The United States and China: Moving Forward on Coal and Climate Change

Kelly Sims Gallagher

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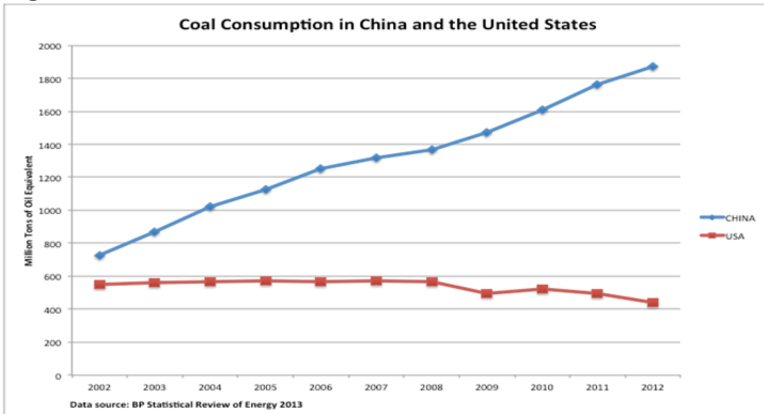
Introduction

In 2013, the concentration of carbon dioxide (CO_2) in the atmosphere crossed a symbolic threshold, reaching 400 parts per million (ppm) for the first time in three million years.[1] Before the industrial revolution, the level was approximately 280 ppm. The United States and China are currently the two largest emitters of CO_2 in the world because they are not only the world's two biggest energy consumers, but also the two largest consumers of coal (see Figure 1). China alone accounts for 50 percent of global coal consumption. As the most carbon-intensive of all fossil fuels, coal's combustion is one of the greatest contributors to climate change and causes considerable conventional air and water pollution. Both countries have recently experienced massive extreme weather events that are likely the consequences of climate change—Hurricane Sandy in the United States and record floods in Beijing in the summer of 2012.

Both countries, too, are endowed with considerable coal reserves. But this natural abundance may prove particularly detrimental to mitigating climate change if the countries cannot improve, demonstrate, and widely deploy technologies that reduce CO_2 emissions from coal during the next 5 to 15 years. As of 2012, US coal reserves are estimated to be 238 billion tons, while Chinese reserves totaled 115 billion tons, accounting for 28% and 13% of the global total, respectively. China's reserves-to-production ratio, however, is much shorter than that of the United States with only 31 years of economically recoverable coal at current rates of consumption compared with 257 years in the United States at current production rates.[2]

Coal is almost certain to continue playing significant roles in each country's energy mix in the medium term, in large part due to its relatively low cost and the energy security benefits related to not having to import substantial foreign supplies of primary energy. As such, without tackling the coal challenge, neither country has much chance of meeting their climate change and carbon reduction commitments.

Figure 1



Source: BP Statistical Review of Energy, 2013

Yet some bright spots have emerged recently in the US energy profile, in particular because of the unexpected shale gas phenomenon. As a result, the price of domestic natural gas has fallen dramatically, from $13/million British thermal units (mBtu) in June 2008 to $3.79/mBtu in June 2013.[3] Cheaper natural gas has made it a highly attractive fuel for new power plant developers in the United States. But if shale gas production in the United States abates for any reason, coal could quickly make a comeback as the power plant fuel of choice. For now, weaker domestic demand for coal has caused US producers to look for overseas buyers, and China is an interested customer. Chinese coal imports have already soared since 2009, the year in which China became a net importer of the commodity.[4]

In terms of power generation, as older coal-fired power plants are retired in the United States, they are largely being replaced with natural gas plants and renewables. In addition, President Barack Obama recently announced that he was considering implementing a new Environmental Protection Agency rule that would regulate greenhouse gas emissions from power plants. If this rule is implemented, new coal plants—and eventually older plants too—are almost certainly going to require carbon capture and sequestration (CCS) technology to meet new regulations.

A crucial difference between the two countries has thus emerged due to the shale gas revolution: the United States is beginning to turn over its aging fleet of power plants and replace them with gas-fired plants or renewables (though it still retains a sizable fleet of coal-fired power plants). China, on the other hand, with its ever-growing demand is continually adding to a very large existing stock of coal-fired power plants. The more coal-fired power plants China builds, the more it is “locked-in” to a coal-dependent future that is incompatible with preventing catastrophic effects of climate change.

It is also important to highlight where the two countries have made significant strides in reducing their coal footprint. For China, in particular, even as it is adding coal-fired generation in absolute terms, its rate of growth is currently much slower than it was during the 2000s. Most of the new Chinese power plants being built are highly efficient, with many being ultra-supercritical plants, the most efficient form of coal-fired power generation. At the same time, China is working hard to diversify its fuel mix, investing heavily in nuclear, renewables, and natural gas power generation. If China achieves its targets in the 12th Five-Year Plan, it will have more gas-fired power generation capacity than nuclear power by 2015.

Unfortunately, the measures to date remain insufficient. For example, both countries have invested substantial sums in advanced coal technologies that can drastically reduce conventional pollution, but neither has invested nearly enough in CCS research and development (R&D) nor managed to greatly reduce the cost of its deployment. Neither has done adequate demonstration of CCS nor deployed these technologies at a scale that would meaningfully serve as a solution to mitigate the effects of climate change.

By failing to demonstrate and commercialize climate-compatible advanced coal with CCS technologies, the United States and China are potentially creating a sticky dilemma for themselves. If they do not have technical and economic confidence in their ability to capture and store CO_2 from large coal facilities, they will be reluctant to impose serious climate change policies. But, if they fail to establish market-formation policies, the deployment of advanced coal and CCS technologies will be minimal, undermining their efforts to seriously address global climate change given how substantially both countries rely on coal today and going forward.

Bilateral collaboration in this realm, which began as early as 1985,[5] has historically been productive and useful to both countries. This paper contains recommendations for bolstering and expanding bilateral cooperation on advanced coal and related carbon capture, utilization, and storage. If pursued earnestly, the actions recommended would significantly address the mutual challenges both countries face in seriously confronting climate change and urban air pollution.

How to reduce the climate impact of coal use

Two main technology options exist for reducing CO_2 emissions resulting from burning coal: 1. Increase the efficiency of coal use, and 2. Capture and utilize or sequester the CO_2 emitted from major coal-consuming industries. The focus below is on the second technological option.

Capturing carbon: technologies and cost

Although CCS is not a technology that must be restricted to coal alone—it could also apply to natural gas power plants—it is the only existing technology that is capable of dramatically reducing the emissions from coal-consuming factories and power plants. The process usually involves separating CO_2 from industrial and power sources, transporting the CO_2 to a storage location, and injecting it into the storage site such as a depleted oil reservoir to prevent escape into the atmosphere.[6] Carbon dioxide can be captured from power plants and chemical production facilities and then injected into depleted oil and gas reservoirs, deep saline aquifers, un-mineable coal seams, deep-sea sediments, and other viable storage sites. In fact, CO_2 is already routinely injected into oil fields for enhanced oil recovery (EOR) and, less frequently, for enhanced natural gas recovery—an example of "utilization".

Different methods exist to capture the gas:

- *Pre-combustion* usually refers to capturing CO_2 from coal gasification processes, such as poly-generation, coal-to-liquids, or integrated gasification combined cycle (IGCC).
- *Post-combustion* is associated with capturing carbon from the waste gases from conventional combustion, such as super-critical or ultra-super critical (USC) power plants.
- *Oxy-fuel combustion* uses oxygen rather than air as the primary oxidant, which produces a flue gas that is almost pure CO_2, rendering it ready for sequestration.

Although some of the different technologies associated with CCS are well established, the integrated process of capturing CO_2, compressing and transporting it, and storing it has not been done at a commercial scale in very many places around the world. Many capture technologies are still immature and expensive. There are, however, a few important existing integrated large-scale demonstrations of CCS, most notably the Weyburn project in Canada (EOR), In Salah in Algeria (gas field), and Sleipner in Norway (saline formation).[7]

These and other demonstration projects, such as one led by Huaneng in China (the biggest Chinese power company), are worthy of continued research, development and deployment (RD&D) support because they are necessary to determine the technology's cost and economic viability. Currently available data cannot fully grapple with the cost question, and these projects add data points and contribute to valuable practical research. The cost of CCS fluctuates considerably and is quite uncertain. While many have traditionally championed the pre-combustion capture process due to its lower cost, recent progress in post-combustion capture technologies is challenging this prevailing view, in part because of different Huaneng pilot-scale demonstration projects.

A 2009 study based on US project data indicated that the cost of first-of-a-kind plants based on coal gasification with carbon capture (not including compression and storage) could be well over $150/ton of CO_2, with a range of $120-$180/ton.[8] As more R&D is conducted and demonstrations built out, however, the costs could come down dramatically, eventually reaching $35-$70/ton with economies of scale. If the carbon is used for EOR, the costs would be further reduced because the CO_2 could be sold to or reused by oil companies.

It is also worth noting that the costs may be different in the Chinese context. A study[9] based on Chinese data on the cost of IGCC versus USC power plants (without CCS) indicated that the cost of constructing an IGCC plant in China is almost half the cost of constructing an equivalent plant in the United States.[10] Labor costs, in particular, make the construction of major facilities less expensive in China. The costs associated with transport and storage of CO_2 in China, however, could be higher than in the United States due to the lack of knowledge about the storage potential in different geological formations and the lack of CO_2 pipeline availability.

Current state of play in coal technologies

China

A few years ago, China was widely viewed as leapfrogging ahead of the United States and Europe when it broke ground on its GreenGen plant in Tianjin. The GreenGen facility was China's first IGCC plant and expected to be the largest of its kind in the world. It was modeled on the ill-fated FutureGen plant in the United States. The Chinese plant will demonstrate and showcase one of China's new coal gasification technologies, and in a later phase, it will hopefully begin to capture CO_2. GreenGen uses Huaneng's TPRI gasifier and relies on a General Electric gas turbine for the combined cycle component of the plant. The project took more time to build than expected, with some cost overruns, though reportedly much lower than the new Edwardsport plant in Indiana (see below). GreenGen reportedly began operation in April, though it has not formally announced that construction is complete.

Most of the new coal-fired power plants that China has built in the last few years have been high-efficiency coal plants, including quite a large number of USC coal plants. But many long-planned advanced coal demonstration projects in the country have stalled either because of prohibitive costs or lack of government project approval. Specifically, the National Energy Administration (NEA), under the National Development and Reform Commission (NDRC), has not approved any other IGCC demonstration plants in China since GreenGen, nor has it supported any large CCS demonstration projects.

Many plants have been awaiting approval for years, and even have the backing of the Ministry of Science and Technology (MOST), which has supported the R&D behind many of these planned demonstration projects. IGCC proposals that have languished in China include the Dongguan repowering and new IGCC plants in Guangdong Province, the Lianyungang IGCC plus CCS plant in Jiangsu Province, the Huadian Banshan plant in Hangzhou, and the Langfang IGCC plant plus CO_2 EOR. In addition, coal-to-liquids plants are prime targets for CCS demonstrations, most notably the Shenhua plant in Ordos, Inner Mongolia, because it is the largest point source of CO_2 in the world.

NDRC may have had a change of heart recently, however. It released a position paper in April 2013 that stated its firm commitment to advanced coal technologies, including CCS.[11] This may be interpreted as a sign of Beijing's revived intention to move forward on some of the projects. The notice specifically urges local governments to "strengthen support and guidance for Carbon Capture, Utilization, and Storage (CCUS) pilot and demonstration efforts, based on the climate change program in the national 12th Five-Year Plan, and the CCUS section of the 12th Five-Year Greenhouse Gas Emission Control Working Plan." The document calls for development of CCUS demonstration projects and sites as well as the exploration and establishment of a financial incentive mechanism.

Despite the Chinese Academy of Science (CAS) and MOST's longstanding commitment to advanced coal technologies, the Chinese government's emphasis in terms of funding is still mainly on enhancing energy efficiency, coal gasification, coal-to-liquids, and CO_2 capture and utilization. Carbon storage RD&D is still in its infancy in China, with researchers from one division of CAS paving the way. Put simply, carbon storage research and demonstration has been relatively neglected in the Chinese R&D agenda compared to other advanced coal technologies.

United States

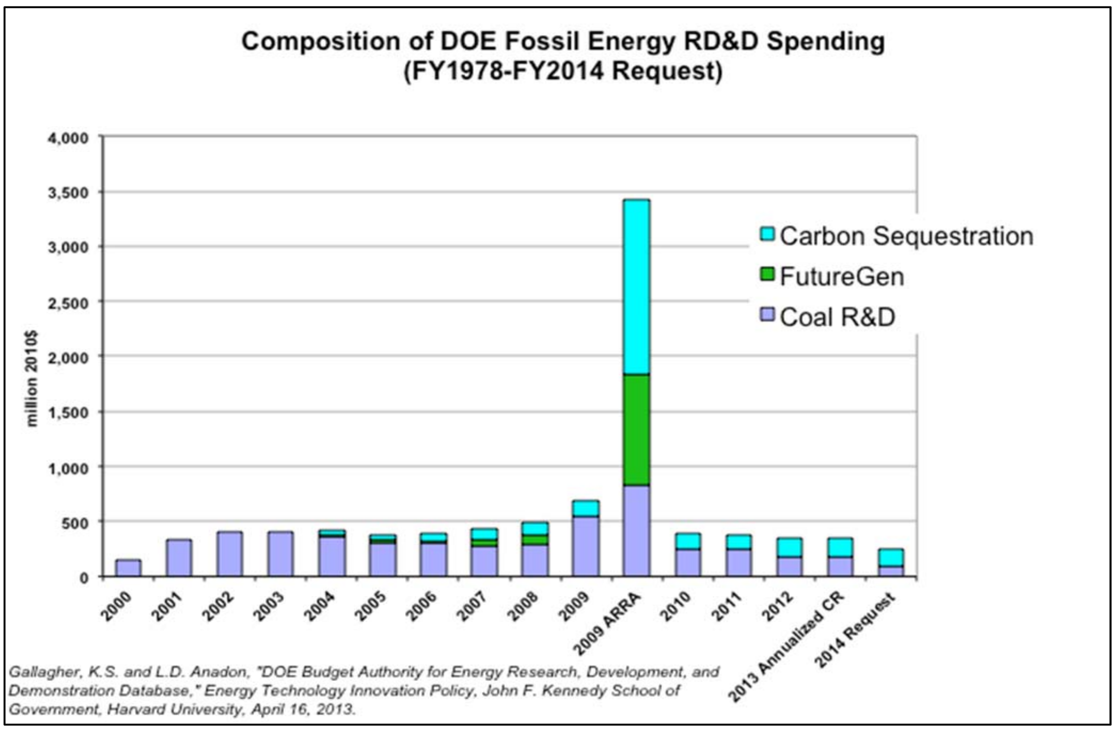
The situation in the United States is similar to China's in some respects, though arguably modestly less bleak. Significant subsidies for advanced coal deployment were included in the Energy Policy Act of 2005 and the American Reinvestment and Recovery Act (ARRA) of 2009, but only a few plants moved forward with advanced coal technologies and none with CCS at a commercial scale. In general, RD&D investment in CCS technology has been steady but relatively low during the first Obama administration (see Figure 2).

One such project was Duke Energy's Edwardsport IGCC plant, which commenced operations in June 2013 in Indiana. At a capacity of 618 MW, the Edwardsport plant replaced an old coal-fired plant, thereby greatly reducing conventional air pollution and also CO_2 emissions due to efficiency gains. The Edwardsport plant, however, has no plans to capture and store carbon dioxide at this time due to the lack of policy incentives to do so. Another company, Southern Co., is currently building a lignite-fired IGCC plant in Kemper County, Mississippi. Both projects, however, have experienced significant cost overruns. (The other two IGCC projects are Summit Power's Texas Clean Energy Project and SCS Energy's Hydrogen Energy California, both still in pre-construction stages).

Established in 2003, the Department of Energy's (DoE) seven regional carbon sequestration partnerships have largely defined CCS opportunities around the United States. Quite a few pilot scale CO_2 field tests, injections, and demonstration projects have already taken place, with many more planned.[12] DoE is also managing industrial partnerships for pilot-scale CCUS projects, receiving $3.4 billion from the economic stimulus for RD&D on advanced coal and CCUS.

Also in 2003, the DoE announced its intention to support a commercial-scale IGCC with CCS plant: FutureGen. The plant was planned, an industrial alliance created, foreign partners (including from China) secured, and the site selected. At the eleventh hour, however, the federal government decided to withhold its support for the original FutureGen plant due to concerns on the part of the Secretary of Energy at the time. When the stimulus act was passed, $1 billion was allocated for FutureGen “2.0”, to be located in a particular site called Meredosia in Illinois. Instead of building a new IGCC plant, the FutureGen Alliance will now repower Ameren’s 200 MW plant in Meredosia with advanced oxy-combustion technology. The project partners will build a 175-mile-long CO_2 pipeline connecting Meredosia with Mattoon, Illinois, where a CO_2 storage site with up to 1 million tons of storage per year will be placed. In February, DoE announced that FutureGen 2.0 was moving into Phase II to begin preliminary design, pre-construction, and engineering, though construction is not scheduled to be complete until 2017. If it is actually completed, FutureGen 2.0 will likely be the first commercial-scale CCS project in the United States.

Figure 2



Areas of cooperation

Both governments now have a rich and long history of collaboration in advanced coal technologies dating back to the signing of the Protocol on Science and Technology Cooperation in 1979. The Protocol on Fossil Energy R&D was signed in 1985, followed by a specific 1987 agreement on CO_2 research under this protocol. The protocol was revised in 2000 and it currently has six annexes.[13] In addition to the protocol, many other forums have been established for cooperation, including the Carbon Sequestration Leadership Initiative, energy policy dialogues, and most recently the US-China Clean Energy Research Center (CERC).

One of the latest and most important bilateral collaborative initiatives, the CERC was established in 2009 in an agreement between President Obama and then-Chinese President Hu Jintao. The CERC focuses on three major areas: building efficiency, clean vehicles, and advanced coal.[14] In the advanced coal area, there are 38 research activities, 240 researchers, and 26 partners, with equal contribution of funding from both sides.[15] An innovative intellectual property (IP) agreement was established for the CERC that provides strengthened IP protection for technologies developed under the CERC, including a technology management plan that was endorsed by both governments.[16] The CERC is making progress even though it is still a relatively young organization. Challenges so far revolve around contribution of additional funding on both sides (as opposed to re-allocating existing funds), ensuring true cooperative research rather than research in parallel, and clarity of leadership within the departments of the two governments.

In recent years, the level of engagement across the private sector has been equally if not more substantial. Firms in both countries are engaged in trade in goods and services, licenses, and foreign direct investment. GreenGen, for example, is using GE's gas turbines in its IGCC plant, and Southern Co.'s TRIG gasifier was imported for the Dongguan retrofit in Guangdong Province. Meanwhile the TPRI gasifier was licensed by FutureFuels and the Huadong gasifier was licensed by Valero. Duke Energy has now signed several memoranda of understanding with Huaneng for development and demonstration of advanced coal, CCS, and renewable technologies.

Assessment of current collaborative efforts

Bilateral cooperation on technical research in advanced coal technologies continues to deepen and become richer. The network of researchers is becoming more robust, and relationships among partners, government officials, and firms are ripening. Unexpected and substantial progress has been made on IP and technology management, and the prospects for continued collaboration appear very strong. It will be important to stay the course on both the CERC and the Fossil Fuel Protocol to ensure that the projects already agreed to in both arenas are both substantial and successful as learning endeavors. Trust and mutual understanding is being cultivated in these projects, which will contribute to other collaborations in the future.

However, the problem remains of too many meetings and not enough concrete projects where substantive collaborative research is conducted. Too often the mode of cooperation is for both sides to proceed in parallel rather than to engage directly in joint research. Where collaboration is more extensive, it often results from researcher exchanges, in which longer durations would be useful.

The technical research is currently excessively and unnecessarily stove-piped from both social science research and climate change policy discussions and developments. There is little point in isolating technical R&D from the rest of the innovation system, which is now well understood to have numerous feedbacks and interconnections. R&D cannot be separated from demonstration, market-formation, and diffusion. Some of the most substantial hurdles for CCS are not technical in nature, but rather are economic, social, or political. It is therefore important for collaborative research programs to incorporate analysis of policy, economics, risk, and public opinion in advanced coal and CCUS technologies. In addition, it would be helpful to bridge the considerable agency divides among DoE and the State Department in the United States, and MOST, NDRC, and the Ministry of Foreign Affairs in China. Progress on technology development and diffusion goes hand in hand with climate change policy and the international negotiations on this topic. Technological progress is unlikely to move rapidly without policy support and vice versa, but currently there is little productive discussion along these lines.

Conclusion and recommendations

The completion of leadership transitions in both countries affords an excellent opportunity to reassess cooperation on advanced coal technology. Both countries remain committed to the development and deployment of cleaner and more efficient coal technologies, but have been challenged by the higher costs of some of these technologies and the paucity of commercial-scale demonstrations of key technologies. Policy support mechanisms have been experimented with in both countries, but so far have not yielded a real market for wide deployment of CCUS technologies.

Without effective policies that create some limited demand for CCUS technologies, commercial scale demonstrations will never be built. And without those demonstrations, costs will never come down because there will be no opportunities for learning and improving efficiency. The pilot scale post-combustion demonstrations in China show the benefit of investing in demonstrations because the costs appear to be substantially less than everyone expected at the pilot scale. Now, the technology must be scaled up.

The main rationales for future cooperation are three-fold. First, both countries would benefit from sharing the costs of research, development, and demonstration. With budget sequestration in the United States and many competing demands for government funds in China, neither country, on its own, is inclined to back substantial projects at a time when they are most badly needed. Second, firms and researchers in both countries could leverage more learning opportunities if they can participate in a wider variety of pilot projects and programs in both countries. Third, through working together on joint ventures, research projects, and demonstration programs, individuals, academic experts, and firms can gain mutual understanding and build up trust. Without a good understanding of the constraints and challenges on each side, and without enduring trust, deeper bilateral cooperation in the realms of CCS investment and innovation is unlikely to expand.

A set of policy recommendations for moving forward on US-China cooperation on advanced coal and CCS technologies follows:

- **Support policy and economic research as well as technical R&D**. Economic analysis, policy support mechanisms, risk analysis, and public acceptance research are at least as important as technological breakthroughs in order to achieve the actual commercial deployment of CCUS technologies. But this sort of social science research about the deployment of advanced energy technologies is given short shrift in both countries.
- **Establish a robust program of researcher exchange**. These exchanges should last 6-12 months in order to build relationships and trust so that collaborative research can continue in a deeper and more meaningful way. Exchanges should not only be in science and technology, but also in economics, policy, and public acceptance research.
- **Study the development of low-interest government financing programs for firms pursuing joint ventures in the other country**. For US firms, the Chinese market will be very important in achieving a return on R&D investments, and vice versa for Chinese firms. Clean energy firms have identified access to capital as a challenge, especially in the United States.[17]
- **Consider more explicitly reducing conventional air pollution as a driver and co-benefit, in addition to CO_2 reduction, of advanced coal technologies**. Perhaps factor the reduction of conventional air pollution into RD&D objectives given the substantial challenges associated with conventional air pollution in China today.
- **Consider once again the establishment of large-scale joint demonstrations to share costs and risks, particularly for carbon utilization and storage technologies**. Though not new, this recommendation continues to make sense mainly because both countries are balking at the high costs of CCS demonstration in the absence of any carbon policy that creates financial incentives for reducing CO_2 emissions from coal. Both countries now have new IGCC plants—the obvious next step is larger-scale carbon storage.
- **Support smaller scale pilot CCUS demonstrations to gain more experience.** More feasibility studies for commercial demonstrations need to be conducted with particular technologies under different conditions. This recommendation builds on the above, complementing larger scale demonstrations.
- **Consider locating projects in low-carbon development zones or states with carbon policies in both countries.** Given that there is apparently greater political support in some regions than others, it makes sense to develop projects where political support is less likely to wane over time.
- **Focus in a more dedicated way on carbon utilization and storage for research, development, and demonstration**. Work needs to shift focus from advanced coal combustion and carbon capture, where much research has already been conducted.

Glossary

CCS = Carbon capture and sequestration

CCUS = Carbon capture, utilization, and storage

EOR = Enhanced oil recovery

RD&D = Research, development, and deployment/demonstration

IGCC = Integrated gasification combined cycle

USC = Ultra-super critical

NDRC = National Development and Reform Commission

NEA = National Energy Administration

MOST = Ministry of Science and Technology

CAS = Chinese Academy of Sciences

ARRA = American Recovery and Reinvestment Act

CERC = US-China Clean Energy Research Center

[1] Shukman, David, "Carbon Dioxide Passes Symbolic Mark", BBC, May 10, 2013, http://www.bbc.co.uk/news/science-environment-22486153

[2] BP Statistical Review 2013, available for download at: http://www.bp.com/en/global/corporate/about-bp/statistical-review-of-world-energy-2013.html

[3] Henry Hub Gulf Coast natural gas price: http://www.eia.gov/dnav/ng/hist/rngwhhdd.htm

[4] Ibid.

[5] The Protocol on Fossil Energy (1985)

[6] IPCC, Interdisciplinary Panel on Climate Change, Third Assessment Report, *Cambridge University Press,* 2005, page 3

[7] Ibid, page 33.

[8] Al-Juaied, Mohammed and Adam Whitmore 2009, "Realistic Costs of Carbon Capture," Discussion Paper, BCSIA, Harvard Kennedy School, available at: http://belfercenter.ksg.harvard.edu/publication/19185/realistic_costs_of_carbon_capture.html.

[9] In this study we determined that the capital costs of IGCC in China were between 7500-9000 yuan/kW ($1010/kW-1300/kW at current exchange rates).

[9] This compares with estimates in the United States of nearly $4,000/kW for the Duke Edwardsport (assuming no capture).

[10] Zhao, Lifeng, Xiao, Yunhan, Gallagher, Kelly Sims, Wang, Bo and Xu Xiang 2008, "Economic Assessment of Deploying Advanced Coal Power Technologies in the Chinese Context," *Energy Policy*, Vol. 36, No. 7: 2709-2718.

[11] NDRC Climate [2013] Document No. 849, English translation available at: http://www.globalccsinstitute.com/publications/notice-national-development-and-reform-commission-ndrc-promoting-carbon-capture.

[12] A full list is available on DOE's website: http://energy.gov/fe/science-innovation/carbon-capture-and-storage-research/regional-partnerships

[13] For a list, please see: http://energy.gov/fe/services/international-cooperation/bilateral-agreements-china

[14] As of 2013, CERC had 84 projects, of which more than two-thirds are joint initiatives. More than 1,000 researchers and 119 partners are engaged in CERC projects.

[15] Speech delivered by Dr. Robert C. Marlay, U.S. Director of the US-China Clean Energy Research Center in Washington, DC, March 29, 2013.

[16] According to DoE, "The framework enables research partners to share information with confidence and to retain appropriate rights for new technologies they create. Research partners can share the benefits of breakthroughs according to IP agreements established before work begins and extend those benefits by entering traditional commercial contracts to set the terms and to allocate their rights to—and royalties from—their creations" (see http://www.us-china-cerc.org/Intellectual_Property.html for more information).

[17] Gallagher, Kelly S. 2014, *The Globalization of Clean Energy Technology: Lessons from China*, The MIT Press: Cambridge, MA (forthcoming).