natural gas) become depleted, coal will remain an abundant fossil fuel resource (See Figure 1). Unless cleaner and more efficient coal technologies are implemented, increasing use of coal will exacerbate local, regional and global pollution problems. From a global perspective, the large role of coal for the foreseeable future combined with the mounting concern for air quality and carbon dioxide emissions make the implementation of clean coal technologies essential.

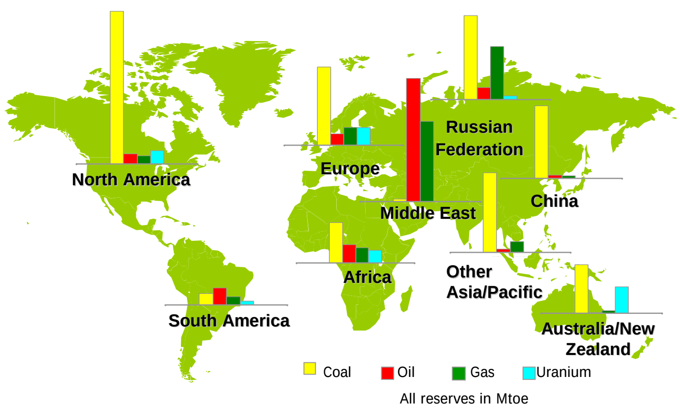

Figure 1: Coal Dominates Global Nonrenewable Fuel Reserves - Lifetimes for known reserves at current depletion levels are about 40 years for oil 65 years for gas, and 160 years for coal (500 years for some countries), using data from BP Statistical Review 2005 and WEC Survey of Energy Resources 2001.

1.2 Special Status of China: Because of its enormous potential impact, the consequences of China's economic development and associated energy development are vital not only to China, but also to the rest of the world. China is the most populous and has one of the most rapidly growing economies in the world, achieving annual GDP growth of about ten percent over the last twenty years. China ranks next to the U.S. in energy consumption, with a fifth of the

Organization for Economic Cooperation and Development's (OECD) and a tenth of the world's total primary energy consumption (ZhiDong, 2003).

As a consequence of this sustained economic growth, energy demand is growing so rapidly as to jeopardize development goals, as evidenced by a widespread shortage of power in 24 of 31 provinces in 2004 (Ping, 2005). As a consequence of the size and characteristics of the energy system, China also has the largest absolute SO_2 emissions and the second largest carbon dioxide emissions in the world (Ren, Zeng, & Zhou, 2005).

1.3 Uses of Coal in China: Coal combustion accounts for more than three quarters of electricity generation in China, with capacity totaling 360 GW in 2002 (See Figure 2). However, electricity generation is responsible for only 50 percent of Chinese coal consumption, far below the global average of 69 percent. Industry consumes the majority of the coal (42 percent of total) not used in electricity generation (Philibert & Podkanski, 2005). Residential and commercial uses account for the remaining 10 percent. Industrial boilers are used primarily in light industries that require process heat and power, such as the textile industry, and as a source of space heating for commercial buildings, apartment buildings, and district heating, especially in northern China (Philibert & Podkanski, 2005).

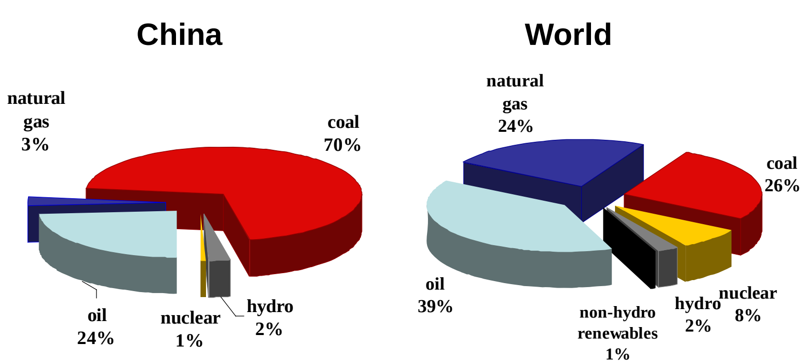

Figure 2 : Coal Use Large Percentage of China's Energy Mix Compared to World

1.4 Growth Projections: The Chinese government has stated the goal of transforming China to a middle level developed country by 2050, focusing initially on quadrupling the size of the economy by 2020. A doubling of power generation capacity is expected by 2020, followed by a tripling by 2030 (Philibert & Podkanski, 2005; Ping, 2005). Much of the growth is expected in coal-fired power plants, whose capacity is expected to grow from 360 GW in 2002 to 776 GW in 2030 (See Figure 3) (Philibert & Podkanski, 2005). Although the share of coal in total power generation (1187 GW in 2030) is expected to fall from today's level of 75 percent due to growth in gas-fired generation and renewables, the absolute increase in coal capacity expected through 2030 is unsurpassed (IEA- 2004a Scenario) .

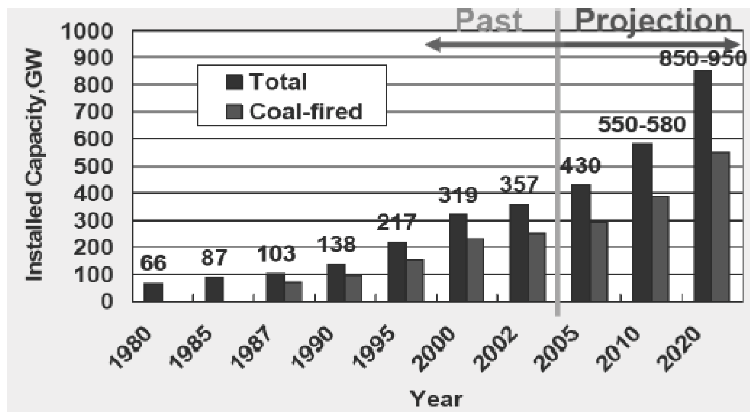

Figure 3: China's Installed Electricity Generation Capacity - Past, Present, and Future

China's dominant position in terms of coal power growth is supported by the observation that no less than 80 percent of global coal fired power plants ordered between 2001 and 2003 are destined for China (Philibert & Podkanski, 2005). Thus, the background for energy considerations in China is a rapid stable increase in energy demand and consumption, with fossil fuels remaining the dominant energy source in the coming decades (DeLaquil, Wenying, & Larson, 2003).

2 CHALLENGES TO ENERGY SECTOR GROWTH

For China to expand its economy fourfold by 2020 and meet its goals for economic development, energy security, and environmental protection, the current trajectory of energy system growth must be altered to address the challenges inherent to achieving the stated goals (Three E's of Sustainable Development, 16th Party Congress, October 2002) ((TFEST), 2003). The principal challenges that must be addressed as China's energy sector expands fall into three categories: (1) air pollution; (2) energy security; and (3) carbon dioxide emissions. An additional challenge arises from two particular characteristics of the energy system and its current status in China: first, though China's energy system capacity is growing rapidly, most of this capacity is yet to be constructed; and second, once constructed, the energy system has tremendous inertia. This problem of energy system investment lock-in adds additional urgency to the consideration of policies addressing the three fundamental challenges facing China's energy system development.

2.1 Air Pollution: The role of the environment in energy development is becoming more important in China as the costs of public health and environmental damages rise. Air pollution has become the most severe of these problems, with resulting economic consequences projected to grow from over seven percent today to 13 percent of GDP in 2020 ((TFEST), 2003). In Eastern China, for example, emissions of NH_3 are expected to rise by 20 percent, non-methane volatile organic compounds (NMVOC) by 50 percent, and all other species by 130–250 percent in 2020 with reference to 2000 levels (Xiaoping Wang et al., 2005). Similarly, total SO_2 production is expected to rise from 23 million tons in 1999 to 57 million tons by 2030. Against this projected growth, the government is aiming for a challenging total desulphurization rate of up to 65 percent by 2030, though this may reduce cloud albedo and lead to increased warming (ZhiDong, 2003). The energy sector is responsible for a large and growing share of air pollution and is coming under increasing pressure to reduce emissions levels while increasing output.

2.2 Energy Security - Avoiding Foreign Oil Dependence: China has stated a goal of meeting projected liquid fuel needs, especially for transportation, without endangering the security of energy supply by becoming excessively reliant on foreign oil imports. To achieve this goal, China would like to import a maximum of 30 percent of its crude oil ((TFEST), 2003). As found

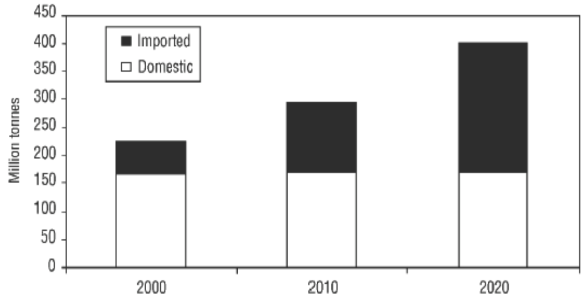

Figure 4: China's Projected Oil Consumption. Projection from the Energy Research Institute's Sustainable Energy Development and Carbon Emission Scenario 3 (high efficiency, but without coal gasification) (TFEST, 2003).

by a recent Energy Research Institute (ERI) analysis, oil imports may exceed 60 percent of total consumption by 2020 under the current energy growth trajectory (See Figure 4). Beyond China's opposition to such a significant dependence on foreign energy, more fundamental questions remain about who could provide such imports and whether China could afford them.

The conversion of coal to liquid fuels via advanced coal technologies is likely to play a crucial role in any effort to stem the growth of oil imports. A recent Task Force on Energy Strategies and Technologies (TFEST) analysis suggests that China could reduce projected oil imports by up to 30 percent in 2020 by aggressively pursuing an advanced coal technology strategy beginning immediately ((TFEST), 2003). Given current priorities, efforts to reduce the growth of oil imports are likely to play an active role in determining the future of China's energy sector (See **Appendix A** for more discussion).

2.3 Carbon Emissions In 2000, China emitted about 800 million tons of carbon from fuel combustion, making it the second largest carbon dioxide emitter in the world, with about 13 percent of global emissions (See Figure 5) (Chen, 2005). Between 1990 and 2004, carbon dioxide emissions from China increased by about 94 percent (about 700 million tons of carbon), equivalent to about 37 percent of the total global increase in this

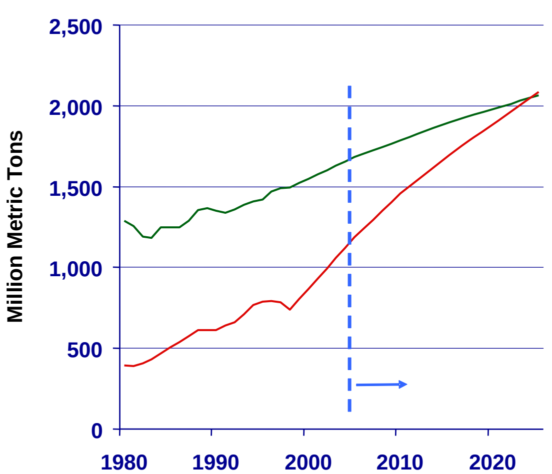

Figure 5: China's Carbon Emissions (red) Projected to Approach U.S. Levels (green) (projection from the Lawrence Berkeley National Laboratory)

period. Though carbon dioxide emissions in ten other developing countries increased even more rapidly, the next highest increase (India) amounted to less than 12 percent of China's absolute increase (Jefferson, 2006). Carbon dioxide emissions from energy consumption in China are projected to increase to 2270 million tons of carbon in 2030, equivalent to about 96% of the combined total North America and OECD Europe emissions in 1999 (ZhiDong, 2003).[1]

As climate change impacts become more pressing, such emissions differentials will attract increasing attention, leading to mounting pressure on long term energy development decisions in these countries.[2] To enable China to make a contribution to greenhouse gas emissions mitigation "on the basis of equity and in accordance with its common but differentiated responsibilities and respective capabilities," as established by the United Nations Framework Convention on Climate Change, the energy sector must develop on a new trajectory.[3]

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[1] Although China's per capita emissions will continue to remain far below that of the OECD countries today (1.5 tons carbon per capita in 2030 for China compared with three tons carbon per capita in 1999 for OECD countries), China's contribution to global GHG emissions will become increasingly significant in absolute terms(ZhiDong, 2003).

[2] In 2002, the average efficiency of coal-fired power plants in the OECD was 36 percent, compared with 30 percent for coal-fired power plants in the developing countries. As a consequence, 20 percent more carbon dioxide is emitted for each kilowatt-hour of electricity produced from coal in developing countries than from coal in the developed countries (Philibert & Podkanski, 2005).

[3] Already, China is coming under pressure from the developed countries to agree to some form of voluntary commitment to greenhouse gas (GHG) reductions (Chen, 2005).

2.4 Investment Lock-in: In addition to the challenges of air pollution, energy security, and carbon dioxide emissions discussed above, the unusual position of China early on its trajectory of energy system growth introduces an additional challenge. Policy will play a significant role in determining whether this challenge represents an opportunity or a risk.

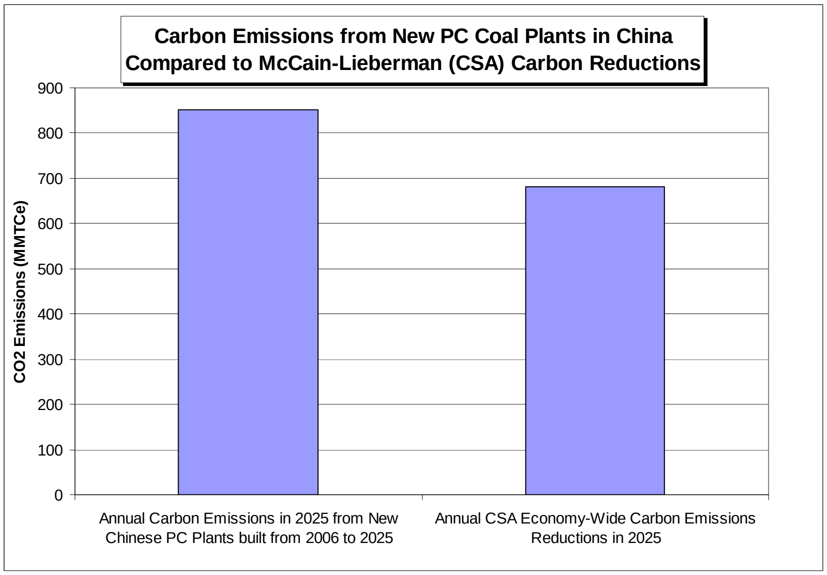

Figure 6: China's Projected New PC Power Plant CO_2 Emissions Exceed Proposed McCain-Lieberman Climate-Stewardship Act (CSA) CO_2 Reductions

The risk arises from the possibility that China's energy demand growth will be satisfied by rapid growth in new pulverized coal (PC) plant capacity. Such growth entails significant ramifications that arise from three characteristics of PC power generation: (1) PC power plants are amongst the longest-lived energy system investments, operating for 50 – 60 years; (2) PC power plants are the most carbon intensive energy system investments; and (3) addition of carbon capture and storage technology at a future date is expected to be prohibitively expensive (Sun, 2005). However, despite these considerations, large numbers of new PC power plants are under construction today and are expected to be built over the next 25 years, especially in China and India, where PC is the dominant electricity generation technology due to its maturity, familiarity, and favorable economics (See Figure 9). If built, these new PC plants will consume more coal during their lifetimes than all of industrial society to the present and will make any stabilization plans extremely difficult by absorbing a large portion of the global carbon budget (Figure 6, 7). However, this risk also represents an opportunity; although China's energy system is expanding rapidly, most of new capacity is yet to be constructed. More specifically, two thirds of China's coal-fired electricity generation capacity projected for 2020 is yet to be built (TFEST, 2003) (See Figure 8). Since China will construct a large portion of its durable energy infrastructure in the coming years, China has a great opportunity to shape its energy sector, much more so than countries with slow growth or large amounts of sunk capital in existing infrastructure (Jin & Liu, 1999). Time is extremely important because large investments planned for electricity generation over the next decade will lock in the method of coal use in China through 2020 and for many decades following. To avoid lock-in, a significant portion of new coal-fired electricity generation capacity must be constructed on a sustainable modernized path. Though rapid growth in renewables is also a component of any sustainable energy development path, coal will continue to play a dominant role in China's electricity generation

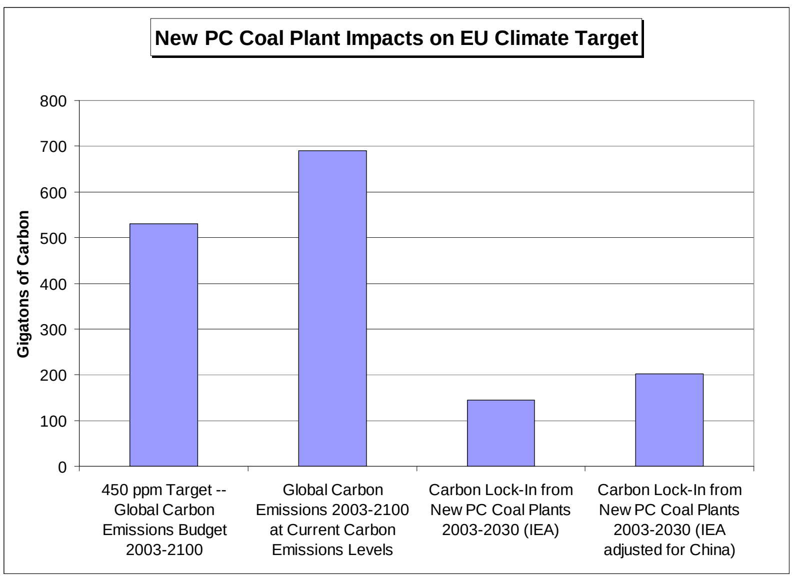

Figure 7: Projected Carbon Lock-in from New PC Plants Through 2030

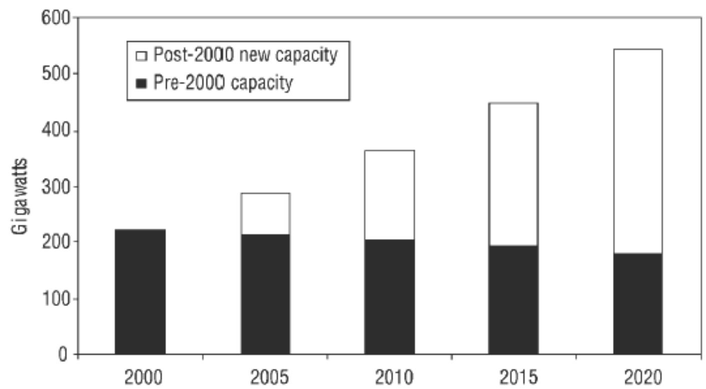

Figure 8: China's Projected Coal Power Plant Capacity - The Electric Power Technology Market Association of China estimated that two-thirds of the coal plant capacity that will be operating in 2020 is yet to be built (TFEST, 2003).

system due to its abundance, familiarity, and favorable economics. Analyses indicate that such an advanced coal technology strategy based on coal gasification would require only a small (about one percent) increase in total energy system cost compared with business as usual, though it would require significantly higher capital investments in energy technologies. These higher capital costs, however, would be offset by lower energy costs, especially from reduced energy imports (DeLaquil et al., 2003). With China and India accounting for more than half of expected global growth in PC plants, the importance of coal modernization via gasification is particularly significant for energy development in these countries (See Figure 9).

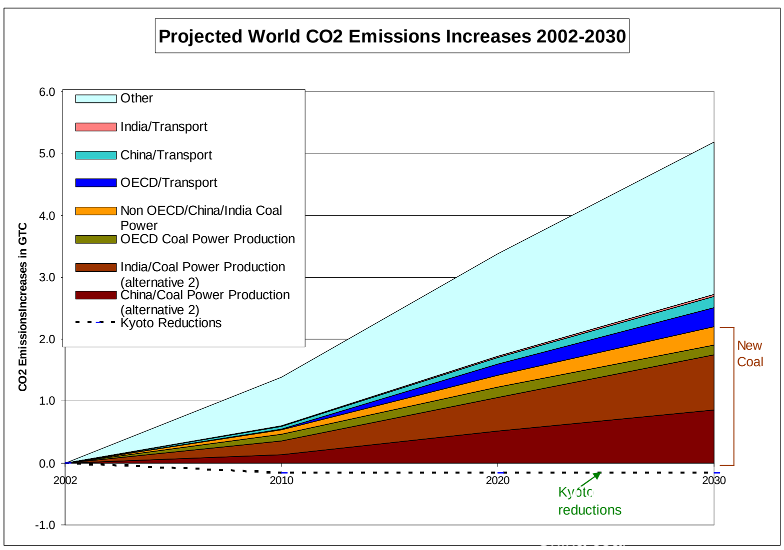

Figure 9: New Coal in China and India Dominates Projected Carbon Growth

3 CLEAN COAL TECHNOLOGY

3.1 Coal Gasification Technology: Gasification is the partial oxidation of a solid or liquid hydrocarbon feedstock to produce a gaseous product (synthesis gas or "syngas") composed primarily of hydrogen (H_2) and carbon monoxide (CO). This synthesis gas is a versatile product that can be used for several purposes, including (1) as a clean substitute for natural gas,[4] since impurities such as sulfur, nitrogen, particulates, and volatile mercury are removed during gasification; (2) to generate electricity efficiently using modern gas turbines in Integrated Gasification and Combined Cycle (IGCC) schemes; or (3) to produce a variety of synthetic liquid fuels, ranging from fuels compatible with existing compression-ignition engines to hydrogen for fuel cells (See Figure 11) (Watson, 2005). In addition to the air quality and energy security benefits available from coal gasification, gasification also provides a practical opportunity for carbon capture and storage. Thus, gasification represents the key technology to allow coal modernization in a manner that addresses the three fundamental challenges facing China's energy system development.

Coal gasification is based on technologies that are known and proven and is already in use extensively throughout the world (See Figure 10). There are currently about 385 utility scale gasifiers operating at over 100 projects across the globe. These gasifiers are used to produce electricity in the U.S., Europe, and Japan, chemicals and methane in the U.S., liquid fuels in South Africa, and ammonia fertilizer in China and India (Rosenberg et al., 2005). Several commercially used gasifier designs are currently available, including technologies from Shell, GE Energy, ConocoPhillips, Lurgi, and Noell (Rosenberg et al., 2005).

China already has extensive experience with gasification technology with about 8000 gasifiers currently installed, half of which use atmospheric fixed-bed technology to gasify coal (comprising about nine GW of

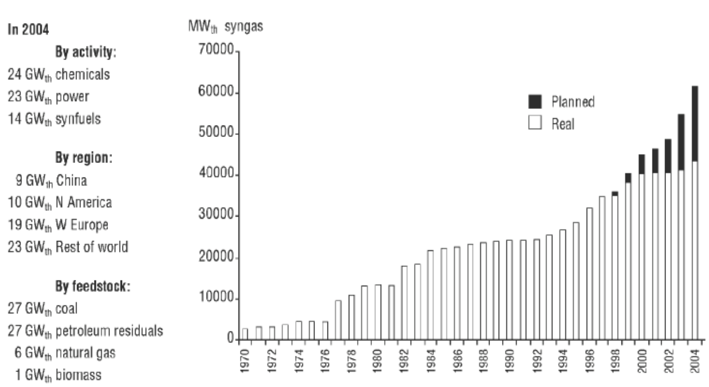

Figure 10: Cumulative Global Gasification Capacity and Growth (TFEST, 2003)

natural gas, but it can also be converted to ally available (Rosenberg, Walker, & Alpern, capacity) (Wanwang, 1999). This capacity, however, exists in the chemical industry rather than the power industry, suggesting that cross-sector fertilization would be advantageous. Furthermore, most of these installations are small and rely on inefficient and outdated designs, though a limited number of more advanced foreign gasifiers have been constructed in China, including a handful of Texaco and Lurgi gasifiers used for fertilizer, synthetic natural gas, and methanol production (Hongtao et al., 2003). Great efficiency and emissions reduction benefits would be realized from the wider use of such cleaner more advanced gasifier designs from foreign companies. For the case of a polygeneration plant based on coal gasification, though all components are currently commercially available, integration is new and requires learning by experience. Thus, successful implementation requires integration and investment in existing technologies rather than the development of new ones.

3.2 Comparison of Coal Gasification and Boiler Technologies Gasification offers several substantial environmental advantages over the direct combustion of coal in conventional PC systems, including (1) air pollutant reductions, (2) energy security benefits, and (3) carbon emissions reduction potential. In particular, polygeneration to produce electricity, liquid fuels, and petrochemicals offers the greatest range of advantages, making it the most attractive strategy for the advancement of coal gasification.

Today's dominant PC power plants result in emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, and mercury

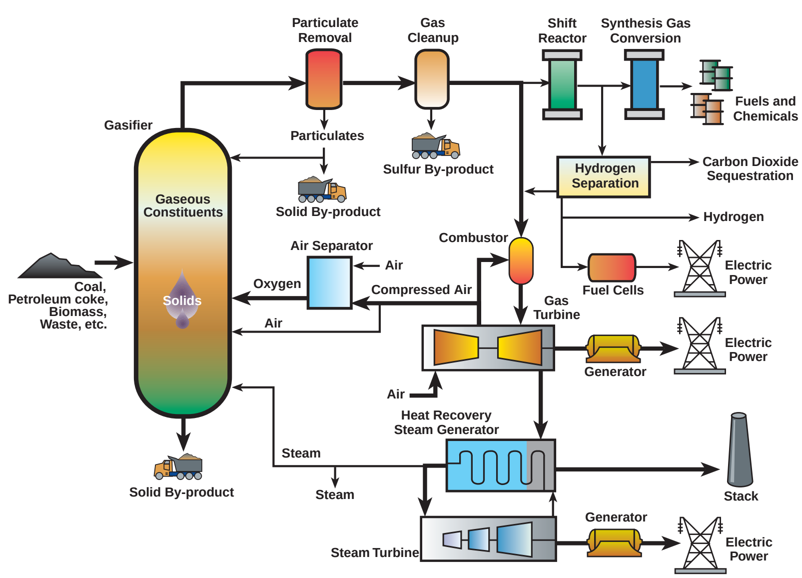

Figure 11: Gasification Technology Schematic (Gasification Technology Council, 2006)

(Moskovitz, 2000). Though these emissions can be reduced through combustion or post-combustion control processes, gasification allows pre-combustion fuel clean-up that is more cost-effective due to a greater concentration of pollutants, lower mass flow rate, and higher pressure than is found in post-combustion flue gases (Rosenberg et al., 2005). This pre-combustion synthesis gas clean-up allows more cost-effective and equal or better emissions reductions than post-combustion treatments, achieving an emissions profile similar to that for natural gas combined cycle electricity generation. Gasification also allows the effective (almost 100 percent) removal of mercury through the use of carbon beds in post syngas cleanup (Rosenberg et al., 2005). Carbon beds are more cost-effective and produce significantly less solid waste than activated carbon injection at a PC plant. Furthermore, since carbon bed waste is managed as a hazardous waste, reemission is inhibited.

Gasification offers several additional environmental advantages over PC combustion. First, the use of gas turbines and combined cycles allows greater efficiency in electricity generation. Second, gasification allows 20 – 50 percent reductions in water usage compared with conventional coal plants, as well as the possibility of dry cooling to further reduce water use. Third, gasification allows approximately a 50 percent reduction by volume in solid waste production. Furthermore, the solid waste is less likely to leach toxic metals than fly ash from conventional coal plants since ash melts and is vitrified in gasification. Gasification also results in the production of marketable sulfur and non-leachable slag byproducts (Watson, 2005).

Gasification offers a means by which to counter China’s growing dependence on foreign oil imports and to thereby enhance energy security, since syngas from gasification can be processed in a polygeneration plant to produce high quality liquid fuels, such as sulfur-free diesel, methanol, and dimethyl ether (DME), as well as a variety of other products, including electricity, hydrogen, steam, and petrochemicals (Larson & Tingjin, 2003).

3.3 Gasification for Electricity Production: Coal gasification can be used with a combined cycle power block to generate electricity in a process called integrated gasification combined cycle (IGCC) generation. IGCC systems produce syngas by coal gasification, clean the syngas with gas cleanup equipment, and combust the syngas in gas turbines to produce electricity. Residual heat is recovered from the turbine exhaust gas in a heat recovery boiler and used to produce additional electricity in a steam turbine generator. IGCC power plants are among the cleanest and most efficient of the advanced coal technologies, setting new standards for pollutant emissions and offering efficiencies rising above 50 percent (Philibert & Podkanski, 2005).

Although the first coal-fired IGCC plant entered into operation over 20 years ago, the technology has not exited the demonstration phase. In 2003, there were 14 IGCC projects in commercial operation, including two in Asia.[5] All have been at least partially supported with public funding.

Currently, several IGCC plants are in the approval process in the US. In Japan, a 250 MW demonstration project is coming online in 2008, funded by a consortium of utilities and government subsidies (Watson, 2005).[6] A number of other coal, petroleum coke, and heavy oil IGCC projects are currently being considered worldwide.

3.4 Polygeneration for

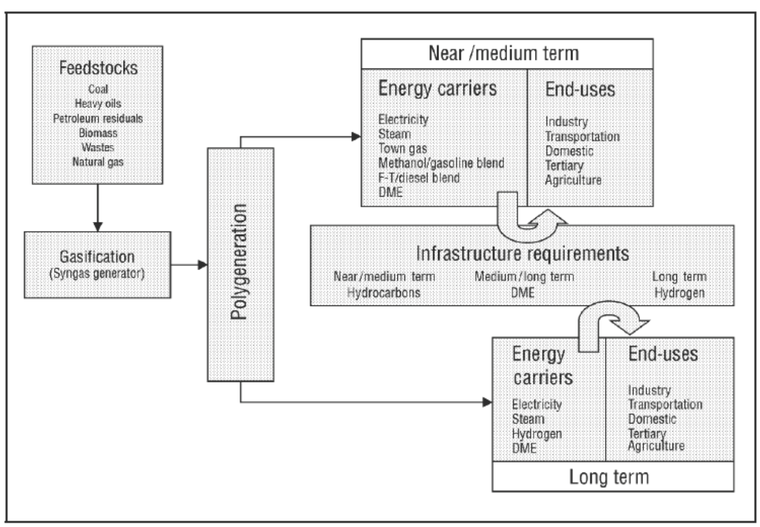

Figure 12: Polygeneration Schematic (TFEST, 2003)

[5] Of these 14 IGCC projects, eight were loc … s, such as coal and petroleum coke, and six us … Shell technology, one used Krupp Uhde, or … y (Rosenberg et al., 2005). Additionally, gasi … such as hydrogen for ammonia/urea synthe… refineries.

[6] At least two new IGCC plants have been … st two U.S. utilities have announced plans to …

Production of Electricity and Liquid Fuels In addition to IGCC, the synthesis gas generated from coal gasification can be used to produce a variety of liquid fuels, process fuel feedstocks, chemicals, heat, steam, and electricity in a polygeneration plant (Figure 12) (Watson, Xue, Oldham, MacKerron, & Thomas, 2000). This scheme is attractive because after all pollutants, such as sulfur, nitrogen, and mercury, are removed from the syngas, the syngas can be used to manufacture the chemical that best serves performance goals (such as high cetane or high octane) and emission goals (such as inherently low particulate and NOx emissions).[7] Thus, in addition to providing a strategy allowing China to reduce the growth in its dependence on foreign sources of oil and natural gas, polygeneration allows the production of synthetic liquid fuels that are superior to conventional hydrocarbon fuels with regard to both performance and emissions characteristics (See **Appendix B** for a detailed description of near-term and long-term polygeneration capabilities) (Williams, 2001).

Modernization of coal via gasification introduces new infrastructure challenges and opportunities for China, but the range of potential products from polygeneration avoids the need for sudden infrastructure changes. Coal modernization also could provide opportunities for alleviating some existing infrastructure problems in China, such as the current railway infrastructure problem of coal transport utilizing 70 percent of rail capacity. If polygeneration plants were located near coal mines, fuel and electricity could be

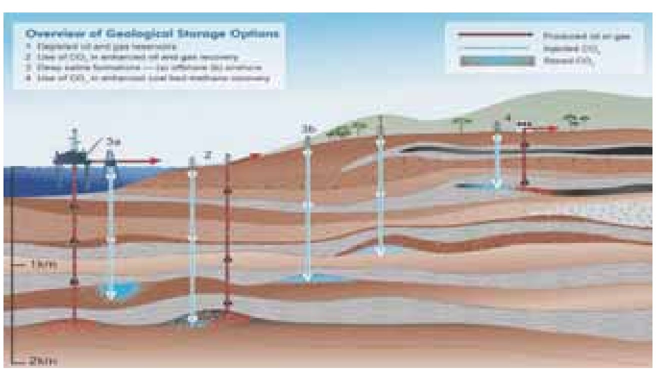

Figure 13: Geologic Sequestration Options (IPCC, 2005)

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iance with conventional hydrocarbon fuels will echnology and improvements in fuel quality, y continual modifications of both production and end-use processes are avoided with gasification technologies since most pollutants are removed in the standard gasification process.

transported to market by pipeline and wire (Jin & Liu, 1999).

3.5 Carbon Capture and Storage (CCS): Perhaps most significant globally, gasification provides a practical opportunity for reducing carbon dioxide emissions from coal-fired electricity generation through carbon capture and storage (See Figure 13). By adding water-gas shift reactors and physical absorption processes to the treatment of syngas from oxygen-blown gasification, a nearly pure stream of carbon dioxide that can be segregated at low marginal costs is obtained (Ren et al., 2005). This approach to carbon dioxide capture is widely held to be more cost-effective than post-combustion capture with conventional coal combustion technologies (Rosenberg et al., 2005).

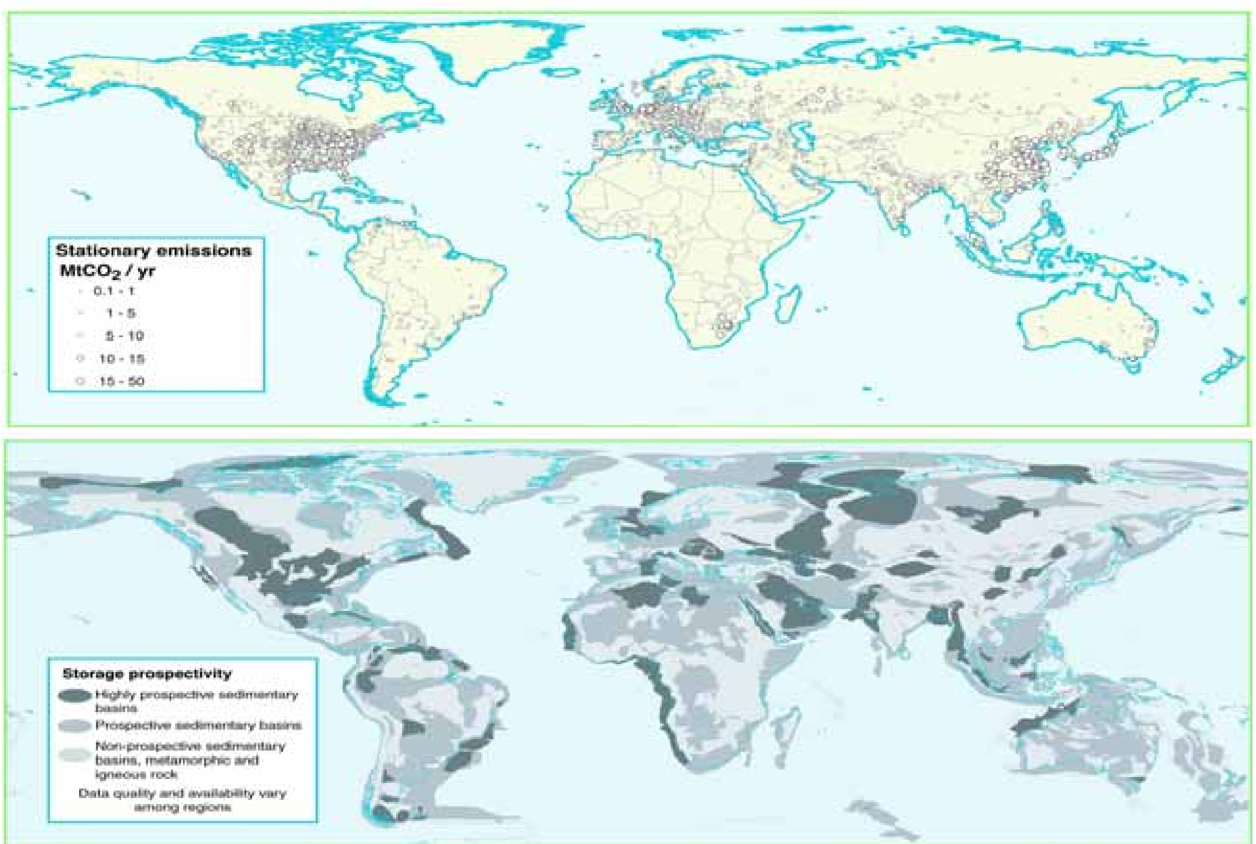

Figure 14: Good fit between global distribution of large carbon dioxide emission sources and prospective geologic storage (IPCC, 2005)

As stated by the U.S. National Commission on Energy Policy, "Coal-based integrated gasification combined cycle (IGCC) technology […] can open the door to economic carbon capture and storage, [and] holds great promise for advancing national as well as global economic, environmental, and energy security goals. The future of coal and the success of greenhouse gas mitigation policies may well hinge to a large extent on whether this technology can be successfully commercialized and deployed over the next 20 years" (Rosenberg et al., 2005). Though the significance of the issues associated with CCS cannot be overstated— the potential carbon emissions reduction benefits of coal gasification rest almost entirely on their successful resolution—it is beyond the scope of this paper to explore them (See **Appendix F** for a more lengthy discussion). However, should these issues be successfully resolved, extensive geologic storage capacity is available in China (Figure 14).

4 POLICY BARRIERS AND RECOMMENDATIONS

4.1 Policy Challenges:

Two fundamental premises underlie the need to actively modernize the growth of China's energy system. First, China is likely to sustain at least six percent annual economic growth in the next 30 years. Second, energy system growth with base technologies, utilizing coal combustion for power generation and petroleum fuels, cannot meet the development goals for air pollution, potential carbon dioxide alleviation, and especially for energy security ((TFEST), 2003). An advanced technologies strategy, utilizing a combination of energy efficiency, natural gas, renewable energy, and modernized coal, may be able to provide similar energy services at similar costs while also limiting oil and natural gas imports to about 30 percent of total supply and satisfying objectives for air pollution and carbon dioxide emissions (See Figure 15) (ZhiDong, 2003).

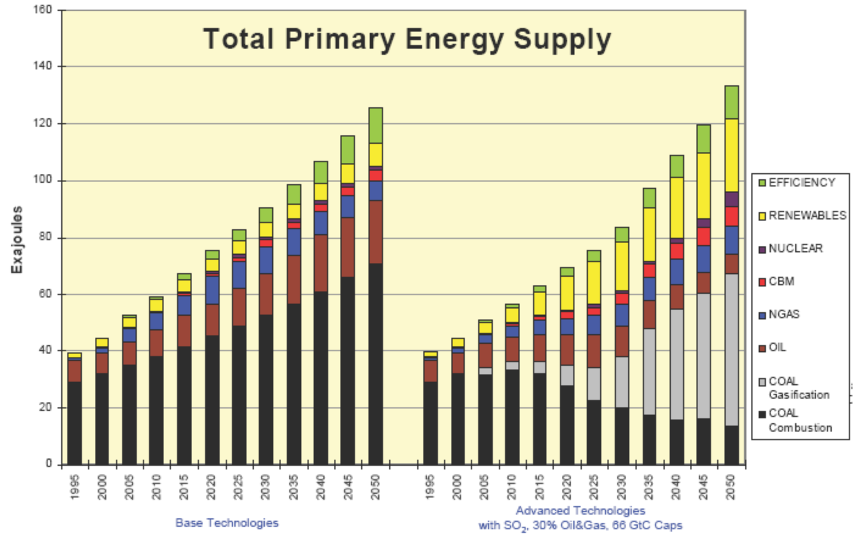

Figure 15: Coal Gasification Not Adopted in Absence of Policy - In the advanced technologies scenario SO_2 emissions are reduced from 23.7 Mt in 1995 to 16.2 Mt in 2020 and 8.8 Mt in 2050. Oil and natural gas imports are limited to 30 percent of consumption. The 66 GtC cap is China's cumulative carbon emission allowance based on CO_2 stabilization at 450ppm and year 2000 population-based apportioning of globally allowed carbon emissions (TFEST, 2003).

Energy demand growth, constrained by air pollution, potentially by carbon emissions, and by energy security, suggests a critical need to develop CCS-enabled coal gasification. Gasification based energy system growth provides an attractive alternative to pulverized coal growth in China, serving as a pathway for alleviating energy security issues arising from dependence on foreign oil imports, reducing air pollution, and providing a potential lower-cost route to reductions in carbon dioxide emissions. Despite the less favorable economics for gasification in China at present, it is becoming an increasingly attractive technology for producing synthetic natural gas, liquid fuels, ammonia, and other chemicals. Such polygeneration schemes allow the realization of the energy security benefits of coal gasification, as well as the air pollution advantages and the potential carbon dioxide mitigation benefits. Hence, the additional drivers provided by polygeneration may prove sufficient to motivate the development of IGCC in China within a favorable policy environment (Xiaohua Wang & Feng, 2003).

For deployment to proceed, a favorable policy environment must address the barriers to coal gasification. The major global barriers to widespread commercialization fall into five categories: (1) Environmental Policy; (2) Institutional Capabilities; (3) Intellectual Property Rights Protection; (4) Investment and Trade rules; and (5) Finance and Economics (See **Appendix E** for discussion of an additional issue). Each barrier is described below and followed by associated policy recommendations.

4.2 Recommendation I: Environmental Policy

Barrier: Environmental regulations are poorly enforced and often inadequate to justify investment in clean technology (Zhufeng & Jie, 2001).

This barrier is often cited as one of the most problematic obstacles to the development of clean coal technology in China, second only to the need for general economic reforms (Philibert & Podkanski, 2005). Two issues contribute to this barrier: first, existing regulations are not adequately tough to change behavior and justify investment in clean technology such as gasification; and second, existing standards are enforced weakly and inconsistently. For these reasons, existing environmental regulations have only affected the energy sector marginally; since the incentive to reduce pollution is lacking despite a growing desire to do so, environmental considerations typically fall far behind economic or social ones, especially in cases such as gasification where new technology and expertise must be acquired. Even when tougher laws are enacted, little is often achieved since the market does not respond in the absence of enforcement (See **Appendix C** for an exception where environmental regulations are strictly enforced).

In addition to the general problems for environmental enforcement such as the lack of sufficient resources in government agencies such as the State Environmental Protection Agency (SEPA) and the dominance of economic growth in decision-making, enforcement is often prohibited by the absence of appropriate monitoring equipment at many industrial installations (Philibert & Podkanski, 2005). This equipment is often costly because it is imported; thus, the acquisition of technologies and the development of domestic manufacturing capacity for such products, perhaps through joint venture companies, could lead to more widespread monitoring, enabling more effective enforcement of environmental regulations.[8]

Recommendations:

(1) Enforce existing environmental regulations to reward clean technologies.

(2) Install monitoring equipment more widely to enable enforcement and develop domestic monitoring equipment manufacturing capacity.

(3) Introduce new pollution standards more gradually to give industry time to adjust.

4.3 Recommendation II: Institutional Capabilities

[8] Recent initiatives, such as efforts to strengthen the pollution fee system, indicate that pollution regulation enforcement is becoming a higher priority. In some regions, environmental policies are similar to those in industrialized countries, suggesting that emphasis should be placed on implementation of existing regulations, rather than promulgation of new ones.

Barrier: The innovation system is weak and fragmented and many companies lack commercial skills and neglect appropriate training.

Though China has advanced scientific/technological capabilities in universities and research institutes and extensive manufacturing capacities in industry, the two sectors are ineffectively bridged and not connected to foreign companies, resulting in a suboptimal environment for innovation (Jin & Liu, 1999).[9] The fragmented innovation system creates barriers to the transfer and development of advanced coal technologies. Though some obstacles arise from insufficient technical expertise in Chinese organizations, the more significant problem is a general lack of commercial and organizational proficiency in the overall innovation system.

The lack of industrial organization structures that allow continuous research, development, and manufacturing obstructs not only domestic innovation, but also hinders international collaboration and technology transfer because manufacturing capacities and design capacities often reside in different institutions. This hinders technological collaboration since foreign companies often must communicate design issues through design institutes rather than directly to manufacturers that lack advanced technological skills. The separation of design and manufacture also makes it difficult for foreign companies to locate the appropriate initial contacts (See **Appendix D** for additional discussion) (Weidou & Johansson, 2004).

An innovation scheme for the research and development of key clean coal technology is proposed here: First, the related government department originates a project utilizing clean coal technology and solicits bids from companies. The winning bidder would then select and fund research institutions as needed. The research institute would be accountable to the company, and

[9] This separation between design and manufacturing and resulting lack of commercial/innovation skills arises from the history of China's enterprise system, where design work was performed in dedicated design institutes and State-owned manufacturing enterprises relied on centrally planned production schedules. Today, commercial behavior such as competition for contracts is replacing central planning, but the disjoint between design and manufacture remains.

the company in turn would be accountable to the government. This organization would effectively give the companies the leading role, facilitating coordination, research and development, and commercialization. The government department would play a role coordinating research and development and would support demonstration projects with additional incentives such as tax benefits and subsidies.

Recommendation:

(1) Reform the innovation process to allow coordinated research, development, demonstration, and commercialization of advanced technologies such as coal gasification.

4.4 Recommendation III: Intellectual Property Rights

Barrier: Intellectual property rights protection for advanced coal gasification technology is inadequate, hindering technology acquisition and diffusion (Philibert & Podkanski, 2005).

Intellectual property right issues- the concern that designs will be copied outside of license agreements- remains one of the primary obstacles to both domestic innovation and technology transfer. Within China, many institutions and universities refuse technology exchanges to preserve technological advantages and protect intellectual property rights. Similarly, foreign firms are often reluctant to transfer technology out of fear that designs will be illegally copied and utilized in China without adequate compensation.[10]

Recommendation:

(1) Strengthen intellectual property rights protection for advanced coal technologies.

4.5 Recommendation IV: Investment and Trade Rules

[10] However, intellectual property right protection is gradually improving in China, perhaps as the commercialization or former State-owned industries strengthens respect for intellectual property rights. Nevertheless, measures should be further developed to provide a rigorous legal framework for the rights and responsibilities of clean coal technology developers, owners, and users, both domestic and foreign, so that interests are legally protected.

Barrier: Foreign ownership restrictions and complex approval processes for investments restrict foreign investor access to the potentially large Chinese market for advanced coal technologies, hindering the development of technology transfer relationships.

First, restrictions on foreign ownership in joint ventures with Chinese companies drastically reduce foreign investment and technology transfer. Although the desire of the Chinese Government to protect domestic firms and improve their capabilities through collaboration may seem legitimate, foreign investors demand a share of management control over joint venture companies in which they invest, especially if the collaboration involves technology transfer (Watson et al., 2000). Instead, however foreign money is readily accepted by joint ventures, but these joint ventures often refuse to engage in joint decision-making, leading to a situation where foreign investors contribute significant funding without gaining any managerial or financial control (Zhufeng & Jie, 2001).[11]

Second, the negotiation and approval process for foreign investments in China is significantly more arduous and complex than in many other countries; it can take months or even years to reach agreements for certain investments (Watson et al., 2000). This is particularly problematic for smaller companies that lack the resources to develop long term contacts with the Chinese Government and industries. Currently, the most active foreign firms in China tend to be large companies such as Shell International. While many smaller more focused companies in the advanced coal technology business see China as a potentially promising market for their products, expertise, and technology, due to the abundance of China's coal reserves and the size of the market, expansion into easier foreign markets is often preferred over China (Watson et al., 2000).

[11] It may even be the case that 100 percent foreign investor ownership of new installations could be better for China's environment and technology transfer in the short term by granting a foreign owner complete control over the management and operation of the facility and a higher financial interest in its efficient operation.

In addition to concern about intellectual property rights protection, smaller companies often have a difficult time obtaining the information needed to evaluate risks appropriately. An international organization could reduce this asymmetry by providing information support to smaller companies, allowing them to more accurately assess the risks and resources required for a venture (Sun, 2005).

Recommendations:

(1) Continue liberalizing foreign investment to allow greater foreign ownership and control of firms operating in China.

(2) Streamline the approval process for large foreign investments, particularly those related to coal gasification development.

(3) Encourage the OECD to develop an information clearinghouse to provide detailed information on the Chinese energy sector tailored for use by smaller firms considering investment in China.

The transfer of technology to China warrants particular attention. Ample opportunities exist for technology transfer to improve the performance of China's power generation sector, such as the provision of management and technical training, the application of advanced control systems, the installation of monitoring equipment, the implementation of improved maintenance regimes, and the development of modern technologies that could benefit from foreign expertise, such as coal gasification. Technology transfer can occur through a variety of mechanisms including joint ventures, technical assistance, and project-specific collaboration (Philibert & Podkanski, 2005).

Technology transfer is often confused with the simple export of hardware; however, successful technology acquisition also requires the wider transfer of knowledge. In some cases, knowledge transfer such as design, management, operation, and maintenance skills may be more important than hardware transfer. For both partners in technology transfer agreements, however, the transfer of tangible and prestigious hardware is often overemphasized. This leads to an incomplete transfer process if the Chinese firm lacks the wider knowledge required for optimal installation and management (Philibert & Podkanski, 2005).

Recommendations: The following recommendations, prepared for China, offer an approach to coordinating technology transfer of coal gasification technologies to allow the development of an improved innovation system in China, thereby allowing economic growth based on modernized power generation growth.

(1) Actively develop new channels for technology transfer, beginning with the acquisition of clean coal technology through the Clean Development Mechanism (CDM).

(2) Define priority channels for technology transfer, favoring technology acquisition through foreign direct investment (FDI) and licensing (with appropriate IPR protection) over simple equipment imports.

(3) Develop administrative and economic measures to support the adoption of already imported technologies to allow the absorption of imported technology. Such measures could include subsidies for goal gasification demonstration projects and risk sharing (such as through loan guarantees) for early adopters of transferred technology

(4) Adopt measures to integrate technology transfer with domestic research and development to support the establishment of an integrated innovation system. For example, the central government could initiate clean coal technology-based projects and leave the management of these projects to private firms who could select partners with the requisite technological and management capabilities.

4.6 Recommendation V: Finance and Economics

Barriers: Coal gasification-based power schemes rely on expensive imported technology and incomplete internalization of environmental and energy security externalities artificially reduce the financial incentive for such projects. Additionally, informational barriers arise from the unfamiliarity of the power generation sector with coal gasification technology (Atwood, Fung, & Clark, 2003).

Lack of finance is often cited as the most significant obstacle to the transfer and implementation of coal gasification. This lack of finance arises from several sources: (1) coal gasification power generation schemes rely on costly imported technology, introducing an additional financial barrier to implementation and underscoring the need for effective technology transfer; (2) externalities, such as those of air pollution and energy security, are not appropriately valued, thereby distorting market incentives. In this situation an economically viable project will not attract private finance until externalities are internalized such as through pollution charges or public concessional finance; (3) even when a project is both economically and financially viable, finance still may not be forthcoming due to apprehension of risks involved with lack of information or experience with a technology scheme. These information/managerial obstacles[12] can theoretically be resolved within the private financial sphere; however, public support is likely to play a crucial role (Philibert & Podkanski, 2005).[13]

[12] Such information/managerial obstacles include: (a) gasification technology is unfamiliar to the power industry, which sees it as belonging to a chemical plant not a power plant; (b) firms are reluctant to be early adopters and assume technology application risk; (c) business models for gasification IGCC or polygeneration plants are undeveloped; and (d) few IGCC or polygeneration units are in operation, many do not use coal, and many are located overseas.

[13] The deployment of advanced power generation technologies such as coal gasification for polygeneration is likely to begin with the construction of initial demonstration plants. Such demonstration projects are likely to rely on public finance such as loan guarantees, capital subsidies, or grants. This lack of finance for capital intensive demonstration projects is an obstacle throughout the world, with these technology schemes just beginning to become viable without major public support in the U.S. However, such demonstrations offer an attractive path forward for the development of coal gasification-based schemes as they serve as an integrative framework in which many

Recommendations:

(1) Environmental policies that accurately reflect the costs of pollution must be implemented and enforced to create the appropriate economic incentives for clean coal financing.

(2) Technology transfer and absorption is crucial to allow not only the acquisition of clean coal technologies but also the domestic manufacture of such hardware at much lower costs than for imported equipment.

(3) Demonstration projects should be developed to increase familiarity with the technology and address the information barriers to gasification-based power generation. Such projects would benefit from the establishment of avenues to public finance such as loan guarantees, capital subsidies, and grants.

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barriers to gasification are addressed, including the informational/managerial obstacles and the technology transfer issues.

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6 APPENDICES

Appendix A: Energy Security

Energy security presents a pressing challenge for the development of China's energy system. China, a country with minimal domestic oil resources, is determined to avoid a position of excessive reliance on foreign oil imports; however, as demand for liquid fuels continues to grow rapidly, especially for the transportation sector, China is projected to become increasingly dependent on foreign oil imports.

Another analysis considering both oil and natural gas and assuming self-sufficiency of coal and optimistic domestic production of crude oil and natural gas projected that the fossil fuel supply shortfall will increase to 710 Mtoe in 2030, with oil responsible for 567 Mtoe and natural gas responsible for 142 Mtoe of the shortfall. If imports rise to offset this shortfall, the share of import-dependence will rise to 76% for oil and 52% for natural gas (ZhiDong, 2003). Beyond China's opposition to such a significant dependence on foreign energy, more fundamental questions remain about who could provide such imports and whether China could afford them.

Appendix B: Polygeneration

Furthermore, polygeneration allows the evolution from one set of technological options in the near term (2006-2020) to a potentially more attractive set of options in the long term (beyond 2020). In the near term, clean synthetic fuels such as synthetic natural gas, methanol, Fischer-Tropsch (F-T) liquids, and DME could be produced in polygeneration facilities that also make electricity, providing a range of energy services for several potential markets, including transportation, urban, and rural: (1) substitute transportation fuels that require no new infrastructure, such as methanol blended with gasoline or F-T liquids blended with diesel; (2) substitute transportation fuels that require new infrastructure, such as DME for buses, trucks, and cars as compression-ignition engines become more widespread; (3) electricity and synthetic natural gas as a replacement for coal in urban domestic heating, cooking, and industrial heating; and (4) DME as a cooking fuel for rural areas, augmenting tight supplies of liquefied petroleum gas (LPG) in the existing LPG infrastructure (Larson, Zongxin, DeLaquil, Wenying, & Pengfei, 2003).

In the long term, polygeneration including CCS could allow schemes such as the production of hydrogen as an energy carrier with near-zero emissions of carbon dioxide or the production of rural electricity from biomass polygeneration facilities co-producing DME for transportation and cooking (Williams, 2001).

Appendix C: Environmental Policy

Notable exceptions to the typical lack of environmental regulations enforcement occur for energy projects based on imported equipment. Often the Chinese Government treats these installations as technological and environmental showcases, leading to unusually stringent oversight by China's State Environmental Protection Administration (SEPA), as well as international funding agencies such as the World Bank in certain situations. While these instances demonstrate that SEPA has sufficient power to enforce environmental regulations, this differential treatment biases the market against installing modern power plants that attract scrutiny and are simultaneously undercut by inefficient capacity owned by provincial power companies. Foreign companies would have a greater incentive to transfer technology if they were confident that inferior technology would be penalized. This lack of confidence that enforcement will favor cleaner technology over dirtier options, even if the laws do, significantly weakens the incentive to develop clean technologies in China (Watson et al., 2000).

The weakness of enforcement is likely to become more damaging to advanced generating capacity as the electricity industry is deregulated, since expensive but cleaner new plants will have a more difficult time competing against older depreciated State-owned plants. Unless a mechanism such as enforcement of existing environmental regulations rewards the use of clean technologies, freer pricing of electricity may harm the development of cleaner generating capacity such as gasification-based systems.

Appendix D: Institutional Barriers

The lack of innovation capacity at the manufacturing level also hinders the transfer of advanced coal technology knowledge and management skills beyond a simple hardware order. Wider collaboration beyond hardware transfer is necessary for advanced technologies such as gasification-based schemes, since gasification is an emerging industry compared with the established boiler industry, standard designs and guarantee packages for advanced gasification installations are not fully developed, and operation and maintenance are critical to the success of the technology.

Additionally, many Chinese industries rely on complex networks of national, regional and local organizations such as research institutes and manufacturing companies, making it difficult for foreign companies to find the appropriate initial contacts. This is particularly disadvantageous for smaller foreign firms lacking the resources to search exhaustively for fitting partners in China. These firms can become discouraged by the number of potential communication routes and entry points, none of which may be optimal (Watson et al., 2000).

Though Chinese research institutes have the technical capabilities to develop advanced coal technologies including gasification, the research institutes lack a history of effectively commercializing their innovations due to their typical separation from design institutes and manufacturing enterprises. The innovation process has proven more successful when manufacturing or design enterprises solicit assistance from and compensate research institutions for solving a specific problem (Zhufeng & Jie, 2001).

Appendix E: Technological Barriers

Two of the most significant remaining technological barriers to coal gasification are: (1) the currently higher capital and operating costs for gasification based power plants compared with typical coal combustion technology; (2) availability/reliability concerns that are costly to reduce with a spare train; and (3) questions remain about suitability and cost of using low quality coals, such as lignite.

At present, capital costs are typically 20 percent higher for IGCC plants than for PC plants, especially in China where IGCC plants do not have a chance of competing economically with conventional coal-steam power plants unless SO_2 and NOx emission controls are required and enforced. Reliability also remains one the principle challenges hindering extensive commercialization. Though many of the existing coal-fired IGCC power plants have reached availability levels of 75-80 percent in recent years, none has achieved the target availability level of 85 percent demanded for commercialization. Additionally, operating an integrated combined cycle and gasification plant and ensuring sufficient gas cleanup for modern gas turbines remain challenging, especially when utilizing low rank coals (Watson, 2005).

Many of the policies suggested previously- such as strengthened enforcement of environmental regulations, restructuring the innovation process, and encouraging foreign collaboration and technology transfer- would help lead to resolution of these issues by allowing accumulation of more experience.

Appendix F: Carbon Capture and Storage

The carbon dioxide emission reduction potential of coal gasification depends on realization of carbon sequestration, requiring both the resolution of remaining scientific issues and the appropriate policy environment.

Current carbon sequestration science supports the feasibility of carbon capture and storage (CCS). The International Panel on Climate Change (IPCC), for example, foresees CCS providing a large portion of total CO_2 least cost reductions during this century, reducing total carbon mitigation costs by 30% relative to the scenario where CCS is absent (See Figure 16) (IPCC, 2005). The oil and gas industry has fairly extensive experience with above ground and injection CO_2 management gained from practices such as acid gas injection, enhanced oil recovery, natural gas storage, and CO_2 transport (See Figure 17). Thus, the remaining scientific questions about the long term viability of sequestration focus on subsurface issues that are poorly delineated by past experiences. These remaining questions include: How well do we understand storage mechanisms? What is the likelihood of CO_2 escape from injection sites? And what are the associated risks? How would leakage be detected? What rate of leakage eliminates benefits of CCS? How will injection sites be certified and guaranteed? Who will monitor and verify subsurface CO_2 storage? Large scale demonstration projects are critical to the successful resolution of these remaining issues, deployment of CCS, and development of a regulatory framework.

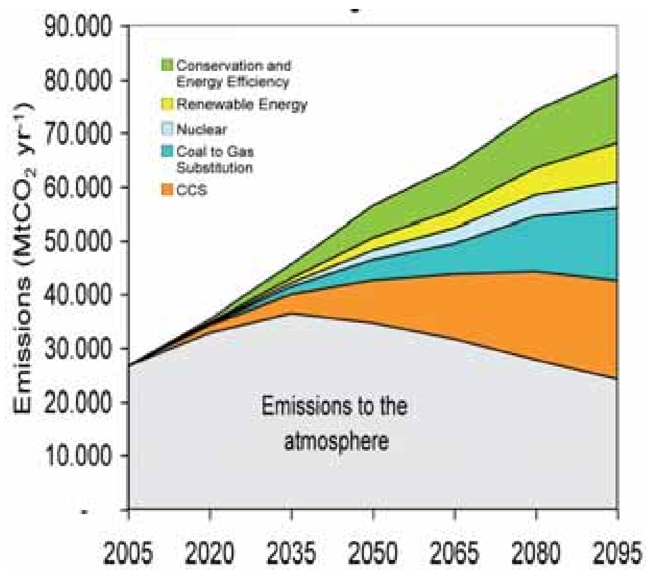

Figure 16: IPCC projects Carbon Capture and Storage Playing Major Role in Emissions Abatement (IPCC, 2005)

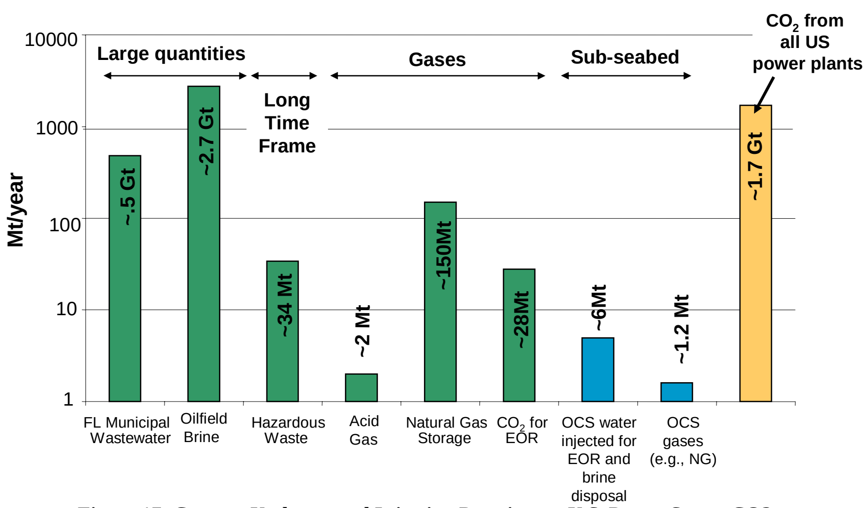

Figure 17: Current Underground Injection Practices vs U.S. Power Sector CO2 (Morgan, 2002)

Though CO_2 can be separated and captured more cost-effectively from a gasification-based power plant than from a conventional PC power plant, no existing IGCC power plant currently captures CO_2. However, experience with CO_2 capture technology has been gained in other industries such as hydrogen, ammonia, synthetic liquid fuels production and purification of natural gas. These processes typically have vented CO_2 to the atmosphere; however, the same technology (physical absorption of the CO_2 by a solvent) could be employed in CO_2 capture from a gasification-based power plant (Stephens, 2005).

Adding capture technology to a gasification-based power plant entails more than a simple modification: not only is the addition of CO_2 capture equipment required, but precombustion CO_2 removal increases the hydrogen content of the syngas, altering the design requirements for the gas turbine. Precombustion CO_2 capture also changes the characteristics of optimal syngas clean-up processes and increases energy (Stephens, 2005). The non-trivial changes required to incorporate CO_2 capture suggest that consideration of future CO_2 capture capabilities should play a role in planning from the initial stages to enable cost-effective future modifications.

Two means of including consideration of CO_2 capture in early planning are proposed here. First, a conceptual plan for future CCS-enabling retrofits could be required in the initial planning stages. This requirement would not entail any actual changes in the construction of the facility, but it would introduce consideration of future CO_2 CCS capability into the design of the without adding significant costs. Alternatively, allocation of sufficient space in the facility to accommodate the CO_2 capture equipment and resizing of some components to allow maintenance of power levels could be required. This would entail more significant preinvestment, estimated to increase capital costs by about 5 percent (Stephens, 2005).

However, since regulatory and economic incentives for CCS have not yet developed, the rationale for requiring CCS for coal gasification installations is debatable. In the short term, it may be most productive to focus on implementing coal gasification, perhaps with conceptual plans for future CCS-enabling retrofits, while developing CCS experience in demonstration projects. At present carbon management policies are not strong enough to incentivize CCS; however, the potential for participation in CDM agreements based on decarbonizing coal may become attractive. Alternatively, partial decarbonization of coal and CCS could be conducted as an acid gas management strategy in conjunction with synfuel production. However, the significant costs of incorporating CO_2 CCS require additional regulatory or financial incentives extending beyond support for gasification technology for integrated projects incorporating both coal gasification and CCS (Stephens, 2005).