U.S.-China Cooperation On Low-Emissions Coal Technologies:

Realities and Opportunities

A report based on a Dialogue sponsored by the Atlantic Council and the
U.S./China Energy and Environment Technology Center
at Tshingua and Tulane Universities

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I. EXECUTIVE SUMMARY

The Atlantic Council of the United States (the Council) and the U.S./China Energy and Environmental Technology Center (EETC) at Tsinghua and Tulane Universities co-sponsored a Dialogue, "U.S.-China Cooperation on Low-Emissions Coal Technologies" in Beijing from June 24-26, 2009. This report synthesizes and summarizes the information presented during the Dialogue to allow for an ongoing exchange of information and ideas between the meeting participants and key stakeholders in the effort to lower emissions from the use of coal.

The Dialogue examined the realities and opportunities for cooperation between the two countries regarding the development of low emissions coal technologies. The reality is that coal is essential to the energy security needs of China and the United States. Yet, coal-based electricity is the largest man-made contributor worldwide to greenhouse gas (GHG) emissions. Thus, for China and the United States to maintain viable energy portfolios while simultaneously implementing strong environmental remediation programs, both nations have strong incentives to identify concrete steps for accelerating the development and deployment of low emissions technologies and policies.

China and the United States will continue to utilize their expansive coal resources well into the middle of the 21st Century. China is largely focused on developing domestically viable options for clean coal technology (CCT), primarily through a measured reduction policy that will incorporate all commercially viable solutions. China plans to deploy a commercially viable Integrated Gas Combined Cycle (IGCC) program along with other technologies including Carbon Capture and Storage/Sequestration (CCS). China will not continue to increase its emissions without limit, but its view is that it is too soon for China to consider an emissions cap.

To date, China and the United States have independently focused on developing a portfolio of low emissions coal technologies to improve cost effectiveness and lower energy intensiveness. There is a need to determine which technological concepts should be pursued under a collaborative framework given individual country circumstances.

The major recommendation of the Dialogue participants was that chances for successful United States-China cooperation would be significantly enhanced if China and the United States establish an "Implementing Mechanism for Cooperation" (IMC) that utilizes existing cooperative mechanisms and involves the top levels of both governments. This mechanism can act as a government-to-government framework to facilitate bilateral initiatives in the public and private sectors. This framework will lower uncertainty and risk by promoting best practices and facilitating collaborative clean coal research, development and demonstration. However, for this new framework to be successful, it must be both properly endowed and operate over the long term.

The initiation of such a mechanism will need to be supported at the highest level of government. With the United States (U.S.) and Chinese governments evidently committed to greater cooperation, there is an excellent opportunity to create a solid, well-structured framework that will ensure vibrant economies while facing environmental challenges.

This overarching recommendation regarding the IMC should be back-stopped by a series of detailed actions to be undertaken by both countries. In the near future, it is recommended that one of the first steps should be that China and the United States, together, undertake a follow-on dialogue to create a U.S.-China road map regarding CCS to address:

- Joint coordination of the R&D being done in both China and the United States with regard to lowering capture costs;
- Coordinate policy and capacity building efforts to facilitate deployment and intellectual property sharing;
- Develop an agenda to "cross-breed" the FutureGen and the GreenGen projects to maximize the resources the public and private sectors are dedicating to these CCS programs.

Concomitant with the strengthening of the approaches of cooperation, the United States and China will face the challenge and necessity of dealing with the many realities identified during the Dialogue. Specific key issues to be addressed should include the following:

- **Funding**
  - Accessing expanded World Bank funding of the Global Environmental Facility;
  - Coordinating efforts to ensure CCS projects are included in the Clean Development Mechanism (CDM) and/or are eligible for certified emission reduction credits in global agreements;
  - Establishment of a significant global fund to support international research and development of technologies that could be jointly owned;
- **Lowering Costs**

  - Development of a long-term joint research program that specifically focuses on reducing the capital cost and energy consumption associated with CCS;
  - Develop standardized designs for CCTs that could significantly reduce capital and operating costs;
- **Intellectual Property Rights**
  - Create a platform for U.S. and Chinese industry to establish joint industry partnerships; for many companies, concerns over intellectual property rights (IPR) are no longer inhibiting the desire to form partnerships;
  - Develop an energy sector, or sub-sector, approach to resolving concerns over intellectual property rights. Chinese industries and universities are rapidly developing new technologies that need to be protected;
- **Standards and Benchmarks**
  - Establishment of common benchmarks to support "best practices" in the operation of coal fired power plants;
  - Build on the regulatory analysis undertaken by World Resources Institute (WRI) to establish regulatory "best practices" that could be applied globally; aim to establish procedures that would allow "fast track" permitting of new facilities;
  - Common and/or compatible standards should be established for plant performance and the measurement and monitoring of emissions in order to facilitate the two way flow of technology and investments;
- **Partnerships**
  - Enable Chinese companies to participate in U.S. Regional Coal Sequestration Partnerships (RCSP) Program, and U.S. industry to expand joint ventures in China, with the appreciation that China has the potential to develop IGCC plants at lower costs than U.S. industry;
  - Systematically expand the content and number of institutional partnership relationships between national laboratories and universities. These should be designed to provide for longer-term fellowships to enable participants to gain an understanding of each other's cultural structures and administrative systems as well as to gain from cross training in technical subjects;
  - Collaborate on helping China to develop appropriate monitoring and verification systems for GHG emission reductions as a result of China's myriad policies and programs. The Unites States can impart its experience with related monitoring equipment, technologies and best regulatory practices; help train professional staff in this area; and demonstrate transparent and effective communication, auditing and reporting systems;

- **Technology Developments**
    - Formally establish a database of potential geological storage sites for CO_2. Utilize existing petroleum industry expertise in development of the database and in particular help China to improve its data collection and information sharing capabilities;
    - Design and establish programs to explain the necessity and benefits of CCS and other CCTs, including the interface to long-term energy security and other pollution objectives;
    - Develop a clear game plan for developing pre- and post-combustion technologies recognizing the two approaches require separate research and development paths. There needs to be more than the identification of a few jointly funded projects. Clear timelines need to be established and progress on a comprehensive program monitored. There will be earlier progress on pre-combustion while post-combustion is not likely to be available until after 2020. Jointly develop and demonstrate integrated processes for removing SOX, NOX, mercury and particulate matter along with capturing CO_2;
    - Determine if there are opportunities to jointly research and develop novel approaches to sequestering CO_2;
    - Establish a procedure where by industry, national labs and universities can interact through a Secretariat of the IMC to present its senior officials with breakthrough concepts and technology developments.

Overall, there are more similarities than differences between China and the United States, creating opportunities for collaboration. The fundamental solutions to a low carbon economy are being described in the same way in both countries: start with energy efficiency, use all coal, oil and gas resources, accelerate use of zero emissions energy sources such as nuclear and renewables, and ultimately use coal with CCS. The basic agreement on the path forward presents a true opportunity for collaborative efforts between the United States and China.

II. INTRODUCTION

The Atlantic Council of the United States (the Council) and the U.S./China Energy and Environment Technology Center at Tsinghua and Tulane Universities co-sponsored a Dialogue, "United States-China Cooperation on Low-Emissions Coal Technologies" in

Beijing from June 24-26, 2009.[1] This was the fifth meeting of U.S. and Chinese participants on energy issues sponsored by the Council. The Council's goal is to develop dialogues with nations to deepen understanding of the problems of our times, expand appreciation for each country's views and demonstrate how environmental and energy relationships influence the general security of all of our countries.

The participants and speakers represented an impressive and wide range of American and Chinese stakeholders from industry, academia, governmental foreign and domestic policy-making agencies, think tanks, and international organizations. The Chinese group was comprised of representatives from the Energy Research Institute, the Chinese Academy of Science's Institute of Engineering Thermal Physics, Tsinghua University, the China University of Petroleum, the Huaneng Group, Ministry of Science and Technology's Energy Division, the Chinese Office of the World Bank, and the State Council. On the U.S. side, speakers and participants came from Harvard University, Tulane University, Worley Parsons Resources and Energy, West Virginia University's Department of Geology and Geography, the Atlantic Council, the Beijing Office of the U.S. Department of State, GE Energy, World Resources Institute, the Department of Energy's Office of Fossil Fuel, the University of Texas's Jackson School of Geosciences, Columbia University's Department of Earth and Environmental Engineering, the Center for Strategic and International Studies, the National Energy Technology Laboratory, EnTech Strategies, and McKinsey.

As a result of this meeting, the participants will be better able to help their respective government policy makers and industry leaders develop clean coal policies that both protect the environment and ensure economic growth. While specific financial or technology transfers per se will not ensue directly from this meeting, the participants obtained a better understanding of each others' positions, and gained up-to-date information for developing appropriate policies that may lead to needed technology transfers between the United States and China. The discussions during the workshop often focused on clarifying the role of U.S. industry versus governmental organizations in establishing cooperative arrangements on CCT.

This report synthesizes and summarizes the information presented during the Dialogue to allow for an ongoing exchange of information and ideas between the meeting participants and key stakeholders in the effort to lower emissions from the use of coal. In the global energy outlook section, the forecasts for coal usage in the world, China and United States are put into perspective vis-à-vis demand and supply for other fossil

[1] This meeting followed on the heels of the United States-China Dialogue on Cooperation on Nuclear Power held in Washington, DC in March 2009. The final report can be accessed at http://www.acus.org/publication/us-china-cooperation-nuclear-power

fuels, renewables and nuclear generation, as well as how efficiency measures may affect the demand side of the equation. The report examines efforts in the United States and China to mitigate greenhouse gas (GHG) emissions through a look at government policies, efficiency measures, changes in respective energy portfolios, and how CCT and CCS technologies are being developed and deployed. The myriad bilateral, multilateral, international, and government-industry cooperative agreements are recognized for their contributions to the effort to develop the necessary strategies and technologies that will permit both countries to use coal in an environmentally sustainable fashion. It also looks at the realities that both countries face in dealing with complex but substantially different energy portfolios, the imperative of continued use of coal in China and the United States, the status of IGCC projects, the challenges and opportunities surrounding the development and deployment of CCS technologies, and finally, what is required to take the existing cooperative agreements to their next level. As the Dialogue's goal was to identify ways in which China and the United States could deepen and accelerate their efforts, the report presents the recommendations that were made in the formal presentations and during the final roundtable discussion of all the Dialogue participants.

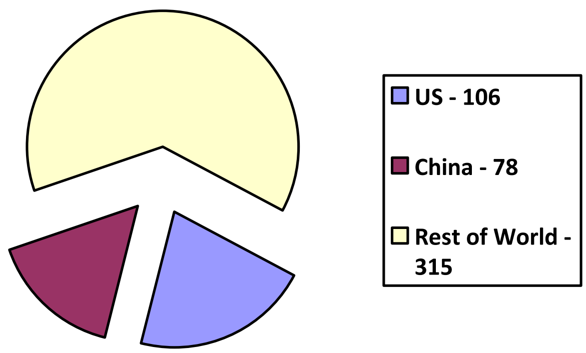
III. Global Energy Outlook

Section III provides a framework for the discussion and recommendations regarding how China and the United States will successfully produce and use energy with lower emissions of GHG in the future. It presents information on energy supply and demand in the world, China and the United States. The prominent role of coal in both countries is examined. Finally, Section III looks at emissions today and as projected to occur under various scenarios by 2030.

A. World Supply and Demand

World primary energy consumption as of 2006 reached approximately 499 exajoules (EJ) as shown in Figure 1. China and the United States are the two largest energy consuming nations in the world. China (at 78 EJ) and the U.S. (at 106 EJ) account for 184 EJ, or 37% of the world's primary energy consumption. To place some context around these consumption numbers, note that the United States accounts for 25% of world Gross Domestic Product (GDP) and 21% of global primary energy consumption. Conversely, China contributes 6% to the global GDP while using over 15% of primary energy supply. This points to the potential, in China especially, for improving energy efficiency measures that will enhance productivity and reduce environmental impacts. The United States also has opportunities to further reduce energy intensity per unit of GDP. The need for increased energy efficiency provides opportunities for collaborative efforts between both nations.

Figure 1: 2006 World Primary Energy Consumption



Source: King, Carey W. "U.S.-China Cooperation on Low-Emissions Coal Technologies: World Energy Projections: Past to the Future." Beijing, China. 25 June 2009.

Global energy demand is expected to increase over 45% by 2030 due to increased economic activity and population growth[2]. Over 70% of this increase will come from developing countries, led by China and India. Based on current growth projections, China will overtake the United States in total energy consumption by approximately 2010 and become the world's largest primary energy consumer.[3] Satisfying the world's appetite for energy will be a formidable (but reachable) challenge as global power generation capacity must reach 4 million Megawatts (MW), or the equivalent of four times the current U.S. power capacity.

Global electric capacity is forecasted to rise from 18, 921 thermal watt hours (TWh) in 2006, to 24,975 TWh by 2015, reaching a forecasted 33,265 TWh by 2030 in the

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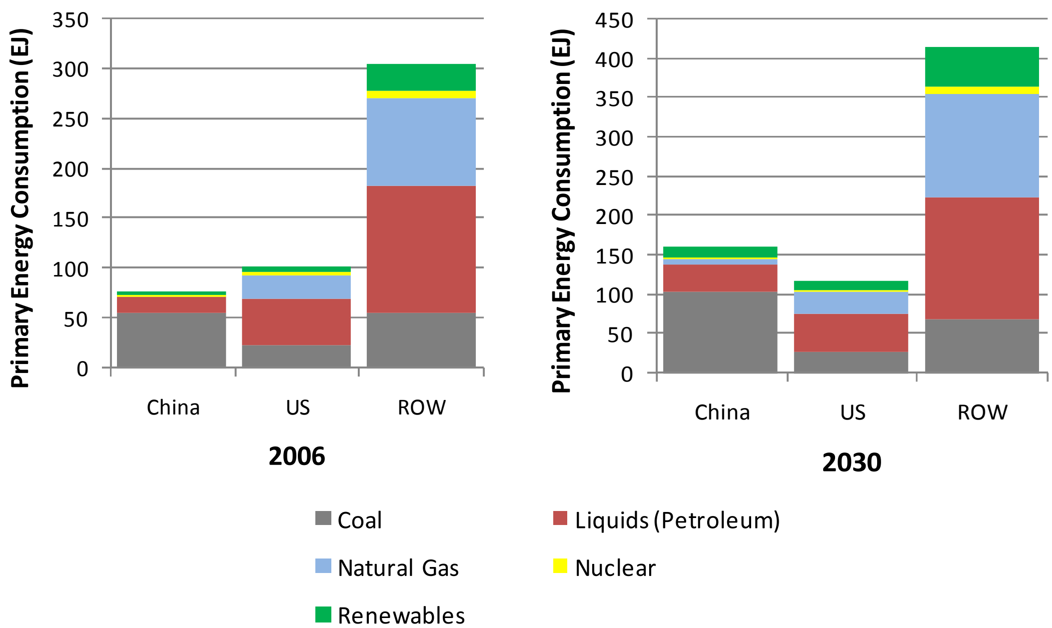
[2] The "reference case" scenario assumes that world population will grow at an annual average of 1%, from 6.5 billion in 2006 to 8.2 billion by 2030. The rate of world GDP growth, the primary factor in demand increases, is assumed to average 3.3% during this period (P. 59, 78, 81 International Energy Agency. World Energy Outlook: 2007. Paris, France: OECD/IEA, 2007.

[3] Carey W. King, "World Energy Future: Past to the Future."
Note that by 2015, US primary energy demand will be 2396 million tons of oil equivalent as compared to China's 2906 million tons of oil equivalent, Table 2.2, P.81 International Energy Agency. 2008 World Energy Outlook. Paris France: OECD/IEA. 2008.

International Energy Agency's (IEA) reference case scenario.[4] This represents an increase of 76% over the period.

The forecast up to 2030, seen in Figure 2, compares the primary energy sources from 2006 up to 2030 regarding coal, natural gas, renewables, oil and nuclear power. Worldwide, fossil fuels will account for 80% of the global energy mix in 2030. While oil remains the dominant fuel, global demand for coal will increase the most in absolute terms and will account for 28%[5] of world primary energy demand.

Figure 2: Foundations of U.S., China and World Energy Consumption from 2006 to 2030



Source: King, Carey W. "U.S.-China Cooperation on Low-Emissions Coal Technologies: World Energy Projections: Past to the Future." Beijing, China, 25 June 2009.

B. United States and China Energy Portfolios

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[4] P. 594, International Energy Agency. World Energy Outlook: 2007. Paris, France: OECD/IEA, 2007.
[5] Ibid.

American and Chinese energy portfolios are moving in markedly different directions. With regard to coal, in 2006, China consumed double the amount of coal than the United States, 55 EJ compared to 24 EJ. In the future, as also seen in Figure 2, China will almost double its coal consumption by 2030. China is expected to rely increasingly on its domestic coal reserves to keep up with demand. U.S. coal consumption is forecasted to modestly increase by 11%, unless there are major changes in U.S. energy laws and regulations. China will more rapidly increase its use of renewable sources than the United States, while continuing to moderately use oil and natural gas for energy consumption.

China's electricity capacity is expected to double in the next twenty years from a current capacity of 800 Gigawatts (GW) to 1,600 GW. Coal plants are expected to provide between 900 and 1,000 GW of power, equal to about 65% of the nation's total power needs. However, China's use of coal is expected to peak in the 2020 to 2030 period, and its use is forecasted to remain essentially constant thereafter.

China's energy security through 2030 will depend primarily on coal, due to its abundant domestic supply (and comparatively small recoverable reserves of oil and gas)[6], while it undertakes a long-term expansion of renewable and nuclear energy. In 2005, China's proven recoverable reserves of coal were 114.5 billion tons, 12.6% of the world total. China's coal resources are estimated to be 5570 billion tons with 1018 billion tons of proven reserves and 4552 billion tons of forecasted reserves.[7] [8]

In the next twenty years, U.S. energy demand is expected to increase 11% (as compared to an increase of 45% for the world). The United States has a more diversified energy portfolio than China, more representative of the other "rest of the world (ROW)" countries (as seen in Figure 2), but U.S. dependence on coal remains disproportional high for power generation.[9] The United States consumes one-half less coal than China (24 EJ as opposed to 55 EJ)

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[6] The total proven recoverable reserves for oil and gas are only 7.75% that of coal (P 318, 329, International Energy Agency. World Energy Outlook: 2007. Paris, France: OECD/IEA, 2007).

[7]Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing China, 25 June 2009.

[8] For comparison, according to the Energy Information Agency, "Coal Reserves." May 2009. Energy Information Agency, Official Statistics from the U.S. Government, accessed at <http://www.eia.doe.gov/neic/infosheets/coalreserves.html> on September 8, 2009, the Unites States' "demonstrated reserve base" contains 489 billion tons while it currently only consumes one billion tons per year. It further estimates that "recoverable" coal reserves reached 263 billion tons.

Today, 85% of U.S. demand is met by fossil fuels-41% by oil, 23% by coal and 22% by gas. Nuclear energy and renewables make up the reminder with 8% and 6%, respectively. Through 2030, the most significant change in the U.S. energy mix will likely be a doubling of renewable energy sources from 6% to 13%. U.S. reliance on fossil fuels is expected to decreases to 78%, and will remain the dominant source of energy. Oil's share will be reduced to 34%, while coal and gas will remain constant at 23% and 22%, respectively. Nuclear power's share is projected to remain at the 8% level to 2030.[10]

C. GHG Emissions Outlook

Many scientists, energy experts and global leaders have concluded that GHG emissions will significantly impact the world's food, water, ecosystems and weather. Due to the environmental concerns of GHG--specifically carbon--emissions, the world's two largest emitters of carbon have come together in this Dialogue to discuss strategies to collaborate on mitigating them.

Fossil fuel emissions will substantially increase as international demand for fossil fuels grows over the next hundred years. Global cumulative CO_2 emissions have risen approximately 20% since 1990. The United States is responsible for 30% of cumulative atmospheric carbon emissions, while China has only contributed 8%.[11] However, China bypassed the United States as the world's largest emitter of energy-related CO_2 in 2007.[12] To date, cumulative U.S. CO_2 emissions equal 1,150 billion tons as compared to China's cumulative releases of 310 billion tons. Coal usage worldwide will result in increased global CO_2 emissions from 11 GT in 2005 to 19 GT by 2030.[13]

The United Nation's Intergovernmental Panel working group has developed three potential CO_2 emission reduction scenarios for the year 2030, shown in Figure 3. There is a baseline forecast in which emissions are not curbed, a second scenario involving an atmospheric reduction to 550 parts per million (ppm), and a third scenario calling for a more drastic CO_2 reduction to 450 ppm. Depending upon the projected ppm, the three emission reduction scenarios result in between 25 and 39 GT of CO_2 in the atmosphere

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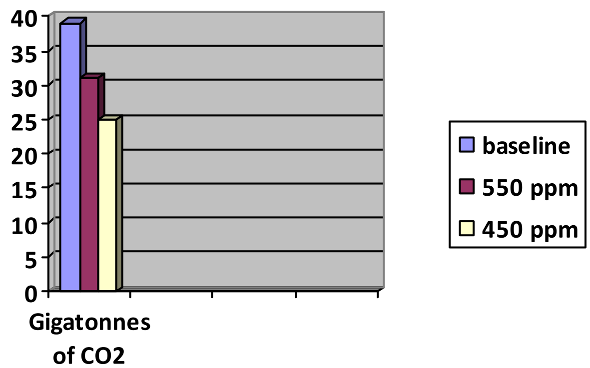
[10] International Energy Agency. World Energy Outlook: 2009. Paris, France: OECD/IEA, 2009.
[11] According to the International Energy Agency's World Energy Outlook 2007, cumulative emissions by region are as follows: "rest of the world" 33%, United States 30%, European Union 23%, China 8%, Japan 4%, and India 2%.
[12] P. 384, International Energy Agency. World Energy Outlook: 2008. Paris, France: OECD/IEA, 2008.
[13] Giove III, Joseph. "U.S.-China Cooperation on Low-Emissions Coal Technologies: US Clean Coal Research, Development, and Demonstration Programs." Beijing, China, 25-26 June 2009.

by 2030. The success of U.S.-China collaboration as envisioned by this Dialogue will be a key to successfully reaching these lower levels of CO_2 emissions.

Figure 3: Global Carbon Emissions Scenarios



Source: Met, Bertz. "Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge: Cambridge University Press, 2007.

IV. MITIGATING CO_2 EMISSIONS

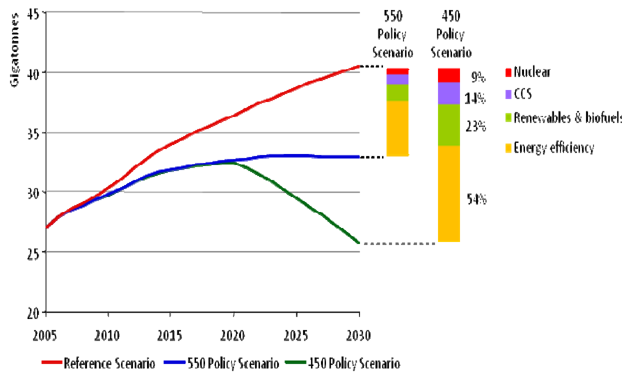
Both the United States and China have been engaged in international climate negotiations but efforts to lower CO_2 emissions have been primarily taken on a unilateral basis. In order to achieve emissions mitigation goals, both nations have a common interest to advance CCT technologies and strategies through bilateral frameworks.

As is true for the United States and China, reductions worldwide in energy-related carbon emissions will result from efficiency gains and deployment of low-carbon sources of energy such as nuclear power and renewables. Under the three commonly discussed climate change scenarios described in Figure 3, in order to reduce emissions by 8%[14] below 2005 levels in 2030 as postulated in the preferred 450 ppm GHG scenario, the targets are achieved 54% through efficiency measures, 23% by utilization of

[14] P. 446, International Energy Agency. World Energy Outlook: 2008. Paris, France: OECD/IEA, 2008.

renewables and biofuels, 14% by CCS and 9% by using nuclear energy for electricity production.

Figure 4: Reductions in Energy-Related CO_2 Emissions in the Climate-Policy Scenarios



Source: P. 446, International Energy Agency. World Energy Outlook: 2008. Paris, France: OECD/IEA, 2008.

A. China

1. Policy Framework

China's policy is predicated upon mitigating emissions while increasing economic growth and prosperity. Vital to considerations regarding a strategic energy policy are the goals of continuing modernization and reductions in poverty. China is willing to take measures to mitigate GHG domestically. China will not continue to grow emissions without limit, but its China's view that it is too soon to consider an emissions cap.

At the United Nations General Assembly meeting in New York on September 22, 2009, President Hu Jintao announced China's four-pronged approach and commitment. President HU stated that China would:

- Endeavor to cut CO_2 emissions per unit of GDP by a notable margin from 2005 levels by 2020;
- Increase the share of non-fossil fuels in primary energy consumption to approximately 15% by 2020 and vigorously develop renewable and nuclear energy sources;
- Increase domestic CO_2 absorption by increasing forest coverage by 40 million hectares and forest volume stocks by 1.3 billion cubic meters by 2020; and,

- Step up efforts to develop a low carbon economy through technology research, development and deployment.[15]

In 2007, China established a national climate change leaders group, giving responsibility to the National Development and Reform Commission (NDRC). It put forward a national program for climate change and set a target that China's per-unit GDP energy consumption would decrease 20% by the year 2010 compared to 2005.[16]

While China's emissions are slated to rise from 5 GT in 2005 to between 11 and 13 GT by 2050, as shown in Figure 5, China has initiated low carbon scenario policies using a multi-pronged approach in order to address the emissions issue.

The first element is improving energy efficiency (although this is not specifically shown in the Figure.) It is likely China will continue to mitigate CO_2 emissions significantly through improvements in infrastructure until 2050. China's 11th Five Year Plan (for 2006-2010) calls for a reduction in energy intensity of its economy by 20% of 2005 levels (per unit of GDP energy consumption) through 2010. Depending on the growth rate, resulting energy savings could total 700 Mtce or 19.5 quads.[17]

Second, China will make changes in its energy mix. As also seen in Figure 4, China will reduce its share of coal and oil in the energy mix, moderately expand the use of natural gas, and significantly change the use of non-carbon emitting sources of energy, especially nuclear and renewables (shown as "other" in the Figure.)

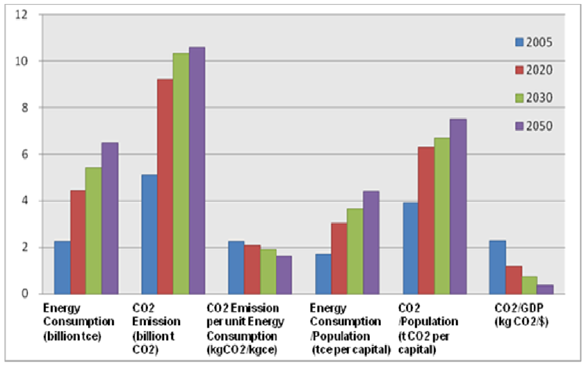
At the appropriate time, China will begin to use other CCT options such as IGCC and CCS strategies.

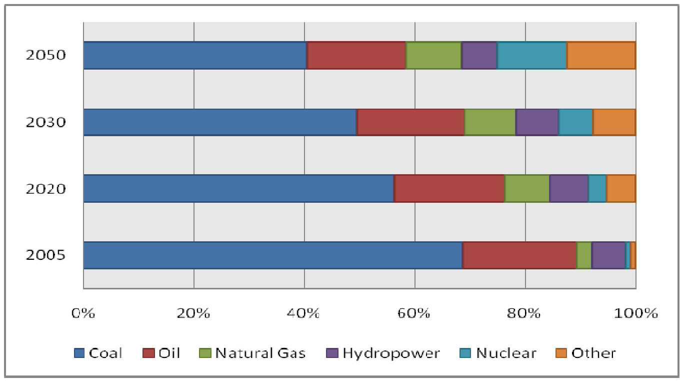
Figure 5: Summary of China's Low Carbon Energy Scenario Approaches and Results

[15] The speech was accessed on September 23, 2009 at http://www.nytimes.com/2009/09/23/world/asia/23hu.text.html?_r=1&pagewanted=print

[16] Zhenhua, Xie. "U.S.-China Cooperation on Low-Emissions Coal Technologies: U.S.-China climate Change Cooperation," Carnegie Endowment for International Peace, Washington, DC, 18 March 2009.

[17] Chu, Steven. "Meeting the Energy and Climate Challenge: A Tale of Two Countries." Beijing, China, 15 July 2009.





Source: Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing, China, 25-26 June 2009.

China has dedicated significant funding for low emissions coal activities. Recently 210 billion RMB (US$30.9 billion) was allocated to energy conservation, emissions reductions and ecological projects in China's stimulus package. Since 2006, China has annually spent 14 billion RMB (US $2.06 billion) on energy and environmental issues. In addition, as of April 2009, China approved 1,766 CDM projects.[18]

2. Efficiency Measures

China's greatest gains in reducing emissions have come from increasing the efficiency of its existing infrastructure. Table 1 summarizes ten key efficiency measures China is taking and the expected annual energy savings.

[18] Jiang, Kejun. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Energy and Emission Scenario up to 2050 for China." Beijing, China 25-26 June 2009.

Table 1: Ten Key Efficiency Projects in China

Project	Expected Annual Savings
Energy efficiency and conservation in buildings	100 Mtce
Oil conservation and substitution	38 Mt of oil=54.3 Mtce
Renovation of coal-fired industrial boilers	50 Mtce
District level combined heat and power projects	35 Mtce
Energy efficient lighting	29 TWh=3.56 Mtce
Motor system energy efficiency	20 TWh=2.46 Mtce
Waste heat and pressure utilization	1.35 Mtce
Energy systems optimization	Not specified
Government procurement of energy efficient products	Not specified
Monitoring and evaluating systems	Not specified
Total	**>250 Mtce**

Source: Chu, Steven. "Meeting the Energy and Climate Challenge: A Tale of Two Countries." Beijing, China, 15 July 2009

Foreseeable technological developments will play a major part in Chinese GHG emission mitigation efforts into the future. Heavy industry will emit fewer GHG emissions due to decreased production and stricter blast furnace standards. This will also be achieved by IGCC and/or polygeneration, which will permit efficiencies greater than 60% in coal powered plants. Further mitigation of emissions will result from increased usage of hybrid and electric vehicles, ultra-performance air conditioning, advanced solar water heating, and renewable technologies such as offshore wind farms.

National regulations will play a vital role in increasing efficiency. The 2007 edition of the *Guiding Catalogue for Structural Adjustment of Industry* sets minimum standards on new power generators and denotes criteria for closing older units. The *Catalogue* also forbids the construction of new coal plants operating with less than 300MW outside the grid, gross efficiency less than 42% and air-cooled units with a gross efficiency less than 40%. Congruent with these guidelines, China will continue to eliminate small coal-fired units with capacities less than 100 MW.[19]

[19] Since 2006, 34.21 GW of small units were eliminated, another 31 GW are planned to be closed in the next three years.

China plans to improve the thermal efficiency of its coal fired plants. From 1993-2003, China reduced its average power plant coal consumption by 16%, mainly by increasing the proportion of larger, more efficient coal fired power units. Moreover, between 2003 and 2007 China increased its efficiency by 15%. Further improvements will be made with the introduction of 60 supercritical and ultra-supercritical units of 600 plus MW capacity. By 2010 supercritical and ultra-supercritical units will account for over 40% of newly built thermal power generating units. From 2010 to 2020, new power plants with unit capacities of 600 MW and above will be required to be supercritical and about half of the newly built power generating units will be ultra-supercritical. Supercritical units are expected to account over 15% of the total power capacity by 2010 and 30% by 2020.[20]

Steel is one of China's largest industries utilizing energy from coal. Steel production in China increased by 500% between 1996 and 2008,[21] making China the world's largest steel producer with a 38% share of the global market.[22] However, this remarkable growth is unlikely to continue into the future, one of the factors that may permit the increase in China's coal usage to plateau in the 2020 to 2030 time period. Further steel production will face constraints, which, combined with new technologies, will help to decrease China's CO_2 emissions. The steel industry is projected to reach its peak production by 2020 after which production will begin to level off. This energy intensive industry nevertheless is undergoing technological innovations focused on energy efficiency and a reduction of coal use. For example, new blast furnace standards have the potential to dramatically reduce coal consumption and improve industry efficiency.

In a projected low emission scenario modeled by Chinese experts, reductions will be attained by incorporating new technologies into the production of steel and other energy intensive construction materials. Emissions will be further reduced by an overall decrease in production of these goods. For example, China is projected to decrease production of steel, cement and glass by 2050 as follows:

- Steel production will decrease from 430 to 360 million tons; energy usage will diminish from 760 to 545 Kilowatt gas coal equivalent per ton (Kgce/t);
- Cement production will decline from 1200 million to 900 million tons; energy usage will fall from 132 to 77 Kgce/t;

[20] Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing, China, 25-26 June 2009.
[21] Steel production increased from 100 million tons in 1996 to 540 in 2008.
[22] "World crude steel production decreases by 1.2% in 2008." 22 Jan 2009. World Steel Production. 10 August 2009 <http://www.worldsteel.org/?action=newsdetail&id=257>

- Glass manufacturing will decrease from 800 million cases to 580 million cases; energy usage will fall from 24 to 13.1 Kgce/weight per case.[23]

It is projected that increased car ownership in China will significantly impact its use of fossil fuels for transportation and related steel production. As China's GDP continues rising steadily, car ownership will skyrocket from 3.37 cars per 100 households in urban areas in 2005 to 78 cars by 2050. However, China projects that the average distance a family will travel in a year will decrease from 9500 kilometers in 2005 to 7480 kilometers annually by 2050. Additionally, the cars will be fueled 13% by bio-fuels, almost 20% by electricity and almost 8% by fuel cells.[24] China has adopted an auto fuel economy standard which should increase the fleet fuel economy of Chinese cars to the equivalent of 35 miles per gallon by 2015.

China also utilizes economic incentives to promote efficiency and GHG emission mitigation efforts. It has adjusted refined oil and natural gas prices, eliminated the subsidy for high-energy-consumption enterprises, and now offers a preferential electricity price for power plants using clean energy sources. It has lowered and in some cases eliminated tax rebates for high energy consuming exports and gives preferential tax treatment for enterprises using conservation measures. The 10^{th} 5 Year Plan (2000-2005) allocated 2.5 billion RMB (US$368 million) for science and technology to encourage efficiency. In the 4 trillion RMB stimulus package, 14.5% was allocated to climate change initiatives.[25]

3. Changes in China's Energy Portfolio

China's top energy priority is to expedite the development of zero-carbon power sources, such as, nuclear, hydropower, wind, solar and other renewables. Since 2000, China has increased hydropower capacity from 80 GW to 170 GW (the largest in the world), nuclear generating capacity from 3 GW to 9.1 GW with over 10 new units under construction, and increased wind power capacity to 12 GW. Government policy calls for further increasing nuclear power's share from 1% to 4-5% of the total generating fleet by 2020[26] and renewable power's share from 10% total energy consumption by

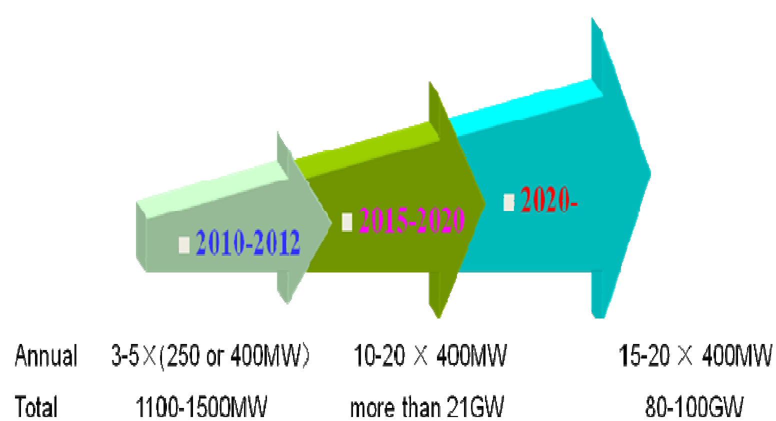
[23] Jiang, Kejun. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Energy and Emission Scenario up to 2050 for China." Beijing, China 25-26 June 2009.
[24] *Ibid*.
[25] Zhenhua, Xie. Remarks from "U.S.-China Climate Change Cooperation" hosted by the Carnegie Endowment for International Peace, Washington, DC, 18 March 2009.
[26] Targets have been increased several times already. China's first target of 40 GW by 2020 was revised upward to 60 GW and in April 2009, it was again officially increased to 70 GW. The latest potential figure being reported in *China Daily* is 86 GW.

2010 to 15% in 2020. To reach China's renewables goal, further capacity increases would include increasing hydropower from 170 to 300 GW, wind from 9 to 100 GW, biomass from 0.73 to 30 GW, and solar from 0.13 to 1.8 GW.[27] China aims to have 100 GW of wind capacity by 2020 with new wind farms in Gansu, Inner Mongolia, Xinjiang and Jiangsu provinces.

4. Next Generation CCT

China plans to deploy IGCC facilities on a commercial scale by 2020. This is in line with its short-term strategy of deploying IGCC to reduce emissions and adding CCS in the long-term to reduce them further. The Roadmap in Figure 6 depicts that China has plans for a few small-scale IGCC demonstration facilities in the 250 to 400 MW range between 2010 and 2012 with a total capacity of 1100 to 1500 MW total capacity. Next, China will move toward large scale demonstrations of 10 to 20 plants in the 400 MW range, potentially increasing total Chinese IGCC capacity to 21 GW by 2020. After this, large-scale commercial production is slated to begin with 15 to 20 400 MW facilities. Subsequently, total IGCC capacity will to between 80 and 100 GW, which would represent around 10% of the total coal-fired fleet.

Figure 6: IGCC Demonstration and Commercial Deployment Roadmap for China



Source: Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing, China, 25-26 June 2009.

[27] Xie, Jin. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Status Quo and Perspective of Low-Carbon Power in China." Beijing, China, 25-26 June 2009.

The China Huaneng Group (CHNG) initiated the GreenGen Program[28] in 2004 and is currently upgrading the initial 250 MW IGCC facility located in Tanjin City to a 400MW zero-emission power plant. In May 2009 the Tianjin IGCC project received its government permit and construction begins this year.[29] In the second phase of the project, GreenGen plans to demonstrate highly efficient H_2 and CO_2 separation, and CO_2 storage. Finally in the 2013-2015 timeframe, GreenGen will increase its capacity to about 400MW and feature integration of hydrogen-rich gas from coal, fuel cell power generation, H_2 combined cycle, and CCS to a near-zero emission level.[30]The pulverized coal gasification technology will be exported to the United States through an independent power producer (IPP) which has already signed a licensing agreement with Future Fuels Co. Investment costs are estimated to be twice those for an ultra-critical plants.

GreenGen may provide a unique opportunity for collaboration on IGCC technology by the United States and China, and any other international partners interested in pursuing this technology.

5. CCS in China

China has been officially engaged in CCS projects since 2005, when the Ministry of Science and Technology signed a memorandum to initiate government-supported CCS research. Subsequent government action has been taken to include CCS RD&D and capacity building as part of its CCT portfolio for clean, high-efficient use of coal.

China has a number of CCS projects that test a range of technologies. First, the Jilin Pilot Test has allowed important research to be done on Enhanced Oil Recovery (EOR) techniques[31]. Second, China is exploring multiple geologic storage sites in addition to those in the Jilin oil fields for carbon sequestration. Third, a promising CCS project in Beijing has achieved extremely high capture rates. China is emphasizing projects that strive for zero energy penalty as opposed to zero emissions. The advanced stage of these projects offers unique opportunities to create international best practices regarding new CCS technology.

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[28] The US firm, Peabody, joined GreenGen, and in turn, CHNG, is a member of the US based FutureGen Alliance.
[29] Xie, Jin. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Status quo and Perspective of Low-Carbon Power in China. Beijing, China." Beijing, China 25-26 June 2009.
[30] Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing, China 25-26 June 2009.
[31] Dou, Hongen. "U.S.-China Cooperation on Low-Emissions Coal Technologies: (Translation) China' s EOR and Underground Storage of Green House Gases." Beijing, China, 25-26 June 2009.

As previously discussed, China is looking at a variety of CCS approaches using EOR, such as the Jilin Pilot Test. The Pilot Test will utilize CO_2 capture and EOR technology developed by PetroChina. This project is especially important because long-term, China's oil and gas reservoirs can store up to 900 billion tons of CO_2[32]. In support of this technology, in 2006, the Chinese Ministry of Science and Technology (MOST) approved a variety of EOR and sequestration activities including eight major research and development programs.[33]

In cooperation with the EU, United States, and Australia, China is exploring other geologic storage sties in addition to Jilin oil fields.[34] Programs such as the Near Zero Emissions from Coal 2007-2009 (NZEC), Cooperation Action within China-EU 2006-2009 (COACH), Geological Storage of CO2 2000-2003 (GESTCO), and GeoCapacity are examining geologic storage sites at the Jizhong Depression, the Huabi Oilfield complex, the Jiangsu oilfield, the Daqing oilfield, the Kailuan coalfield, the Dagang oilfield complex, the Shengli oilfield complex, and at the Jiyang super depression area. China is undertaking the research to match sources and sinks.

A carbon capture pilot project is being built at a Bejing coal plant designed by the Xi'An Thermal Power Research Institute. This pilot project is capable of recovering 85% of CO_2 from the collected flue gases, or 3% of the total flue gases, using a chemical solution to absorb and separate the carbon from gases at high temperatures. The plant designed and produced entirely by the Chinese, can trap 3,000 tons of CO_2 annually.

China is also researching innovative approaches that focus on low or zero energy penalty rather than zero emissions. For example, they are exploring polygeneration technologies that recycle un-reacted gas to a power system to produce electricity, which improves conversion of CO_2 into synthesized material which is then sent to an on-site refinery that produces liquid fuels.

Furthermore, the Asian Development Bank (ADB) has agreed to provide $1.25 million in funding towards the development of a road map for CCS projects in China. The Chinese government will provide a further $30 million. This money will finance the formulation of policies and legal regulatory framework needed to support emerging CCS technology.[35]

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[32] Ibid.

[33] Ibid.

[34] Studies have shown that the investment cost is twice that for post combustion activities-4000 RMB compared to 8000 RMB per kilowatt hour. The energy penalty is more than 10%.

[35] Chan, Yvonne. "Asian Development Bank backs China's Clean Coal Research." 7/10/09 BusinessGreen.com. Accessed on August 8, 2009 at <http://www.businessgreen.com/business-green/news/2245817/asiandevelopment-bank-pledges>

B. United States

1. Policy Framework and Government Funding

Recent U.S. policy has focused on lowering GHG emissions through enactment of a variety of White House policies, voluntary industry measures, regulations, legislation and funding support for clean energy technologies. For example, the American Recovery and Reinvestment Act of 2009, also known as the "Stimulus Act", created a one-time infusion of more than $80 billion for clean energy technology.[36] The U.S. has taken other important steps towards emission reductions such as:

- Environmental Protection Agency (EPA) ruled that public health and welfare endangerment could form the basis of future regulation of carbon emissions and encouraged Congress to pass supporting legislation;
- The EPA finalized new rules that requires refineries, cement kilns, glass manufacturers and other large facilities to monitor and report their emissions to the federal government;
- The Obama Administration has proposed higher fuel efficiency standards as well as first CO_2 standards for new cars and trucks. New standards will average 35.5 miles per gallon and 250 grams of CO_2 per mile by 2016. U.S. standards would closely approximate China's mileage target;[37]
- The U.S. government has advanced proposals with significant funding increases for renewables, science and implementation of CO_2 regulations while cutting funding for oil and gas, nuclear, and hydrogen vehicles. It also eliminates some tax benefits for oil and gas;[38]
- New policies have promoted a long-term shift to renewable energy sources and deployment of CCS technology in the near future.

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[36] The funding includes $38 billion for DOE to support renewables and other clean energy technologies, $16 billion for transit systems and intercity passenger rail projects, and $20 billion for tax incentives for renewable, next generation car and efficiency measures.

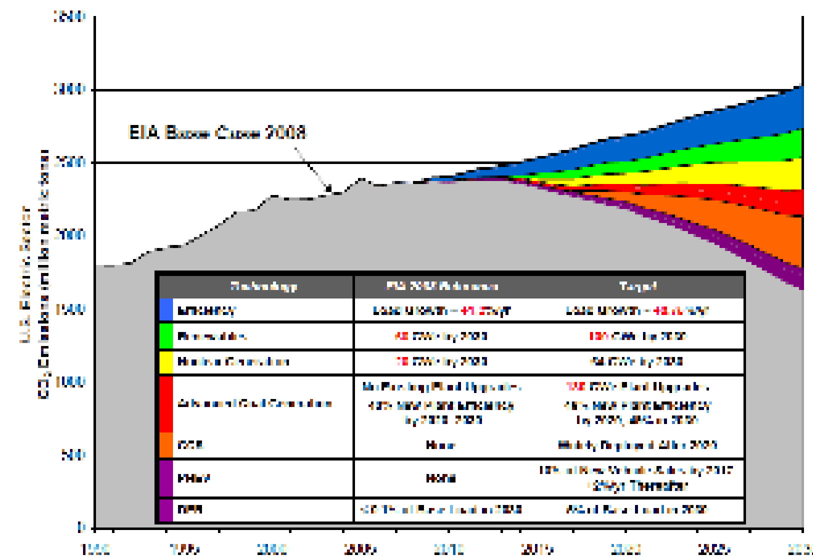
[37] The Obama Administration released details on September 15th of its national suite of auto standards that would mandate increased fuel economy and impose the first-ever greenhouse gas standard on the nation's cars and trucks. The proposals are a joint effort between U.S. EPA and the Transportation Department and would go into effect with model year 2012. The standards would push corporate average fuel economy, or CAFE, standards to a fleetwide average of 35.5 miles per gallon by 2016, four years ahead of the schedule Congress laid out in a 2007 energy law. The carbon dioxide limit under the plan -- which will apply to passenger cars, light-duty trucks and medium-duty passenger vehicles -- would reach an average of 250 grams per mile per vehicle in 2016.

[38] Pumphrey, David. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Energy Policy: Balancing Economy, National Security and Climate Change." Beijing, China 25-26 June 2009.

Like China, the United States will rely on multiple approaches to reduce overall GHG emissions from the power sector.[39] Both countries seek improvements in energy efficiency, changes in the energy mix, and the introduction of advanced and new technologies such as CCS to reduce future emissions.

Figure 7 provides a snapshot of these strategies and their impact on reducing GHG emissions in the electric sector by 2030. Superimposed against the backdrop of the EIA's reference case of emissions as of 2008 and projected out to 2030, the combination of efficiency measures, renewables, nuclear generation, advanced goal generation, CCS, and solar could reduce carbon emissions by approximately 1400 million metric tons by 2030 (from the forecasted reference case of 3000 to 1600 million metric tons). The largest contributor to this goal appears to be efficiency measures plus a significant (and even greater) contribution to be made by CCS technologies.

Figure 7: Strategies to Reduce Carbon Emissions in the U.S. Electricity Sector to 2030



Source: Qtd in: Giove III, Joseph. "U.S.-China Cooperation on Low-Emissions Coal Technologies: U.S. Clean Coal Research, Development, and Demonstration Programs." Beijing, China, 25-26 June 2009.

The U.S. Energy Policy Act of 2005 provided $1.65 billion in investment tax credits to stimulate CCT and out of this fund, dedicated $800 million to IGCC activities. In addition, there is a significant amount of funding, shown in Figure 8, as a result of the "Stimulus" legislation that includes $3.4 billion for coal, including $1.0 billion for

[39] Nationally, 8,300 megawatts of wind-power capacity were added in 2008, bringing the U.S. total to 25,000 megawatts. This represents, however, only 1.3 percent of the nation's total capacity

FutureGen. Activities have been significantly ramped up over the last three years. DOE's total budget has increased from $414 million in 2007 to $692 million in 2009. Clean Coal Power Initiatives (CCPI) funding increased from $58 million in FY 2007 to $288 million in FY 2009. Including the DOE budget and the Stimulus funding, funding for the coal RD&D program in FY 2009 increased by 22% over the total of the cumulative funding from FY 2000 through 2008.[40]

Figure 8: U.S. Government Funding for CCT and CCS Programs Has Increased Significantly from FY 2007 to FY 2009

	($ in thousands)	FY 2007 Adjusted B/A	FY 2008 Adjusted B/A	FY 2009 Omnibus
Demos	CLEAN COAL POWER INITIATIVE	58,758	67,444	288,174
	FUTUREGEN	52,504	72,262	0
R&D	FUELS AND POWER SYSTEMS			
	Innovations for Existing Plants	15,626	35,083	50,000
	Advanced IGCC	55,468	52,029	65,236
	Advanced Turbines	19,475	23,125	28,000
	Carbon Sequestration	97,228	115,620	150,000
	Fuels	21,513	24,088	25,000
	Fuel Cells	61,653	53,956	58,000
	Advanced Research	32,213	36,264	28,000
	Subtotal, Fuels and Power Systems	303,176	340,165	404,236
	TOTAL COAL	414,438	479,871	692,410

Source: Giove III, Joseph. "U.S.-China Cooperation on Low-Emissions Coal Technologies: U.S. Clean Coal Research, Development, and Demonstration Programs." Beijing, China, 25-26 June 2009.

2. Next Generation CCT Initiatives

Multiple CCTs will be evaluated in the United States, including the IGCC with pre-combustion CO_2 capture. The former technology would combine gasification and gas turbines to clean up the fuel stream prior to combustion. The coal pulverization scenario would team up traditional steam boilers and clean up the exhaust post combustion similar to a scrubber process. The first option is ready for commercial demonstration today while the second will not be ready for commercial demonstration before 2020.[41]

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[40] Tomski, Pamela. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Financing Carbon Capture and Storage Systems." Beijing, China, 25-26 June 2009.

[41] There is already a small fleet of IGCC demonstrations worldwide and there are over 30 gasification plants separating CO_2.

While IGCC technologies have been deployed in the United States on a limited basis with two commercial plants[42], there are a number of planned commercial 600 MW plus IGCC projects with CCS in different stages of development throughout the United States, including the Duke Energy Edwardsport IGCC, the Southern California Edision IGCC plant in Utah and Mississippi Power's IGCC using brown coal/lignite. Furthermore, the Polk Tampa IGCC plant is planning a new slipstream CO_2 capture demonstration.

The U.S. government and industry have three major joint-initiatives that advance CCS development and deployment: Innovations for Existing Plants (IEP), the Clean Coal Power Initiative (CCPI) which includes the FutureGen power plant, and the Regional Carbon Sequestration Partnerships (RCSP) Program. DOE is the largest source of funding for early deployment projects in the United States primarily because of high-cost, high-risk aspects of any new technology and lack of comprehensive legal and regulatory frameworks for CCS deployment.

The IEP program redirected its efforts in mid 2008 to include carbon emissions control for existing combustion plants such as the conventional pulverized coal power plants. The project will spend $36 million on 15 projects conducted by U.S. universities and industry. It will fund research on post-combustion capture membranes, sorbents and solvents, oxy-combustion chemical looping, and oxy-fired boiler technology development.

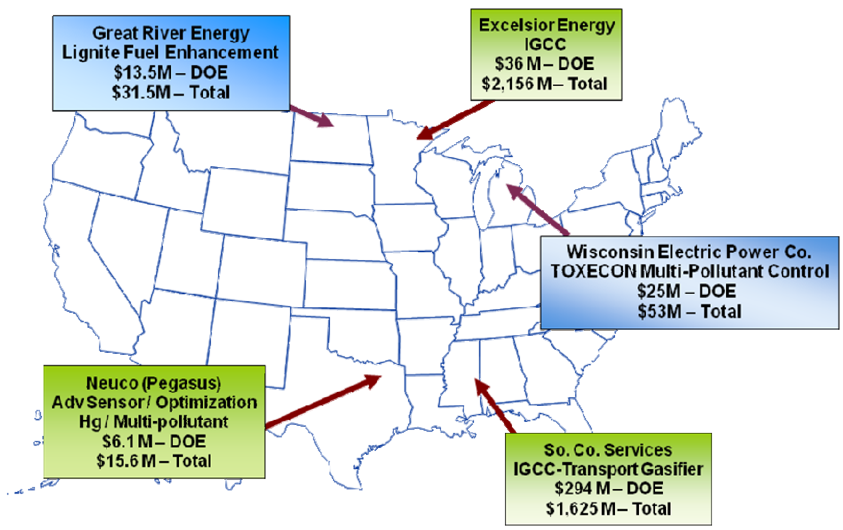
Under the CCPI, 8 projects were selected. Figure 9 shows the location of such projects on the U.S. map. Since 2003, 2 projects withdrew (Colorado Springs, LG&E), 3 projects were discontinued before or during project development (WMPI, University of Kentucky, Western Greenbrier), 2 projects are ongoing (WE Energies, GRE), and 1 project has been completed (Neuco). Under October 2004 round, 1 project withdrew (Peabody Mustang), 2 projects were awarded and are in the project development phase (Mesaba, Southern), and 1 project is in operation (Pegasus). In the final round, projects are focused on advanced power with CCS capability or beneficial recycling of CO_2. DOE anticipates approximately $1.40 billion in funding will be available. The requirements of these projects will be:

- a minimum of 50% carbon capture efficiency;
- progress towards a target of 90% carbon capture efficiency;

[42] The Coolwater 120 MW coal IGCC facility operated between 1984 and 1989. Tampa Electric's 250 MW IGCC, operating since 1996, is the cleanest US coal plant.

- minimum capture of 300,000 tons CO_2/year over 4 years;
- use domestic-mined coal or coal refuse for at least 55% of energy input;
- obtain a minimum 50% cost share from participant in the demonstration;
- up-front funding;
- no more than a 25% cost growth in DOE's share.

Figure 9: Current U.S. Clean Coal Projects Sponsored by DOE



Source: Giove III, Joseph. "U.S.-China Cooperation on Low-Emissions Coal Technologies: U.S. Clean Coal Research, Development, and Demonstration Programs." Beijing, China, 25-26 June 2009.

On July 1, 2009 the DOE announced that two CCS demonstration projects were selected under the CCPI. They will demonstrate different technological concepts to achieve a goal of at least 90 percent CO_2 capture efficiency.

The Basin Electric Power Cooperative will receive $100 million to demonstrate post-combustion CO_2 capture. The Cooperative, located in Beulah, N.D, will partner with Powerspan and Burns & McDonnell to demonstrate the removal of CO_2 from the flue gas of a lignite-based boiler by adding CO_2 to Basin Electric's existing Antelope Valley Station. Powerspan's E CO_2 ammonia-based technology will be used to capture CO_2 on a 120-megawatt electric-equivalent gas stream from the 450 MW Antelope Valley Station Unit 1. The net result will be 90% removal of CO_2 from the treated flue gas, yielding 3,000 short tons per day (1,000,000 tons per year) of pipeline-quality CO_2. The ammonia based SO2 scrubbing system will also produce a liquid stream of ammonium sulfate that will be processed into a fertilizer by-product.

Hydrogen Energy International LLC will receive $308 million and will feature a commercial demonstration of advanced IGCC with full carbon capture in Kern County, California. Hydrogen Energy International LLC, a joint venture owned by BP Alternative Energy and Rio Tinto, will design, construct, and operate an IGCC plant that will take blends of coal and petroleum coke combined with non-potable water, and convert them into hydrogen and CO_2. The CO_2 will be separated from the hydrogen using the methanol-based Rectisol process. The hydrogen gas will be used to fuel a power station, and the CO_2 will be transported by pipeline to nearby oil reservoirs where it will be injected for storage and used for enhanced oil recovery. The project will capture more than 2,000,000 tons per year of CO_2.

U.S. government approval for the FutureGen project, which bridges the gap between current IGCCs and CCS demonstration, was reinstated on June 12, 2009. This 275 MW power plant will be located in Mattoon, Illinois, and will be designed to capture and sequester 90% of its carbon emissions along with other pollutants. However, in order to reduce startup risks and costs, at first it will only capture 60% of emissions. Its other goals include integrated full-scale operations to serve as a test facility for emerging technologies and to capture and sequester at least 1 million tons/year of CO_2. The current cost estimate is $2.4 billion with DOE to contribute $1.073 billion toward the project cost, $400 to 600 million from industry and the rest to be determined. The funding gap will require further cost reductions before the project will be approved.

The GreenGen Program in China is developed by CHGNG, a FutureGen team member, although the collaboration details have not been finalized. Other companies in the partnership include BHP Billiton Ltd., Peabody Energy Corporation, Consol Energy Inc., EON AG, Anglo American PLC, Rio Tinto PLC, Foundation coal Holdings Inc.[43]

3. CCS in the United States

a) Industry CCS Roadmaps and Projects

General Electric (GE), one of the Dialogue participants, promotes the strategy of retrofitting current and next generation plants over time, arguing that IGCC facilities can be retrofitted for CCS even under today's rules, without climate legislation. This can be done under the 2015-2020 timeframe by strategically replacing existing plants and re-siting them near sequestration sites. Then, in the 2020-2030 timeframe, it is

[43] The two largest coal power generators in the United States, American Electric Power Company and Southern Company, announced in late June that they will quit the partnership.

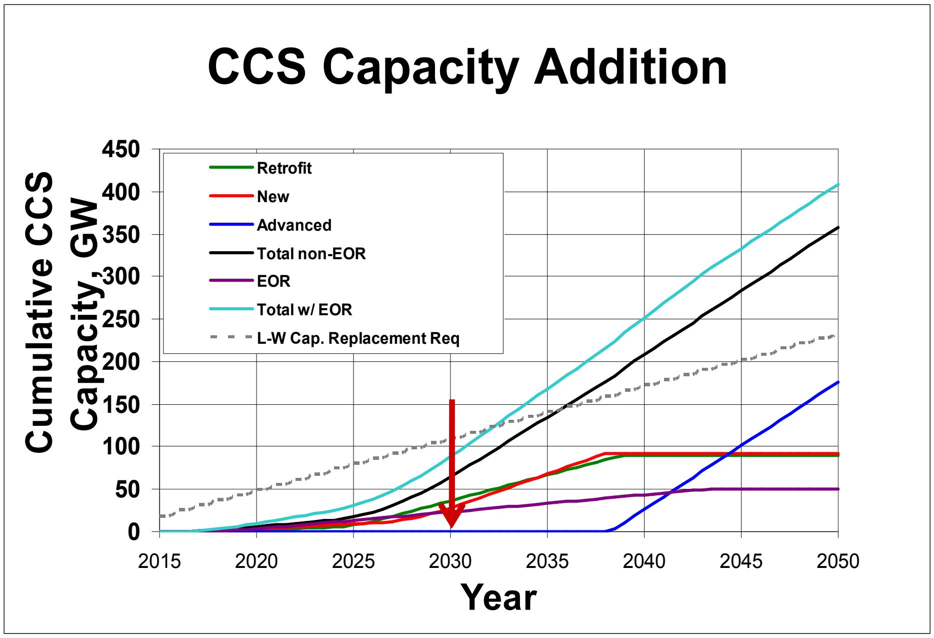
postulated that the plants can be retrofitted to capture higher percentages. GE's studies show that the lowest capital cost and lowest operating penalty strategy would increase the carbon capture rate of IGCCs to the natural gas equivalent capture rate of 50% until standardized designs and components and other technology improvements would allow for a 90% capture rate at new IGCC facilities with CCS. This strategy is very similar to that considered by the Chinese government.

The Coal Utilization Research Council (CURC), a Washington, DC-based 60 member, industry organization is focused on coal related technology development and use. It has developed an action plan for developing a robust CCS program. Its Roadmap calls for:

- Ongoing R&D to continue.
- 5 GW (approximately) of demonstrations of current technology should be implemented now, along with independent (saline) CO_2 storage projects.
- Approximately 10 GW of "1st Movers" (commercially operated systems, not "test platforms") should receive incentives (less so for EOR systems).
- 45 GW of "Early Adopters" (technical problems solved; economic help still needed) should receive support, possibly via a "bonus allowance" or financial hedge approach.
- Program totals 60 GW of CCS; all but the final category (Early Adopter program) can start now

CURC estimates that the cumulative CCS capacity (EOR and CCS sites included) would increase from zero in 2020 to near 75 GW by 2030, 250 GW by 2040 and 400 GW by 2050. Figure10 shows the relative contributions to total CCS capacity provided by retrofitting plants and by EOR area storage.

Figure 10: Providing CCS Through 2050



Source: Yamagata, Ben. "U.S.-China Cooperation on Low-Emissions Coal Technologies: CURC's 5-point Coal w/CCS Program." Beijing, China, 25-26 June 2009.

In addition to industry sponsored policy and research programs, in the United States, the coal industry is undertaking R&D and sponsoring small-scale demonstrations. Alstom has been working on combustion and post-combustion CCS technologies.[44] It considers post-combustion to be the easiest technology to introduce, as it is similar to processes that have already successfully removed NOX and SOX. The technology relies on a chemical process to remove the CO_2 from the stack and then sequester it geologically.[45] At the We Energies demonstration plant, a 5 MW pilot project has been successfully completed that achieved over 90% capture of CO_2. Alstom is now scaling up the technology and the next step will be the 30 MW Mountaineer Project with American Electric Power (AEP), and potentially a second 235 MW commercial-scale capture plant at that site. In addition, Alstom is seeking opportunities for projects in the range of 200 to 300 MW, hoping that by 2015, it will be able to offer commercial-scale designs. 2015 would be a lot sooner than many other projections. [46]

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[44] The international company, Alstom, which recently joined the Pew Center on Global Climate Change Business Environmental Leadership Council, moved its North American operations office to Washington, DC.

[45] Alstom has decided for the moment not to work in the pre-combustion area, considering it to be too complex and still in the evolution phase. Alstom further believes that increased R&D investments in the combustion and post-combustion areas are warranted.

[46] "Carbon Capture: Alstom's Gauthier discusses successful Wisconsin Project." 21 June 2009. E&ETV.com. Accessed on September 8, 2009 at <http://www.eenews.net/tv/transcript/1014>

The Babcock & Wilcox Power Generation Group has also been engaged in oxy-coal combustion R&D since the late 1990s. It demonstrated the technology at its Clean Environment Development Facility with a 30 MW thermal test plant using several types of coal and is ready to propose a 100 MW commercial scale plant.

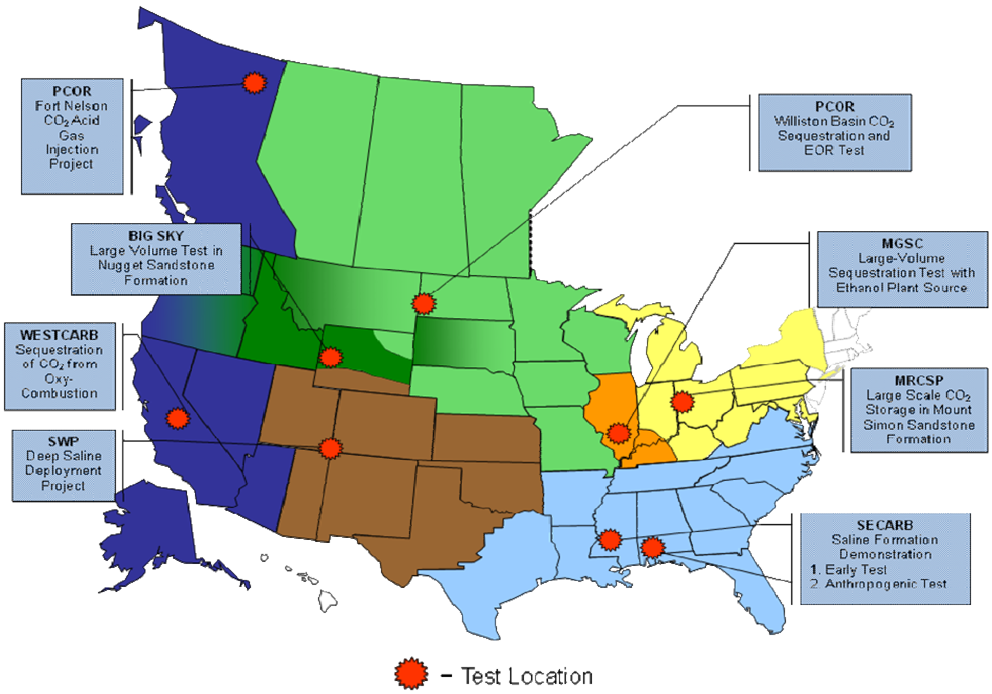
b) DOE CCS Demonstration Activities

DOE is sponsoring many of the CCS demonstration projects in the United States under a program strategy that closely aligns with the industry-led CURC roadmap. DOE began to sponsor R&D in 1996 and expects to continue involvement until 2017 in two areas of work. First, CO_2 sequestration R&D will cover injection tests, monitoring techniques, modeling analyses and risk analysis. Second, advanced low cost/energy efficient CO_2 capture research will take place for separation and compression techniques, power efficiency and finally on capacity recovery. DOE plans for large-scale demonstrations from 2009 to 2020 including research demonstrations through the RCSPs and near-commercial demonstrations at facilities such as FutureGen. Overlapping this demonstration phase would be commercial deployment starting in 2015 with the hope of reaching full commercial deployment by 2025.

The RCSP is a successful U.S. program with 7 partnerships, each identifying geologic structures in its respective area, representing more than 350 organizations in 41 states plus 4 Canadian Provinces and 3 Indian nations.[47] There are nine large scale sequestration projects located in the U.S. that cover many fuel types such as ethanol, oxyfuel, natural gas and helium. Figure 11 shows the locations of the U.S. test locations.

Figure 11: U.S. Map of Large Scale Sequestration Testing Locations

[47] There are other projects including three other large-scale carbon sequestration projects in the world in the North Sea area adjacent to Norway, Weyburn in Canada and Salah in Algeria. With an addition of six in the United States, they could store 3 million metric tons annually, enough storage for a 500 MW coal plant.



Source: Giove III, Joseph. "U.S.-China Cooperation on Low-Emissions Coal Technologies: U.S. Clean Coal Research, Development, and Demonstration Programs." Beijing, China, 25-26 June 2009.

One component of the program is a "geoportal," linking the regional sequestration partnerships with substantive data regarding the potential geologic storage sites in each region. The program, sponsored by the NETL and carried out by the University of West Virginia, has developed a sophisticated, web-based and publicly accessible analytical tool called the "Cyberinfrastructure" (CI)[48] which includes an atlas of carbon sources and potential sinks, decision support tools, management support tools for the seven regional sequestration partnerships. Every two years a paper atlas is published but the computer-accessible data is continually updated. It includes data on more than 10,000 potential sinks and 170-200 billion tons potential storage, as well as on U.S. annual emissions.[49]

The CI project is a perfect example of where U.S. expertise can be imported to China to help that country develop vital information gathering and public communications tools.

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[48] This term refers to infrastructure based upon distributed computer, information, and communication technology.
[49] U.S. annual emissions are in the range of 7 GT. According to the EPA, in 2006, total U.S. GHG emissions were estimated at 7,054.2 million metric tons CO_2 equivalent. This estimate included CO_2 emissions as well as other GHGs such as methane, nitrous oxide , and hydro fluorocarbons. Annual GHG emissions from fossil fuel combustion, primarily CO_2 , were estimated at 5,637.9 million metric tons with 3,781.9 million metric tons from stationary sources (Carr, Timothy. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Developing a Carbon CyberInfrastructure and a Path Forward for International Efforts." Beijing, China 25-26 June 2009).

While not all potential GHG sources have been examined, the CI effort has documented the location of more than 4,796 stationary sources with total annual emissions of 3,276 million metric tons of CO_2. They are now working on its next phase, which will be ready by the fall of 2009, including complicated diagrams to "Google-earth-like" maps showing all the CCS projects in the U.S. It is linked to the United States Geological Service (USGS) earthquake computer server. Canada and Mexico are also working to add their data in real-time.

V. CCT AND CCS COOPERATIVE AGREEMENTS

A. Chinese Partnerships and Agreements

Since the middle of the 2000's, China has embarked on several multilateral initiatives to develop CCTs. China has realized its high dependence on coal as a primary source of power and environmental degradation resulting from its use were potential sources of insecurity. As a result, China has reached out to the international community in an attempt to access technologies that will greatly reduce pollution, water consumption and increase energy efficiency.

To this end, China has been actively seeking participation in international projects and collaboration regarding CCTs. In addition to the limited cooperative programs with the United States, China has been successfully pursuing agreements with the EU and its member states. In September 2005, China signed a Joint Declaration with the EU, followed by the EC-China Memorandum of Understanding in February 2006. This established the four major initiatives (previously described in Section 3.A.5) GESTCO, Geocapacity, COACH, and NZEC.[50] Additionally, China participates in a number of international arrangements to develop CCTs. The primary focus of these agreements is to share knowledge and develop best practices for the burgeoning clean coal industry. Examples include:

- Carbon Sequestration Leadership Forum (CSLF)
- The International Platform on the Hydrogen Economy
- Methane to Markets Partnership
- Task sharing within IEA Implementing Agreements
- Asia-Pacific Partnership on Clean Development and Climate

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50 The NZEC project is of special interest because it includes plans for a Chinese-British joint venture to build a demonstration plant in China by 2015.

- Energy Star bilateral agreements
- Cost sharing within IEA Implementing Agreements
- The Solvent Refined Coal II Demonstration Project
- Multilateral Fund under the Montreal Protocol
- Global Environment Facility
- International Convention for the Prevention of Pollution from Ships (MARPOL)
- European Union Renewables Directive

B. U.S.-China Bilateral Agreements

In 1979, following normalization of U.S. relations with China, one of the first agreements between the countries was on science and technology (S&T) cooperation, signed later that year. For 30 years, the U.S.-China S&T Cooperation Agreement has been a resilient source of cooperation between the countries. The DOE currently manages 12 agreements with China under the S&T framework on a wide variety of energy sciences and technologies including: building and industrial energy efficiency, clean vehicles, renewable energy, nuclear energy and science, and biological and environmental research.

U.S.-China bilateral cooperation activities were established through the "Protocol for Cooperation in the Field of Fossil Energy Technology Development and Utilization Between the Department of Energy and the Ministry of Science and Technology of the People's Republic of China" signed on April 20, 2000, initiated in 2001 and renewed until 2010. The Protocol promotes scientific and technical cooperation in fossil energy research, particularly activities related to development, demonstration and deployment. Initiatives under this protocol include:

- IGCC training program at a U.S. plant proposed by Chinese utilities
- IGCC prefeasibility and cost studies
- GE simulator training at Wesleyan University
- Assisting Shenhua Group Corporation to develop the world's first Direct Coal Liquefaction plant in Ordos, China
- Cooperation between West Virginia University and the Shenhua Group since 2003

This protocol is primarily executed through knowledge exchange programs which bring Chinese coal experts to the United States. Other initiatives that attempt to deepen cooperation beyond knowledge exchanges have faced stumbling blocks over IPRs. For example, a demonstration project that planned to use U.S.-developed coal upgrading technology for low rank coals as a means of cutting emissions and increasing efficiency has been halted because of IP concerns.[51]

The DOE has convened three workshops with more than 250 Chinese utility, environmental, and governmental officials. This has led to many commercial projects and new business arrangements. The first workshop was held in 2003, and was followed by others in 2005 and 2007. The U.S.-China Symposium on CO_2 Emissions Control Science and Technology, another DOE sponsored workshop, held its first meeting in 2001 and another in 2008.

Furthermore, the U.S.-China Energy and Environmental Technology Center or EETC, co-funded by DOE and MOST, was officially established in 1997 with the objective of promoting U.S. clean energy technology transfer by developing training and educational programs related to environmental policies, legislation, technology options, and cost/financing of these options. The primary mechanism used to facilitate these objectives is market liberalization for U.S. clean coal and environmental technologies which will aid in minimizing local, regional, and global environmental impacts from China's energy use. Specifically, since 1995, the EETC has consistently promoted IGCC to China. EETC and Chinese Academy of Sciences jointly published a bilingual and widely used US-China Expert Report on IGCC. In 1996, EETC facilitated the initial meeting in Beijing and testing of U.S. direct liquefaction technology with Chinese coal in the United States. Eventually, Shenhua Group Corporation Ltd.'s subsidiary, China Shenuhua Coal Liquefaction Corporation purchased the IPR from the United States-based Hydrocarbon Technology Inc., providing an excellent business model of technology transfer. Lately, EETC helped the transfer of Babcock and Wilcox's wet flue gas desulfurization technology to China which has become the industry standard in China. Finally, the EETC supports a wide range of fossil energy-related and other clean energy/environmental activities such as supporting the DOE-MOST Protocol in the field of Clean Fossil Energy and the U.S.-China Oil and Gas Industry Forum (OGIF). All of these cooperative activities provide a mutually beneficial and reinforcing foundation for further cooperation.

There are three recent R&D MOUs between China and NETL. They include:

- NETL/China National Petroleum Corporation (2008-2013), with the primary purpose of developing oil and natural gas (methane hydrates, high-temperature/high-pressure drilling and production), CCS, coal bed methane

[51] This program was to be jointly developed by Evergreen Energy and China Power Investment Corporation.

and enhanced coal be methane technologies, including waste utilization and minimization

- NETL/Chinese Academy of Sciences (2009-2014), which has the dual goals of improving computational modeling/simulation of advanced fossil energy-based systems and advancing analysis and integration studies on advanced fossil energy-based systems, especially IGCC and CCS
- NETL/Pacific Northwest National Laboratory/Chinese Academy of Sciences (2009-2014), the goal of which is advanced, low-emission, fuel-flexible gasification and combustion systems, including key components and processes and environmental control technologies for gaseous, water, and solids effluents from these systems, especially CCS

Additionally, at the inaugural meeting of the U.S.-China Strategic and Economic Dialogue (S&ED), July 28th-30th, the officials focused extensively on climate change issues and their respective positions regarding the upcoming Copenhagen summit. As a result of this S&ED summit, a MOU was signed that sets the stage for intensive, future bilateral cooperative mechanisms. According to the press release:

> The two sides pledged to strengthen cooperation on renewable energy, cleaner uses of coal, including carbon capture and sequestration, smart grid, shale gas, second and third generation biofuels and advanced nuclear. [52]

The summit follows the launch of a joint Clean Energy Research Center to bolster R&D on efficiency, CCS and low-emissions technologies. This project was publicly announced at the July 15, 2009 meeting in Beijing between Commerce Secretary Gary Locke, Energy Secretary Steven Chu, Minister of Science and Technology Wan Gan, and Administrator of the National Energy Administration, Zhang Guobao. China and the United States each pledged $15 million and hope to start joint programs by the end of 2009.

All of these summits, MOUs, and plans to open the research center, further bolster the recommendations of this Dialogue.

C. U.S.-China Private Sector Cooperative Relationships

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[52] "Joint Press Release on the First Round of the U.S.-China Strategic and Economic Dialog." 28 July 2009. U.S. Department of Treasury Press Room. Accessed on September 8, 2009 at <http://www.ustreas.gov/press/releases/tg242.htm>

China and the United States are also developing a cooperative framework on CCS technologies through the private sector. Two of the largest U.S. and Chinese private utilities, Duke Energy Corporation and the China Huaneng Group, signed a MOU in Beijing on August 10, 2009 to explore initiatives to produce low carbon emissions power from coal and renewables, particularly from wind. These companies have been on the forefront of IGCC technologies, demonstrated by Duke's progress on the 630 MW IGCC facility in Edwardsport, Indiana and Huaneng's development the GreenGen project. This is an important example of how private sector utilities can jointly cooperate to develop technology more rapidly and help drive down project costs.

D. Multilateral Agreements

The United States is engaged in several multilateral agreements and institutions that are at the forefront of furthering international cooperation to promote CCS technologies. The DOE has developed the RCSPs and is active in the Asia Pacific Economic Cooperation (APEC) organization's efforts to engender effective multilateral cooperation. The United States is also party to the Multilateral Cooperation Carbon Sequestration Leadership Forum and the Global CCS Institute, which are striving to enhance CCS technology as well as promoting international cooperation.

Perhaps the most promising international effort to develop CCS is the DOE's RCSPs. These Partnerships, listed in Table 2, primarily work toward developing new technologies and industry best-practices, and have been successful in advancing important technological developments in a cost-effective and timely manner. These Partnerships have fostered key CCS projects on four continents. While China has not so far been included in these Partnerships, existing agreements provide a model for possible future engagements with the Chinese.

Table 2: DOE CCS Projects Worldwide

Selected DOE Participation in International CO_2 Storage Projects					
Location	**Period**	**Operations**	**Reservoir**	**Operator /Lead Org.**	**International Recognition**

North America, Canada Saskatchewan *Weyburn-Midale*	2000-2009	1.8 mT CO_2/yr commercial 2000	oilfield carbonate EOR	Encana, Apache	IEA GHG R&D Programme, CSLF
North America, Canada, Alberta *Zama Oilfield*	2005-2009	230,000 tons CO_2, 80,000 tons H_2S demo	oilfield EOR	Apache (Reg. Part.)	CSLF
Europe, North Sea *Sleipner*	2002-2006	1 mT CO_2/yr commercial 1996	marine sandstone	Statoil	IEA GHG R&D Programme, European Commission
Europe, Germany, Ketzin *CO2SINK*	2007-2010	60,000-90,000 tonnes CO_2 demo 2008	gasfield sandstone	GeoForsch-ungsZentrum, Potsdam	CSLF, European Commission
Australia, Victoria *Otway* Basin	2005-2010	100,000 tonnes CO_2 demo 2008	gasfield sandstone	*CO2CRC*	CSLF
Africa, Algeria *In Salah*	2005-2010	1 mT CO_2/yr commercial 2004	gasfield sandstone	BP, Sonatrach, Statoil	CSLF, European Commission
Asia, China *Ordos Basin*	2008-TBD	storage assessment prefeasibility study	Ordos Basin	Shenhua Coal	DOE-MOST FE Cooperation Protocol

Source: Smouse, Scott. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Bilateral and Multilateral Cooperation." Beijing, China, 25-26 June 2009.

International organizations have also begun promoting the use of CCS in their member states. The Asia Pacific Economic Cooperation (APEC) organization[53] has initiated the

[53] APEC is the region's organization for facilitating economic growth, cooperation trade and investment. 21 Developed and developing member economies that account for 40% of world population, 54% of world GDP and 44% of global trade.

Expert Group on Clean Fossil Energy to promote the use of CCS in its constituent states. The Expert Group has already begun work on a geosequestration project which will assess geological storage capacity. In addition, the Asia Pacific Partnership's (APP) Clean Fossil Energy Task Force is sponsoring the Wyoming-Shanxi CCS cooperation project, which involves two of the largest coal producing areas in the world.

The Multilateral Cooperation Carbon Sequestration Leadership Forum is another important actor in promoting global CCS activities. The Forum is a Ministerial-level international initiative focused on developing improved, cost-effective CCS technologies. It has representatives from Australia, Brazil, Canada, China, Colombia, Denmark, France, Germany, Greece, India, Italy, Japan, Mexico, Netherlands, Norway, Russia, Saudi Arabia, South Africa, South Korea, United Kingdom, and United States, plus the EU. The Forum works to foster cooperation on R&D, share research results, build capacity and address financial and regulatory barriers. There are currently 20 endorsed projects, including two in China.

The United States is a founding member of the Global CCS Institute, established by Australia with an endowment of AU$100 million (or approximately US $830 million), to fund the institute until 2018.[54] Inaugurated on April 16, 2009, the Institute's primary goal is to foster coordination and learning among the world's leading CCS experts and programs. Currently the Institute is establishing a work plan to develop better global CO_2 storage estimates and promoting capture-ready studies and workshops with APEC. The CCS Institute will hold a Joint Symposium focusing on EOR with International Energy Forum hosted by NDRC/ERI, in Beijing, in September 27-29, 2009. The Institute has already received widespread international support, as it has received backing from 16 national governments and more than 40 major companies. China has joined the Institute as a collaborating participant.

V. ISSUES AND OBSERVATIONS

A. Fundamental Differences between the Energy Portfolios of the United States and China

There are fundamental differences between the energy portfolios in China and the United States, and future demand trends will only deepen them. Today, the United States consumes 21% of the world's energy while China consumes 16% of total world

[54] AU/US dollar conversion assumes a 1.204/1 exchange rate.

energy. However, the demand for energy is rapidly increasing in China and will surpassed the U.S.'s demand by 2010. China consumes twice as much coal as the United States and relies on coal for 70% of its annual energy needs, while the United States uses coal to meet only 23 % of its energy needs. U.S. dependence on oil tops out at 41%, more than double China's use of oil, which stands at 20%. Again, reflecting available domestic supply alternatives--the United States has relatively abundant supplies of natural gas--in the United States, natural gas provides 22% of its energy as compared to 3% for China. At least today, the United States' supply of nuclear supplied electricity far exceeds that for China; 8% of the U.S. energy mix comes from nuclear power whereas nuclear generation provides only 1% for China. In one area, if hydropower and other renewables are combined, both countries utilize those resources for 6% of their power.[55]

B. Energy Efficiency Measures

Increasing energy efficiency presents opportunities for the United States and China to collaborate. Short-term improvement can be attained in China with current technology. However, China's very high dependency upon fossil fuels, coal in particular, will make it difficult to maintain the same rate of increasing energy efficiency without new technologies, thus the importance of international efforts to bring such technologies to China.

As a rapidly developing country that is undergoing substantial urbanization and infrastructure development, China understands the need to pursue stricter energy efficiency standards. The United States is currently a leader in developing energy efficiency technologies and the best-practices developed by U.S. industry have the potential to improve energy efficiency in China. This provides an opportunity for bilateral cooperation on energy efficiency which can help China diminish the expansion in its utilization of coal as the country's future energy needs continue to dramatically increase.

C. China's Coal Imperative

China's demand for coal is unlikely to be reduced in the near term as it rapidly expands its economy and relies on abundant domestic resources. In 2050, China will continue to

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[55] Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing, China, 25-26 June 2009.

rely on coal and is forecasted to emit 11-13 billion tons of CO_2 per year (an increase of 5 to 7 billion tons from the present). Efficiency and fuel switches may only result in a reduction of 2-3 billion tons of CO_2. This points to the necessity for China to undertake CCS.[56]

Despite its reliance on coal, China is committed to addressing GHG and other emissions issues. The current strategy is focused on building new and more efficient coal plants, while closing old polluting plants. Unfortunately, due to the antiquated technology that characterizes most existing power plants, China is still focused on reducing sulfur and nitrogen oxides and other pollutants such as particulate emissions from its coal industry; carbon emissions are at best seen as a secondary issue in terms of controlling emissions.

the linear generation model and develop technologies that can deal with reducing all emissions-not just carbon- on an integrated basis. Such cooperation will prove to be a significant market opportunity for the United States and a way for China to rapidly improve the environmental sustainability of its economy. Additionally, there is a strong incentive for CCS and integrated technologies to be developed in China and exported to the United States, where zoning and domestic politics often prevent or delay demonstration projects.

D. Status and Prospects for IGCC Technology

In the short to medium term, IGCC technology shows a path to lower emissions while still utilizing coal energy. In the long term, multiple types of low to zero emissions coal technologies will be needed for cleaner coal utilization. The likelihood of commercial scale demonstrations of next generation technologies, such as pulverized coal with post-combustion CO_2 capture, occurring before 2020 is extremely low, with a substantial risk that they will not be widely deployed before 2025. Therefore, the introduction of IGCC technology today is essential to mitigate emissions while CCS and other next generation coal technologies are being developed.

A viable U.S. roadmap has been proposed. Objectives include: increasing the capacity of IGCC plants from the 1-5 MW to 200 MW range to show performance and economics and paths to decrease capital costs and emissions; starting deployment of multiple scale

[56] Jin, Hongguang. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Innovative CCS Technologies for Sustainable Development of China," Beijing, China 25-26 June, 2009.

IGCC plants with CCS demonstrations; and, making investments in R&D on both pre- and post-combustion capture to create a meaningful path so that there will be robust use of the technologies by 2020. Success will depend upon starting an accelerated and massive program, including R&D and demonstrations, to drive down costs.

In the United States, IGCC plants can be introduced by replacing coal-fired plants built in the 1950's now nearing the end of their useful lives. A good example of this strategy is Duke Energy's planned Edwardsport facility. Duke expects the technology will be economically viable and will be a lower cost option for electricity production in a carbon-constrained scenario.

Until IGCC plants are commercially viable in a carbon-constrained world, incentives are needed to drive demonstrations forward. Current concerns related to emission taxes, caps and trading schemes are barriers to long-term investments. This uncertainty could be mitigated by policies such as investment tax credits, fast track permitting, and new legislation allowing utility companies to pass on the costs of new plants to rate payers during the construction phase. Without new legislation, utility companies may well be without the necessary threshold of certainty that would allow them to invest in this new technology. Governmental policy has a critical role to play in shaping the future of IGCC and CCS in the United States.

While IGCC plants with CCS are planned in the United States, the Chinese government is actively promoting IGCC technology without the CCS component at the outset. Due to the immediate need for a reduction in harmful emissions, municipalities in China are seeking to enable IGCC demonstration projects for near term improvements in air and water quality. The Chinese government at various levels is providing the support to foster this technology and as IGCC, and eventually CCS technologies mature, it is expected that the government would develop the necessary regulatory framework. In summary, through 2050, China is expected to utilize increasingly sophisticated traditional coal fired plants, IGCC facilities and eventually some CCS capacity.

The United States is faced with a different situation today as domestically it has more energy alternatives to coal than in China. The United States, however, faces growing domestic political opposition from environmental groups against any new coal fired plants, regardless of the technology involved. Unless the economic benefits of coal are chosen by the public at large, political pressure from the environmental community could result in the loss of an entire generation of coal related technologies. For there to be a less economically disruptive transition to a lower carbon economy, the U.S. public needs to embrace a diversified energy portfolio, deploying advanced CCTs as they become technically and economically viable.

E. CCS Status and Issues

1. CCS- The Essential Ingredient for Successful Emissions Reductions

In the long term, significant CO_2 emission reductions without CCS will be impossible to reach in either China or the United States. All the technologies for capture, transport and geologic sequestration of carbon exist at a commercial scale but have yet to be integrated with large coal fired power plants. Furthermore, there are private companies in the United States that are pursuing novel approaches to carbon capture and storage that could be highly effective and efficient. However, while legal and regulatory frameworks for long-term CO_2 storage are under development worldwide, there is no comprehensive framework to support CCS deployment at large-scale.

There are a number of geologic storage options including depleted oil and gas reservoirs, saline formations and deep unminable coalbeds. There is no one favored geologic or least cost CCS approach in the U.S. as conditions vary widely. Sequestration in depleted oil fields currently provides a good, near-term opportunity to store CO_2 and offset costs through enhanced oil recovery.[57] Saline aquifers are the most widely distributed.

Because CCS technologies are still being developed, decision makers must choose technology pathways that incorporate a degree of flexibility. Coal plants can be fitted with a number of carbon capture options that include pre-combustion capture, Oxyfuel combustion, post-combustion capture, and emerging near-zero emission power plants—yet each technology has its own costs and benefits. For example, France is pursuing Oxyfuel combustion, the United States is trying FutureGen which combines an IGCC facility with CCS, and China is going forward with GreenGen. However, developing cost effective technologies will likely lie in incorporating a number of technologies. Thus, decision-makers will be forced to choose optimal technology pathways under various uncertainties, which require that flexibility be built into the decision-making system.

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[57] Although not discussed during the meeting, several US companies are developing processes to utilize CO_2 in the manufacturing of cement. This has the potential to reverse the current adverse impact of cement production by trapping CO_2 permanently. (1 ton of CO_2 is used to make 1 ton of cement) (Biello, David. "Cement from CO_2 : a Concrete Cure for Global Warming?" Scientific American. 8 September 2009. < http://www.calera.biz/pdf/scientifc_american%20copy.pdf>)

Uncertainties are further compounded because sequestration has yet to be adequately demonstrated. CCS must be proven on a large-scale beyond EOR and in deep saline reservoirs with large volume CO_2 injection. Geoscientists believe risks from sequestration will be manageable and carbon seepage will pose a minimal threat. In China, the government owns most of the geologic storage areas, so undertaking CCS is relatively straightforward. However, U.S. storage facility ownership is more complex.

There is a wide variety of storage projects underway or planned. Over 40 different storage projects are currently demonstrating many types of CO_2 storage operations, including: enhanced coaled methane, enhanced gas and oil recovery, depleted gas and oil field, and both onshore and offshore saline aquifers. Currently, China's EOR potential is believed to range from only 900 billion tons of carbon storage.

The outlook for the Unites States is perhaps brighter with regard to CCS developments. For example, in the United States, the CI project is developing an excellent methodology for creating the data collection tools and information sharing mechanisms desperately needed by planners and community leaders alike. There are many international communication and collaboration networks supporting these projects and policy makers are increasingly focused on incorporating CCS into their domestic energy portfolios. However, few are large-scale and many face funding uncertainties or cancellation. A U.S.-China IMC, as suggested by the Dialogue participants, would go a long way toward ameliorating many of these uncertainties and provide the scale needed for long-term cooperation.

In both countries, the infrastructure requirements for pipelines are quite large and the rules for permitting, injection, closure, liability etc are not yet developed. A regulatory framework will be required if CCS will become a viable technology. This need is being addressed by the by the World Resources Institute, which is currently looking at a range of policy measures to assist a diverse number of countries.

If these carbon capture options are to be developed, however, the United States and China must make a renewed effort to enhance international cooperation. Specifically, there is a need for increased post- combustion R&D, and for mitigating water cost for these plants. Creating a joint United States-China Research Development and program would be a critical step in solving these pressing issues.

In order for CCS technologies to be deployed on the necessary scale, its costs must be reduced. Demonstration and deployment will help industry reduce future costs by enabling it to standardize equipment and choose the least-cost alternatives for the coal type and geologic settings available. CCS demonstrations must be accelerated to confirm costs and reliability.

In summary:

- Significant progress on CCS will require government action;
- There is enough technical knowledge to begin CCS demonstrations;
- There is no "best" capture technology. France is pursuing Oxyfuel combustion, the United States is trying FutureGen and China is going forward with GreenGen. The answer may be a portfolio of technologies;
- Technology is available today for carbon capture from new and retrofitted coal-fired IGCC and PC power plants; however, it is very expensive, its parasitic load is very high, and reliability needs to be proven;
- Sequestration needs to be adequately demonstrated, especially in deep saline reservoirs with large-volume CO_2 injection;
- Current government and industry programs do not provide sufficient funding;
- Traditional mechanisms and new approaches are needed;
- High-level attention and engagement needs to be directed to the issues;
- Public funding commitments remain uncertain;
- International CCS community is organizing to engage with financial community to advance financing mechanisms;
- Without financing there will be no deployment.

2. U.S. Deployment Issues

There is a myriad of issues that industry and government must address in order to deploy CCS on a timely basis in the United States. While there is significant recognition of and work on CCS problems, some still argue over whether CCS will be ready fast enough to beat the carbon caps the U.S. government might impose on coal plants causing few new plants to be built. In addition, there are concerns over whether CCS can be deployed fast enough to meet desired global emissions targets. There is a broad range of issues regarding the adequacy of U.S. government policies, legal concerns, regulatory deficiencies, economics, the public's perceptions of low emission technologies, technology development needs, and human capital needs. All of these issues, and more, are summarized in Table 3.

Table 3: Issues with CCS Commercial Deployment in the United States

Human capital	Technology	Public perception	Economics	Legal	Regulatory
Siting/Permitting Financing Operations Science/Technology Construction/Engineering	*Validation /Demonstration Scale Systems Integration Grid Integration Infrastructure Stability/Reliability*	*NIMBY/NUMBY Risk Acceptance Who Pays?*	*Capital Costs Cost of Electricity Carbon Credits Investment Risk Sustainability Commodity CO2*	*Liability Pore Space/ Minterals Surface/ Subsurface*	*Transparency Siting Rights of Way Exisiting Frameworks (UIC) Emerging CCS Frameworks*

Source: Tomski, Pamela. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Financing Carbon Capture & Storage Systems." Beijing, China, 25-26 2009.

3. U.S. Cost Issues

There is no one favored least-cost CCS approach in the United States as conditions vary widely. Sequestration in oil fields currently provides the best return although saline aquifers are the most widely distributed. CCS costs will depend on many factors with capture as the largest cost and the pipelines the least cost. Costs for injection will depend on depth, material and fill rate and therefore, no one cost can be determined.

The charge for CO_2 is the cost of CO_2 from the pipeline (independent of any oil production.) CO_2 can be purchased on a long-term contract from a pipeline company for approximately \$1 to \$2 per mcf, which equates to approximately \$20 per ton.[58] Furthermore, regarding costs, when CO_2 is used for EOR, some is lost in the reservoir and some is eventually produced with the oil, which in turn is recovered and re-injected into the reservoir. The rule of thumb is that about 50% of the CO_2 is lost in this process. The total utilization rate varies depending on the reservoir, but on average, with an injection of one ton of CO_2, one half ton of CO_2 is lost.

The U.S. power generation industry would face high commercial risks implementing CCS technologies due to high capital costs, lack of clarity of the ability to recover costs in the rate base, technology uncertainties, liability issues and limited project execution experience for the utilities. As shown in Figure 12, economic studies prepared by DOE, EPRI and MIT all agree that pulverized coal systems are 60-80% more expensive with CCS, while IGCC plants with carbon capture are only 30% more expensive but cheaper that pulverized coal steam plants (referred to in the Figure as SCPC) with CCS. GE's studies are showing a 20-35 dollar/ton CO_2 cost of CCS using today's technology.

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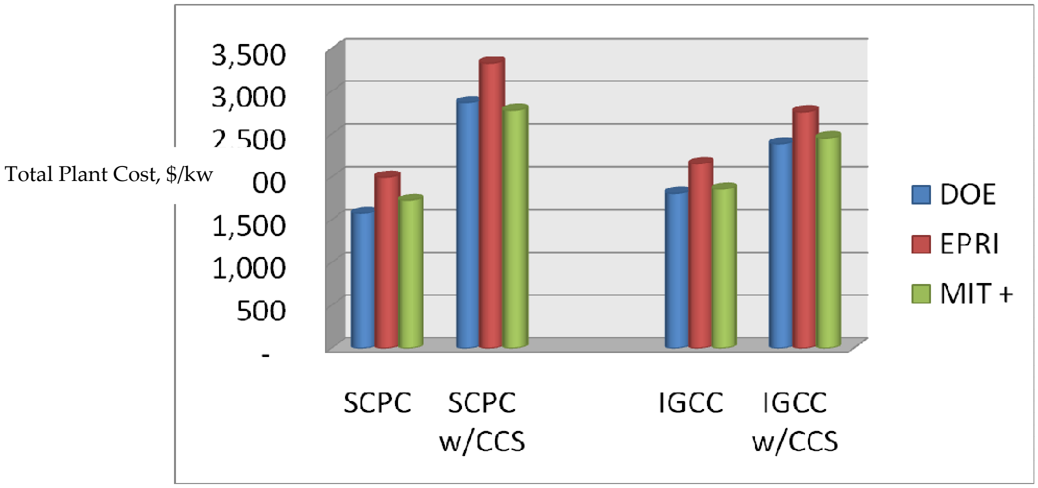
[58] There are 19 thousand cubic feet in a metric ton of CO_2 .

Figure 12: DOE, EPRI and MIT Comparison of CCS Systems' Costs



Source: Tomski, Pamela. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Financing Carbon Capture & Storage Systems." Beijing, China, 25-26 2009.

Another emerging cost/policy issue is the potential scale of infrastructure development needed for pipelines and storage. Currently there are 3,600 miles of CO_2 pipelines while it is estimated that 36,000 miles of pipeline may be required.[59] CCS will only be viable in the United States if there is a price for carbon, and if the federal government provides the policy framework, funding and financial incentives to move CCS into deployment.

4. Cost and Energy Penalty Concerns in China

China is concerned about the cost of a low-carbon scenario and affording technologies that would exceed the cost for technologies under the current energy production and consumption scenario. However, efficiency measures leading to lower energy demand might serve to reduce China's costs overall. Further, Dialogue participants raised the point that the cost of developing IGCC with CCS could potentially be much lower in China than in the United States and EU, perhaps by almost 50% of the total cost.

In several of the Chinese presentations it was shown that current CCS technologies (including post combustion, pre combustion, and Oxyfuel) would incur an energy penalty of 7 to 15 percent points of reduction in efficiency with an economic cost of $20

[59] The US currently has 302,000 miles of natural gas pipelines. Tomski, Pamela. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Financing Carbon Capture & Storage Systems." Beijing, China, 25-26 June 2009.

to 60/ t CO_2.[60] If China were to adopt CCS measures, it could require nearly an extra 1.0 billion of tce/y in China by 2050, impacting the energy security of China. Based on existing CCS technologies, China would pay a cost of $30 to $50/ton and need to capture a large amount of CO_2.[61] [62] China is exploring innovative CCS technologies to decrease investment costs and lower additional coal demand by the year 2050.[63]

Another cost-related issue raised was the distance between the CO_2 sources and the potential storage locations. China would like to develop low-cost, highly efficient transport of CO_2. For example, the potential oil storage fields for the Tianjin IGCC would be located up to 200 kilometers away and estimated pipeline construction costs would be 540 million Yuan ($79 million).[64]

F. Taking Cooperative Agreements to their Next Level

China has historically faced some obstacles when reaching out to the United States. Despite some successes dealing with academic institutions and the U.S. government, private partnerships are still in nascent phases due largely to IPR issues, licensing and domestic political concerns.

On a global basis, the primary focus of the myriad bilateral, multilateral and international agreements and MOUs is to share knowledge and develop best practices for the burgeoning clean coal industry. Few of these agreements have focused on technology transfers. The coal industry may have reached a point where this is no longer an optimal solution for advancing technologies to the next generation level. Without further attention to technology transfer and cooperation it will be increasingly difficult to make CCTs competitive.

The time is at hand for sharing in the development and demonstration of CCTs and CCS options. China may provide a perfect test bed for U.S. companies to develop new

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[60] Zhang, Xiliang. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Economics of Sustainable Energy System Transformation in China." Beijing, China 25-26 June 2009.

[61]Xie, Jin. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Status quo and Perspective of Low-C Power in China." Beijing, China, 25-26 June 2009.

[62] Carbon capture costs around 200 Yuan ($29.31) per ton using current technology; aand actually handling it, processing it so it can be used industrially, will cost another 150 Yuan ($21.98) per tonne (Jin, Xie. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Status Quo and Perspective of Low Carbon Power Plants." Beijing, China 25-26 June 2009.).

[63] Ibid.

[64] Chen, Wenying. "U.S.-China Cooperation on Low-Emissions Coal Technologies: Clean Coal Technology Development and R&D Activities on CCS." Beijing, China 25-26 June 2009.

generation coal plants. There is an evident sentiment coming from Chinese officials and experts for closer high-level cooperation between the Chinese and U.S. governments. The desire is for this cooperation to lead to greater technology transfer and overall cooperation on new coal technology. China appears to be willing to provide the opportunities, and in many cases technology, for U.S. private and public demonstration projects in China. There is currently a great economic and political opportunity regarding this subject. The GreenGen project could be an important first step in such a collaborative relationship.

G. Water Availability is an Emerging Energy Issue

Moving towards a cleaner energy future will require large amounts of water. Adding CCS to existing conventional or natural gas plants could require up to 90% more cooling per net amount of electricity, which would lead to a significant increase in water needs.[65] Water usage would be further impacted because CCS strategies reduce the efficiency of a coal-fired plant, which requires more coal to be burned. Water use must be addressed immediately, as it is a resource that is already taxed in areas of both China and the United States. Thus, the energy and water nexus will become an increasingly important consideration both in power plant siting and retrofitting current coal plants with CCS.

VI. CONCLUSION AND RECOMMENDATIONS

Coal is here to stay globally. China and the United States will continue to utilize their coal resources well into the middle of the 21st Century. However, for coal to remain a viable resource, countries need to use it while reducing air pollution and mitigating CO_2 emissions. As the two largest emitters of CO_2 from coal, China and the United States need to identify concrete steps for accelerating the development and deployment of appropriate technologies and policies.

Most serious assessments of the world's need to remediate GHG emissions issues while providing energy security and maintaining economic prosperity, recognize that these three goals will not be accomplished without major technological breakthroughs. The position of some advocacy groups to stop burning coal is simply not a viable economic alternative currently, and will not be for many decades. In addition, all countries' energy security depends upon maintaining a diverse source of energy, and indigenous supplies will usually be preferred over imports. Moreover, removing carbon from fossil

[65] *Ibid*

fuels also requires addressing CO_2 emissions from oil and natural gas as well as addressing agriculture as a source of emissions and as a potential carbon sink. As the two largest users of coal, China and the United States have an obligation to move beyond dialogues and to identify concrete steps for accelerating the development and deployment of appropriate technologies and policies.

The Dialogue discussions indicated that considerable technological progress is being made by both China and the United States and that there is growing interaction between private industries. The major stumbling block to greater cooperation appears to be the lack of an **Implementing Mechanism for Cooperation** (IMC) that involves the top levels of both governments. Most importantly, the IMC should provide both technical experts as well as private investors access to governmental-led dialogues. Integrating non-government participants should lead to broader understanding and greater support for funding joint projects—which is in turn needed to develop technologies more quickly and to drive down costs. Such a mechanism should have a **Secretariat** to manage cooperation. It was specifically suggested that a high level commission be established that makes use of existing cooperative mechanisms, as well as relying on established agreements, such as the U.S.-China S&T Cooperation Agreement, as it takes time to set up new agreements and structures.

The announcement of the Clean Energy Research Center and the Strategic and Economic Dialogue's pledge to develop cooperative mechanisms, both reinforce the major recommendation that was put forth by participants during the final session of the U.S.-China Cooperation on Low Emissions Coal Technologies meeting. This recommendation is not intended to minimize the value of the many MOUs, or the establishment of a Clean Energy Research Center as these instruments have been and will be instrumental in supporting training, educational programs and the sharing of information.

The purposed of the **Implementing Mechanism for Cooperation** would be to find solutions to the multiple roadblocks that are continually being identified in numerous workshops and bring them to the attention of the countries' leaders, both at the government and private sector levels, quickly and effectively.

This overarching IMC recommendation should be back-stopped by a series of detailed actions to be undertaken by both countries. In the near future, it is recommended that one of the first steps should be that China and the United States, together, undertake a follow-on dialogue to create a U.S.-China road map regarding CCS to address:

- Joint coordination of the R&D being done in both China and the United States with regard to lowering capture costs;
- Coordinate policy and capacity building efforts to facilitate deployment and intellectual property sharing; and,
- Develop an agenda to "cross-breed" the FutureGen and the GreenGen projects to maximize the resources the public and private sectors are dedicating to these CCS programs.

Concomitant with the strengthening of the approaches for cooperation, the United States and China will face the challenge and necessity of dealing with the many realities identified during the Dialogue. Specific key issues to be addressed should include the following:

- **Funding**
  - Accessing expanded World Bank funding of the Global Environmental Facility (GEF)
  - Coordinating efforts to ensure CCS projects are included in the CDMs and/or are eligible for certified emission reduction credits in global agreements;
  - Establishment of a significant global fund to support international research and development of technologies that could be jointly owned;
- **Lowering Costs**
  - Development of a long-term joint research program that specifically focuses on reducing the capital cost and energy consumption associated with CCS;
  - Develop standardized designs for CCTs that could significantly reduce capital and operating costs;
- **Intellectual Property Rights**
  - Create a platform for U.S. and Chinese industry to establish joint industry partnerships; for many companies, concerns over intellectual property rights are no longer inhibiting the desire to form partnerships;
  - Develop an energy sector, or sub-sector, approach to resolving concerns over intellectual property rights. Chinese industries and universities are rapidly developing new technologies that need to be protected;
- **Standards and Benchmarks**
  - Establishment of common benchmarks to support "best practices" in the operation of coal fired power plants;

- Build on the regulatory analysis undertaken by the WRI to establish regulatory "best practices" that could be applied globally; aim to establish procedures that would allow "fast track" permitting of new facilities;
- Common and/or compatible standards should be established for plant performance and the measurement and monitoring of emissions in order to facilitate the two way flow of technology and investments;

- **Partnerships**
  - Enable Chinese companies to participate in U.S. RCSPs, and U.S. industry to expand joint ventures in China, with the appreciation that China has the potential to develop IGCC plants at lower costs than U.S. industry;
  - Systematically expand the content and number of institutional partnership relationships between national laboratories and universities. These should be designed to provide for longer-term fellowships to enable participants to gain an understanding of each other's cultural structures and administrative systems as well as to gain from cross training in technical subjects;
  - Collaborate on helping China to develop appropriate monitoring and verification systems for GHG emission reductions as a result of China's myriad policies and programs. The Unites States can impart its experience with related monitoring equipment, technologies and best regulatory practices; help train professional staff in this area; and demonstrate transparent and effective communication, auditing and reporting systems;
- **Technology Developments**
  - Help China to improve its data collection and information sharing capabilities with regard to potential carbon storage areas. Utilize existing petroleum industry expertise in development of the database, as well as that of the NETL's Cyberinfrastructure program located at the University of West Virginia;
  - Design and establish programs to explain the necessity and benefits of CCS and other CCTs, including the interface to long-term energy security and other pollution objectives;
  - Develop a clear game plan for developing pre- and post-combustion technologies recognizing the two approaches require separate research and development paths. There needs to be more than the identification of a few jointly funded projects. Clear timelines need to be established and progress on a comprehensive program monitored. There will be earlier progress on pre-combustion while post-combustion is not likely to be available until after 2020. Jointly develop and demonstrate integrated

processes for removing SOX, NOX, mercury and particulate matter along with capturing CO_2;

- Determine if there are opportunities to jointly research and develop novel approaches to sequestering CO_2;
- Establish a procedure where by industry, national labs and universities can interact through a Secretariat of the IMC to present its senior officials with breakthrough concepts and technology developments.

The United States and China should continue to strive for a collaborative relationship as envisioned in the ICM. China already has obtained an understanding of the CCTs currently available. The goal should be to determine which technologies should be pursued give the particular circumstance of both countries. In some cases, China is refining and developing new technologies. China's administrative structure, market size, manufacturing cost structures and project development skills will enable it to be a source of cost effective technologies. At the same time, U.S. research and development skills continue to provide opportunities to export new technologies and to implement joint development and commercialization. Working together, the United States and China should be able to develop and commercialize cost effective new CCTs more rapidly than will occur if each country focuses solely on national efforts.

Overall, there are more similarities than differences between China and the United States, creating opportunities for collaboration. The fundamental solutions to a low carbon economy are being described in the same way in both countries: start with energy efficiency, use all coal, oil and gas resources, accelerate use of zero emissions energy sources such as nuclear and renewables, and ultimately use coal with CCS. The basic agreement on the path forward presents a true opportunity for collaborative efforts between the United States and China.

There is already strong cooperation between the United States and China on a variety of issues. No two nations will have a greater economic and environmental impact on the world. A United States-China partnership on coal technologies would provide a model for all developing nations to improve their economic wellbeing based on a secure and environmentally acceptable energy platform. Now is an opportunity for both countries to develop a substantive clean coal cooperation program to demonstrate to the world the enormous benefits of international cooperation.

Acronyms

AEP	American Electric Power
APEC	Asia Pacific Economic Cooperation
APP	Asia Pacific Partnership
CCPI	Clean Coal Power Initiatives
CCT	Clean Coal Technology
CCS	Carbon Capture and Storage/Sequestration
CDM	Clean Development Mechanism
CI	Cyberinfrastructure
CO_2	Carbon Dioxide
COACH	Cooperation Action within China
CSLF	Carbon Sequestration Leadership Forum
CURC	Coal Utilization Research Council
DCL	Direct Coal Liquefaction
DOE	Department of Energy
EETC	U.S./China Energy and Environmental Technology Center at Tsinghua and Tulane
EJ	Exajoules
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERI	Energy Research Institute
EU	European Union
G8	Group of Eight
GCE	gas coal equivalent
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GESTCO	Geological Storage of CO_2
GHG	Green House Gas
GT	Gigaton
GW	Gigawatt
IEA	International Energy Agency
IEP	Innovations for Existing Plants
IGCC	Integrated Gas Combined Cycle
IMC	Implementing Mechanism for Cooperation
IPP	Independent Power Producer
IPR	Intellectual Property Rights
Kgce/t	Kilowatt gas coal equivalent per ton
MARPOL	International Convention for the Prevention of Pollution from Ships

MOST	Ministry of Science and Technology
MOU	Memorandum of Understanding
MW	Megawatt
NDRC	National Development and Reform Commission
NETL	The US National Energy Technology Laboratory
NOX	Nitrogen Oxide
NZEC	Near Zero Emissions of Coal
OECD	Organization for Economic Co-operation and Development
PNNL	Pacific Northwest National Laboratory
PPM	Parts per million
R&D	Research and Development
RCSP	Regional Carbon Sequestration Partnerships
RES	Renewable Electricity Standard
RMB	China's National Currency, also known as the Yuan
S&ED	Strategic and Economic Dialogue
SCPC	Super Critical Pulverized Coal
SOX	Sulphur Oxide
tce/y	Ton of Coal Equivalent a Year
TWh	Thermal Watt Hours
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States

U.S.-China Cooperation on Low-Emissions Coal Technologies

June 24-26
Beijing, China

Co-Sponsored by
The Atlantic Council of the United States
and
The U.S./China Energy & Environment Technology Center
at Tsinghua and Tulane Universities

Co-Chairmen
Prof. WU Zongxin, Institute of Nuclear and New Energy Technology, Tsinghua University
Gen. Richard Lawson, Vice Chair, Board of Directors, Atlantic Council of the United States

June 25

Co-Chair: Prof. WU Zongxin, Institute of Nuclear and New Energy Technology, Tsinghua University

Opening Comments: Prof. HE Jiankun, Director of Low Carbon Energy Lab. Tsinghua University

Session I: Overview of Long -term supply/demand outlook.
Energy demand forecast and projected ability to reduce consumption through conservation and energy efficiency programs. (Intended to provide complete energy picture to establish Chinese and U.S. expectation on the long- term role of coal). Energy supply options to meet expected energy demand over 2009 to 2050 period. Limitations on supply availability of various energy sources and identification of critical supply developments. A discussion of implications of supply/demand outlook over a range of scenarios.

Chinese presentation: JIANG Kejun, ERI, NDRC

U.S. Presentation: Carey King, Research Associate, Jackson School of Geosciences

Session II: Coal consumption by various industries with breakdown by technology and expected evolution from 2009 to 2050. Identification of key technologies required to obtain efficiency improvements and carbon reduction by industry usage and plant type.

U.S. Presentation: Jason Crew, Product Line Leader, Asia, GE Energy

Chinese Presentation: CHEN Wenying, Tsinghua University

Co-Chair: Gen. Richard Lawson, Vice Chair, Board of Directors, Atlantic Council of the United States

Session III: Financing mechanisms to facilitate technology deployment, including advanced coal-based power systems.

U.S. presentation: Pamela Tomski, Managing Partner, EnTech Strategies

Chinese presentation: ZHANG Xiliang, Tsinghua University

Session IV: Road map to low-emissions coal power plants
Identify probable paths for evolving from today's base to 2025 and to 2050. Indicate replacement over time of existing plant fleet and expected introduction of new technology. Indicate potential obstacles to achieving road map in each country. (Discussion focused on where cooperation and possible joint development would be advantageous.)

Chinese Presentation: XIE Jin, Huaneng Group

U.S. Presentation: Pamela Tomski presenter for Ben Yamagata, Executive Director, Coal Utilization Research Council (CURC)

David Pumphrey, Deputy Director and Senior Fellow, Energy and National Security Program, Center for Strategic and International Studies

Co-Chair: Prof. WU Zongxin, Institute of Nuclear and New Energy Technology, Tsinghua University

Session V: Potential to improve industrial and power plant efficiencies to lower coal consumption.

Chinese Presentation: YU Chong, ERI, NDRC

U.S. Presentation: Xinxin Li, Department of Earth and Environmental Engineering, Columbia University

Session VI: Regulatory framework development to increase efficiency and lower CO_2 emissions A discussion on regulations and financial incentives, including CO_2 price that would encourage a more rapid increase in efficiency and a faster reduction in GHG emissions. Indicate what price for CO_2 capture and storage would be economically acceptable?

U.S. Presentation: Deborah Seligsohn, China Program Director, World Resources Institute

Chinese Presentation: BAI Quan, ERI, NDRC

June 26

Co-Chair: Prof. WU Zongxin, Institute of Nuclear and New Energy Technology, Tsinghua University

Session VII: Project Activity and developments in coal gasification, liquefaction and CCS. Review outlook and opportunities to undertake joint projects. Provide specific listing of existing and planned R&D, demonstration projects, and early commercial projects, including budgets.

Chinese Presentation: JIN Hongguang, Institute of Engineering Thermal Physics, Chinese Academy of Science

U.S. Presentation: Joe Giove III, Senior Program Manager, Office of Fossil Energy, U.S. Department of Energy

Session VIII: Update on assessment of potential for geological CO_2 storage and enhanced oil recovery. Review major findings and additional studies required. Identify opportunities for further cooperation.

U.S. **Presentation:** Timothy Carr, Marshall Miller Professor of Energy, Department of Geology and Geography, West Virginia University

Chinese Presentation: Dr. DOU Hongen, China Petroleum & Nature Gas Group

Co-Chair: Gen. Richard Lawson, Vice Chair, Board of Directors, Atlantic Council of the United States

Session IX: Review other third party bilateral and multilateral agreements, like the Asia Pacific Partnership, covering clean coal technology (CCT) and assessment of potential benefits of greater cooperation.

Chinese Presentation: TENG Fei, Tsinghua University

U.S. Presentation: Scott Smouse, International Group Leader, National Energy Technology Laboratory (NETL)

Session X: Roundtable discussion of Specific Recommendations for U.S. – China Cooperation on Accelerating Innovation in Clean Coal Technologies