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# A Roadmap for U.S.-China Collaboration on Carbon Capture and Sequestration

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*The views expressed in this report are those of the primary authors only and do not necessarily represent those of the above advisors and reviewers.*

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# Contents

<b>I. Executive Summary</b> . . . . .	6
<b>II. The case for U.S.-China collaboration on climate solutions</b> . . . . .	11
<b>III. A focus on carbon capture and sequestration.</b> . . . . .	15
What can carbon capture and sequestration do? . . . . .	16
How does carbon capture and sequestration work? . . . . .	17
What needs to be done to improve carbon capture and sequestration technology? . . . . .	19
<b>IV. A roadmap for U.S.-China collaboration</b> . . . . .	20
Sequestration of available pure streams of CO <sub>2</sub> . . . . .	21
Retrofit research, development, and deployment . . . . .	22
Catalyze markets for CCS deployment . . . . .	25
<b>V. Clearing political hurdles in the United States and China</b> . . . . .	30
Obstacles in the United States . . . . .	30
Overcoming obstacles in the United States . . . . .	31
Obstacles in China. . . . .	36
Overcoming obstacles in China. . . . .	37
<b>VI. Conclusion</b> . . . . .	40
<b>Acknowledgments</b> . . . . .	41
<b>Appendices:</b>	
List of Acronyms . . . . .	42
Appendix A: Profiles of Selected CCS Projects in the U.S. . . . .	43
Appendix B: Profiles of Selected CCS Projects in China . . . . .	47
<b>Endnotes</b> . . . . .	49

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## I. Executive Summary

**Global greenhouse gas emissions** are fast approaching unsustainable and alarming levels. There is broad consensus that these emissions, caused primarily from the burning of fossil fuels, have led to global warming. It is increasingly evident that maintaining the current trajectory of greenhouse gas emissions poses wide-ranging and potentially catastrophic risks to natural systems and human welfare. It is also clear that an unprecedented level of global cooperation will be necessary to successfully confront the immense challenge of reversing the effects of climate change.

The United States and China are the world's largest greenhouse gas emitters. Collaboration between the two nations, therefore, offers the greatest opportunity for achieving meaningful reductions in global greenhouse gas emissions. The time is ripe for such collaboration. The two countries have participated in various global commitments on technology cooperation, including the 2007 Bali Action Plan and the Major Economies Forum declarations on Energy and Climate after the G-8 summit in Italy this July. The United States and China also made joint commitments at the July 2009 U.S.-China Strategic and Economic Dialogue in the form of a "Memorandum of Understanding to Enhance Cooperation on Climate Change, Energy and the Environment," and during U.S. Energy Secretary Steven Chu's recent trip to China.

The United States can translate this political goodwill into concrete action, but it will need to begin laying out a roadmap for progress on areas of mutual concern. U.S. leadership in this critical area would strengthen bilateral relations between the United States and China, while building momentum towards a successful outcome at the United Nations multilateral climate change negotiations in Copenhagen this December.

One critical pathway for collaboration specifically identified in the United States and China's recent joint commitments is carbon capture and sequestration technology, or CCS, which has the potential to mitigate emissions from coal-fired power plants. The United States and China's continued reliance on coal-fired power to generate electricity is a reality that must be addressed in any comprehensive climate change policy.

CCS is a process that separates and captures carbon dioxide, or CO<sub>2</sub>, from industrial and power plant flue streams, then compresses the gas and stores it underground, most likely in geological formations. The process essentially captures the greenhouse gas emissions before they enter the atmosphere and stores them underground. The technology has advanced significantly over the past decade and components of CCS have already proven successful in projects around the world.

While CCS still faces considerable technological, financial, and regulatory hurdles, it offers a potential pathway for helping achieve the scientifically-required reductions in global greenhouse gas emissions that energy efficiency, conservation and renewable energies are unlikely to meet on their own. Nothing in our report should be interpreted as suggesting that any one carbon abatement option is more important than any other. It

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is clear, however, that neither country can achieve the emissions reductions it needs to make without addressing its heavy reliance on coal. CCS should therefore be included in a portfolio of climate change mitigation efforts, if it is demonstrated to offer effective and meaningful reductions in carbon emissions.

While the general purpose of this report is to help bring about a new partnership between the U.S. and China, the immediate aim is to help catalyze U.S. leadership to action by sketching out a concrete, collaborative new plan of action on carbon capture and sequestration that the United States government can adopt as it confronts the twin challenges of addressing climate change and strengthening Sino-U.S. relations.

### **A three-pronged approach to CCS collaboration**

A successful partnership on CCS should advance long-term research, development, and deployment of commercial-scale CCS, while at the same time laying the foundation for potential emissions reductions. The three-pronged recommendation below identifies near term opportunities where collaboration can begin immediately and produce early milestones, while simultaneously advancing the longer-term goals of retrofitting existing plants and developing new financing architecture for wider CCS deployment.

#### **1. Sequester the pure CO<sub>2</sub> streams on existing commercial plants**

China has installed more than 100 coal gasifiers that produce as a byproduct pure streams of CO<sub>2</sub> that are currently vented directly into the atmosphere. Emissions from these gasifier plants are more straightforward and less costly to capture than emissions from combustion plants and should therefore be the immediate focus of collaboration. The United States and China should work together during the first phase of CCS collaboration on developing rapid, large-scale demonstrations of geological sequestration for these pure streams of CO<sub>2</sub> that exist today in China. These existing streams are relatively easier to capture and should provide an early successful collaboration between the United States and China.

The United States and China should identify a set of projects at multiple sites in China, and the United States should make substantial contributions to those projects in practice, equipment, and science. Such collaboration could test and compare various sequestration technologies while building the regulatory and financial infrastructure and protocols needed for widespread deployment.

Building up these technologies in China would allow the projects to be completed at less cost than would be possible independently, and such experience could be brought back to the United States to accelerate domestic implementation. Each project would cost \$50-\$100 million total, with a potential U.S. contribution of \$20-\$40 million. The timeframe would likely be two to five years from planning to implementation, upon agreement.

#### **2. Invest in research and development on retrofitting older power plants**

The second prong should focus on spearheading research, development, and demonstration for post-combustion CCS technologies that can be used to retrofit older coal-fired plants

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over the medium and long term. While opportunities exist for collaboration on new coal-fired plants (and China has demonstrated interest in outfitting its new plants with pre-combustion capture capabilities, mostly through Integrated Gasification Combined Cycle technologies), collaborating on new plants alone will not be sufficient to meet global abatement targets because it does nothing to “clean” existing plants. Both countries must ultimately deal with their existing fleet of coal-fired conventional plants in order to meet global targets, either by shutting these down or retrofitting them for CCS.

This effort would identify plants in both countries for large-scale retrofit demonstrations that would help develop and test different new capture technologies to improve effectiveness and lower costs. It would also outline a long-term strategy for retrofitting coal-fired power plants in both the United States and China that respects the political, industrial, and financial dispositions of each.

The research and development center (which might be set up within existing U.S. Department of Energy calls for a collaborative research center) should begin operation immediately. Retrofit demonstration projects would take longer to begin—likely five years from inception to breaking ground (three years for identifying a project and two additional years of preparation).

### **3. Catalyze markets for CCS**

In the absence of a market mechanism for carbon reduction in China, the United States and China will have to provide financial incentives for private capital to invest in carbon capture and sequestration projects. Motivating such private capital will require catalytic public funding as long as there is no private market for carbon abatement or an international structure that can be used to monetize such investments with sufficient offsets.

The United States should consider developing government-backed public finance structures, such as risk insurance or guarantees of CO<sub>2</sub> prices for a set amount of successfully abated carbon similar to those proposed by the American Clean Energy and Security Act of 2009, H.R. 2454. Such support could serve as an initial bridge to market mechanisms.

The United States can in parallel move for the inclusion of CCS-abated carbon in future regimes such as the Clean Development Mechanism (the Kyoto Protocol’s carbon offset system that allows developed countries to offset their emissions by paying for clean-energy projects in developing countries.) This would help establish a medium-term path for private capital to seek returns on investments in first generation CCS projects. This can also help liquidate the initial U.S. government-backed public finance measures.

This initial groundwork can form the basis for a domestic or regional market for abated CO<sub>2</sub> to support longer-term capital investments and the commercialization of U.S. and developed world technologies. Nonetheless, one thing is self-evident: the United States and China will have to eventually build an international mechanism to reduce the costs of second and third generation technologies aimed at meeting global 2020 and 2050 CO<sub>2</sub> output targets.



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## The benefits of collaboration on CCS

This roadmap has been undertaken with the assumption that the United States and China both stand to gain more through collaboration than through independent pursuit of CCS. The practical benefits of a bilateral collaboration will include more rapid deployment, job creation, and lower costs.

### 1. Accelerate U.S. technology

American expertise in sequestration technology and research is well developed and ready to be immediately applied in China as part of a new program. Cooperation between the two countries would accelerate the market penetration of this technology. Conducting initial sequestration projects using the high-purity CO<sub>2</sub> streams more readily available in China will allow both sides to benefit from the faster execution and lower costs that China offers.

Proving technologies as quickly as possible is critical to accelerate development of cost assessments, technical findings, risk profiles, and regulatory frameworks. The working knowledge of CCS practices and protocols gained from initial demonstrations in China would also be available to the United States and would help to accelerate the deployment of CCS facilities in the United States by five to 10 years, with benefits to utility, energy, and technology companies.

### 2. Create U.S. jobs

By taking advantage of U.S. technology and heavy equipment purchases and testing, projects in both the United States and in China would help to improve the competitiveness of U.S. firms in a global market, while also supporting industry and creating jobs in the United States. Although China is developing much cutting-edge technology of its own in this field, a significant amount of the most advanced technology and research and development in the world would logically end up being exported to China to supply its new CCS market. Such collaborative projects would also spur U.S. domestic job growth again through acceleration of wide-scale deployment of CCS technology. Our estimates show that in a baseline scenario, the CCS sector would create 127,000 direct and indirect net-new jobs in the United States by 2022. A five-year acceleration increases that to 430,000 in 2022, and a 10-year acceleration gets us 943,000 in 2022.

### 3. Lower U.S. electricity prices

As CCS is increasingly viewed as a critical part of global carbon abatement efforts, the acceleration of the development of this technology could yield significant reductions in the ensuing electricity rates. Some of the costs of abatement will be borne by utility companies, and some of those costs could be passed on to ratepayers depending on the structure of the pricing mechanism on carbon. CCS collaboration would add value by reducing CCS costs and thus ensuring electricity rates remain lower than might otherwise be the case. McKinsey & Company estimates the global potential of scalable CCS by 2030 to be 3.65 gigatons per year of CO<sub>2</sub>-equivalent abatement, which we estimate will cost \$959 billion

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globally to achieve over the 20 year period. If we are able to accelerate CCS initiatives by five years through cooperation with China, we estimate that the same abatement could be achieved at a cost of \$934 billion, saving \$25 billion. If the collaboration accelerated CCS deployment by 10 years, we estimate the same abatement could be achieved for \$859 billion, saving \$100 billion. The U.S. share of the cost savings is approximately \$5 billion in the scenario with a five-year acceleration, and \$18 billion with a 10-year acceleration.

#### **4. Increase Chinese CCS expertise**

U.S.-China cooperation will provide China with access to new advanced CCS technology, so it too stands to gain the requisite expertise to become even more competitive in a burgeoning future green tech market.

#### **5. Facilitate additional collaboration in preferred Chinese areas**

Collaborating with the United States on CCS will give China more political capital to press for collaborative efforts in other preferred areas, such as technology transfer and investment in the fields of renewable energy and energy efficiency.

#### **6. Direct cost savings**

Several key components of CCS are cheaper in China than in the United States. These include steel, cement, labor, and the savings from more rapid project completion. Focused joint effort could therefore reduce the cost of individual retrofit projects and construction time by as much as 50 percent.

#### **7. Risk sharing**

By combining resources, the United States and China share the risks of CCS failure instead of each country bearing such risks separately.

#### **8. Financial sureness in the market**

Creating standards for safe, effective projects will give the financial community the confidence and tools for investments in ongoing emissions reduction projects in both countries.

#### **9. Rapid emissions reductions**

If this roadmap is implemented, the first phase could result in the indefinite storage of nearly 10 million tons of CO<sub>2</sub> (which would otherwise enter the atmosphere) each year beginning two to five years after project initiation. This reduction in emissions would be the equivalent of taking 2.5 million cars off the road or shutting down three 500 megawatt coal-fired power plants every year.

The global climate crisis demands bold leadership, new partnerships, and the transition to a low-carbon economy. Whatever the outcome of Copenhagen, the solution to global climate change will most likely be borne as much from myriad national and bilateral efforts as from any grand, multinational agreement. It is in recognition of this likelihood that we offer this roadmap.

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## II. The case for U.S.-China collaboration on climate solutions

*“If the two goliaths on the world stage can join hands and commit each other—at the highest levels—to a long-term, vigorous climate and energy partnership, it will truly change the world.”*

—Todd Stern, U.S. Envoy for Climate Change, in prepared remarks at the Center for American Progress on June 3, 2009

### The dangers of global climate change

Global greenhouse gas emissions are fast approaching unsustainable and alarming levels. Unless we alter our current trajectory, we may soon cross a dangerous threshold leaving us with ever fewer options for remedy.

Scientific consensus leaves little doubt as to the causes of global climate change or the gravity of its consequences. Broad and overwhelming evidence demonstrates that the increased concentrations of heat-trapping greenhouse gas in the atmosphere since the industrial age are attributable to human activity—particularly the combustion of fossil fuels—and have led to an increasingly rapid rise in global temperatures.

Indeed, the most recent Assessment Report by the Intergovernmental Panel on Climate Change affirms this correlation with its highest level of certainty yet. It finds a 35 percent increase in atmospheric concentration of CO<sub>2</sub> from preindustrial levels to 2005, which, at 379 parts per million, “by far” exceed the natural range over the last 650,000 years.<sup>1</sup> Global temperatures rose an average of 0.8 degrees Celsius over the last century, with the past three decades alone accounting for a 0.6 degrees Celsius increase.<sup>2</sup> Mid-range estimates by the IPCC predict a temperature increase between 1.8 and 4.0 degrees Celsius by the end of the century.<sup>3</sup>

Abrupt and potentially catastrophic disruptions to human and natural systems loom. Researchers are documenting increased droughts and floods, ocean acidification, loss in snow cover and sea ice, rise in sea level, and loss of biodiversity.<sup>4</sup> Climate change is increasingly discussed in national security terms, as food and water scarcity trigger migration, conflict, and political instability.<sup>5</sup>

Researchers are forecasting costly setbacks for the U.S. economy and national security, including rising property damage from storm surges and wildfires, loss in agricultural output from heat waves and droughts, disruptions to U.S. and Arctic infrastructure and pipelines, threats to clean air and water, and new and destabilizing immigration flows from resource-scarce regions.<sup>6</sup> Moreover, climate-induced humanitarian crises around the world have the potential to strain U.S. resources even further.<sup>7</sup>

The problems for China are expected to be no less severe. China’s spectacular economic growth over the past several decades has come with a price. According to the United Nations

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Development Program, China is home to 16 of the world's 20 most polluted cities, with one-third of the urban population breathing heavily polluted air.<sup>8</sup> Conservative estimates show that environmental degradation costs China 8 percent of GDP per year.<sup>9</sup> Confronting climate change in China is increasingly understood to be critical not only for environmental protection, but also for the maintenance of China's economic, political, and social stability.

Worldwide CO<sub>2</sub> emissions are projected to increase by 39 percent from 2006 to 2030 without a major change in global energy policies and practices that directly address coal.<sup>10</sup> Given this scenario, scientists argue that the world could reach a dangerous "tipping point" in two to three decades, if not sooner, whereby a relatively slight temperature increase triggers disproportionate and irreversible damages.<sup>11</sup>

### The need for U.S.-China cooperation

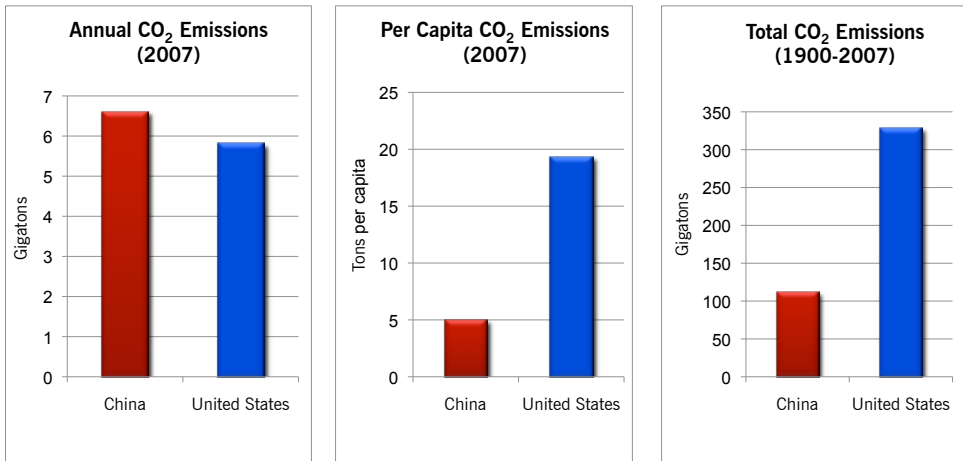
The world has long needed the United States to demonstrate bold leadership on anthropogenic climate change. This report seeks to illuminate one pathway to catalyze United States leadership through a bilateral framework. The simple reality is that for any remedy for global climate change to be meaningful, the United States and China—the world's two largest emitters of greenhouse gasses—must find a way to stand together, collaboratively, at the center of a global effort. As previous reports from both the Asia Society and Center for American Progress have articulated, elevating energy and climate in the U.S.-China agenda would not only demonstrate leadership in addressing the climate imperative, but has the potential to fundamentally reshape the dynamics between the two countries in a positive and comprehensive way.<sup>12</sup>

Yet these two countries still find themselves in a state of paralysis on this critical issue. Many U.S. stakeholders worry that the United States will be at a disadvantage if it signs any domestic legislation or international agreements committing to limits on greenhouse gas emissions unless developing countries such as China agree to similar measures. The Chinese government, on the other hand, firmly opposes placing an absolute limit on its own emissions, pointing to developed countries' responsibility to remedy the effects of their historic cumulative emissions that have led to global warming.

Meanwhile, the United States and China continue to rely heavily on coal to produce energy; it accounts for 50 percent and 80 percent of current electricity generation, respectively. If these two countries cannot find a way to come together to jointly address the problems caused by these emissions, it is highly unlikely that the world will be able to agree on a strategy for effective mitigation any time soon or that the UNFCCC negotiations in Copenhagen this December will arrive at any meaningful outcome.

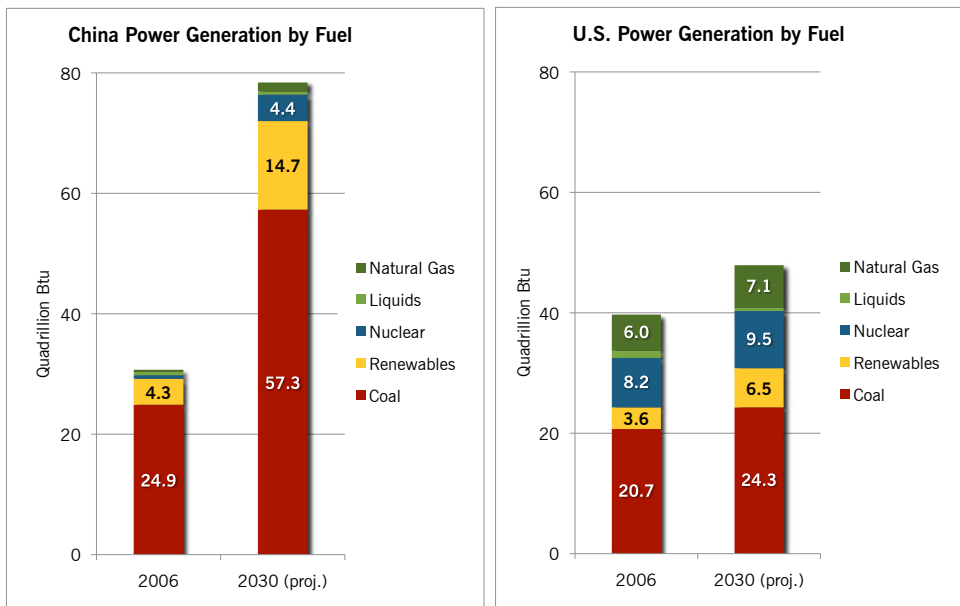
Thus, cooperation between the United States and China is a critical and requisite step to gain the kind of confidence and trust needed to spearhead progress toward an effective global solution. Fortunately, with a new U.S. presidential administration and an increasingly environmentally-conscious Chinese government, this moment is replete with possibility for these two countries to jointly alter the current state of reluctance that has prevailed until now.

## U.S. and China: Annual, Per Capita and Cumulative CO<sub>2</sub> Emissions



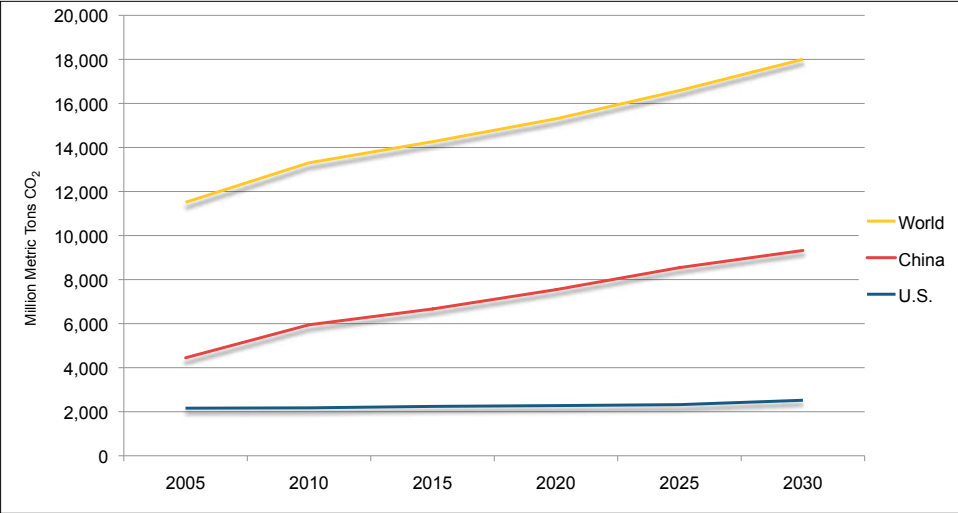
Sources: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center (CDIAC), 2007; the Netherlands Environmental Assessment Agency (MNP), 2007; Population Reference Bureau 2007 World Population Data Sheet

## Power Generation by Fuel



Source: "International Energy Outlook 2009", Energy Information Administration, May 2009

## Carbon Dioxide Emissions from Coal Use (2005-2030)



Note: 2005 data is actual; 2010-2030 data is projected  
Source: "International Energy Outlook 2009", Energy Information Administration, May 2009

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### III. A focus on carbon capture and sequestration

*“When people in America say, or people in Europe say, ‘Well, we can turn our back on coal. Why bother with carbon capture and storage?’ I would say we have to develop the technologies first, because otherwise we would turn our back on 25 percent of the coal reserves in the world, which are in our borders.”*

–Steven Chu, U.S. Energy Secretary, September 22, 2009<sup>13</sup>

Carbon capture and sequestration offers a way to neutralize the harmful emissions that come from the United States and China’s heavy reliance on coal. Both countries will continue to depend on burning large amounts of coal for the foreseeable future, and thus, if this technology can be proven at sufficient levels of scale and safety, the deployment of CCS technologies is an essential element in any effort to stabilize global greenhouse gas emissions.<sup>14</sup>

While CCS still faces considerable technological, financial, and regulatory hurdles, it offers a potential pathway for helping achieve the scientifically-required reductions in global greenhouse gas emissions that energy efficiency, conservation and renewable energies are unlikely to meet on their own. Nothing in our report should be interpreted as suggesting that any one carbon abatement option is more important than any other. There is a compelling argument, however, that neither country can achieve the emissions reductions it needs to make without addressing its heavy reliance on coal. CCS should therefore be included in a portfolio of climate change mitigation efforts if it is demonstrated to offer effective and meaningful reductions in carbon emissions.

The July 2009 U.S.-China Strategic and Economic Dialogue in Washington D.C. resulted not only in more friendly relations, but in a groundbreaking Memorandum of Understanding committing both parties to create, among other things, active channels for CCS cooperation.<sup>15</sup> The newly established U.S.-China Clean Energy Research Center has clean coal, including CCS, as one of three listed areas of research.<sup>16</sup> These bilateral pledges follow the G8’s ambitious goal of establishing 20 commercial CCS projects by 2020, with China playing an integral role.<sup>17</sup>

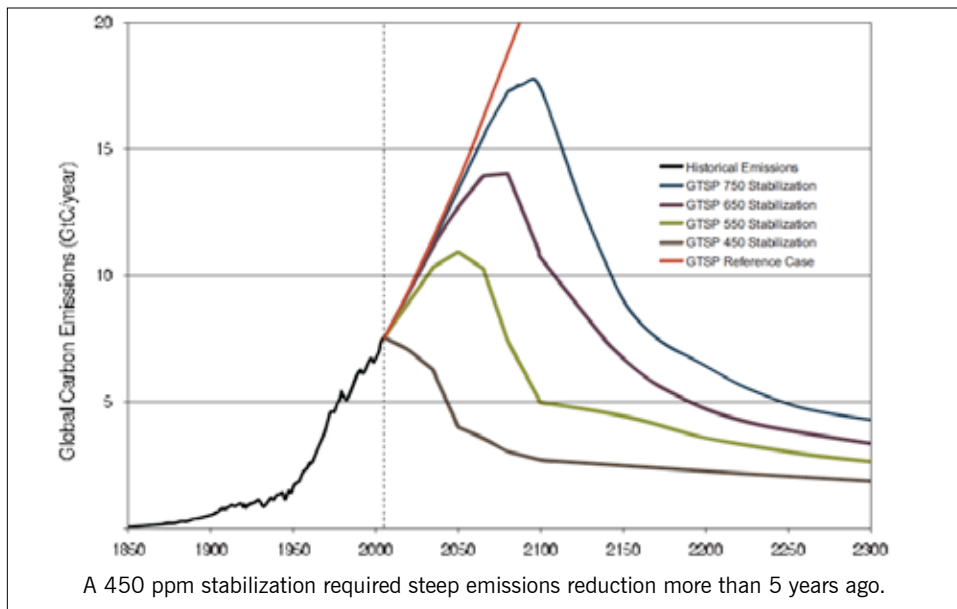
This roadmap for moving forward on CCS collaboration arrives at an opportune time to help translate some of this recently generated goodwill into concrete and active cooperation by suggesting practical ways of galvanizing the efforts of the two into an equitable and effective partnership. Cooperation on CCS, while only one of many areas of necessary cooperation on clean energy and low-carbon technologies, can bring about a win-win partnership.

## What can carbon capture and sequestration do?

CCS technology has been gaining ground as an important potential element in remedying climate change. Several institutions have recently carried out studies examining the technical viability and abatement potential of CCS, including the Intergovernmental Panel on Climate Change, the International Energy Agency, the U.S. Department of Energy, the Massachusetts Institute of Technology, Stanford University, and the Electric Power Research Institute. Their findings have led to a number of conclusions:

1. CCS appears technically sound and feasible, as demonstrated by analogous long-lived industrial processes, as well as a handful of successful projects already implemented in different parts of the world.
2. Deploying CCS will decrease the cost of achieving stabilization of atmospheric concentrations of carbon in a range of scenarios by 50 percent to 80 percent.
3. It is highly unlikely that stabilization below 550 parts per million (ppm) of CO<sub>2</sub>-equivalent in the atmosphere can be achieved without CCS.<sup>18</sup> Energy efficiency efforts, while low in cost, achieve roughly a quarter of the global need required for emissions reductions. CCS and renewable energy efforts, on the other hand, can address roughly three-quarters of the global need for emissions reductions.<sup>19</sup>

## Rapid action is required of both the U.S. and China in the coal sector for climate stabilization





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## How does carbon capture and sequestration work?

### Steps Involved in Carbon Capture and Sequestration

1. Separate and capture CO<sub>2</sub> from industrial and power plant flue streams after combustion or prior to combustion through new generation technologies.
2. Compress and transport the captured CO<sub>2</sub> to storage sites at high concentrations.
3. Inject the captured CO<sub>2</sub> into suitable deep geological formations, where it remains sequestered indefinitely.

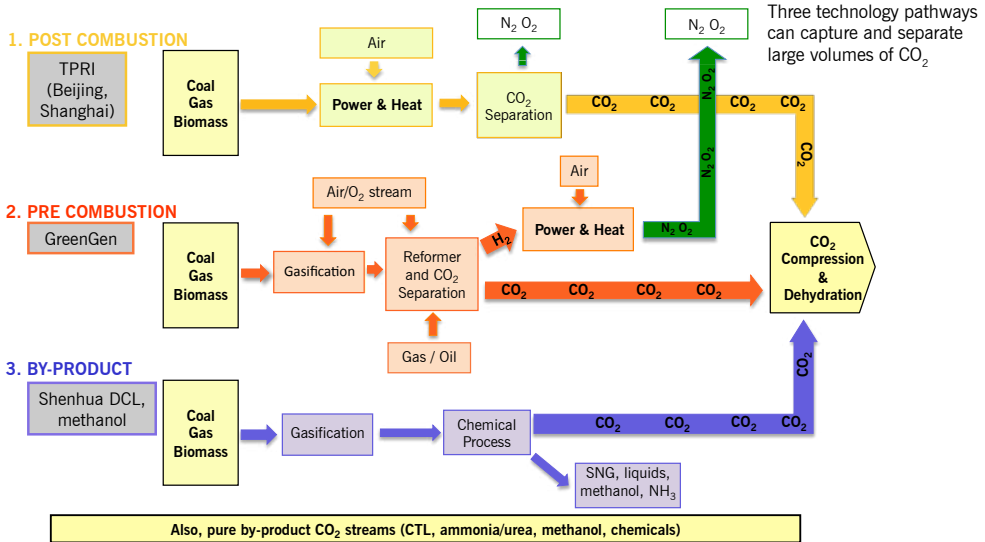
While CCS technology is applicable to a number of contexts—such as natural gas and biomass power generation, petroleum refining, biofuels production, cement making and chemical manufacturing—it is considered a critical technology for reducing CO<sub>2</sub> emissions in coal-fired power generation and can refer to either post-combustion or pre-combustion capture from such plants.<sup>20</sup>

**Pre-combustion capture** involves the removal of CO<sub>2</sub> prior to combustion to produce hydrogen. CO<sub>2</sub> can be captured from the synthesis gas that emerges from the coal gasification reactor before it is mixed with air in a combustion turbine. Pre-combustion CO<sub>2</sub> capture is applicable to coal power plants, with much of the focus on Integrated Coal Gasification Combined Cycle technology. Pre-combustion capture technology requires significant modifications of the power plant, and is therefore only viable for new power plants, not existing plants.

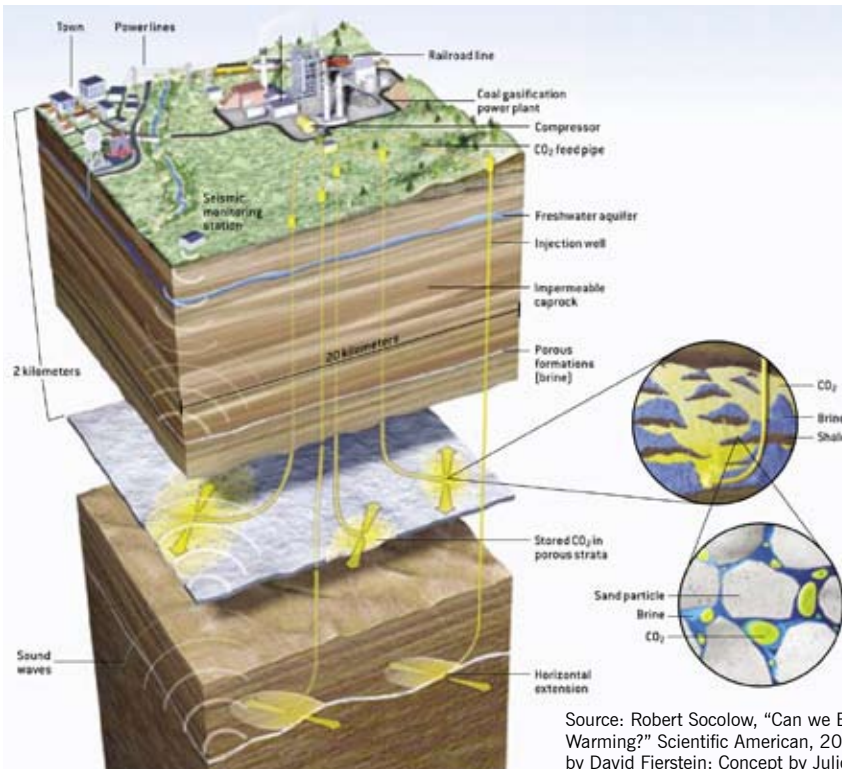
**Post-combustion capture** refers to the removal of the dilute CO<sub>2</sub> from flue gases after hydrocarbon combustion. Existing industrial plants and power stations can be retrofitted with post-combustion capture technology without significant modifications to the original plant. This roadmap focuses primarily on post-combustion capture applications.

The most promising reservoirs for carbon sequestration are porous and permeable rock bodies, generally at depths of roughly one kilometer, where the proper pressure and temperature conditions enable CO<sub>2</sub> to enter a “supercritical phase” in which its viscosity and density become similar to that of oil. A substantial number of these underground geological reservoirs appear to have the potential to store hundreds to thousands of gigatons of CO<sub>2</sub>. For example, saline formations that contain brine in their pore volumes (salinities greater than 10,000 ppm) are particularly suited for storage and are widely distributed geographically. The U.S. Department of Energy has estimated that saline formations in North America can hold between 1,300 and 3,000 gigatons of CO<sub>2</sub>,<sup>21</sup> with comparable volume estimates for mainland China, as well.<sup>22</sup>

## China's three pathways for CCS in research, demonstration, and deployment



## CCS Cross section



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## What needs to be done to improve carbon capture and sequestration technology?

CCS collaboration should focus on advancing three areas:

**1. Demonstration plants:** Accelerate the deployment of post-combustion CO<sub>2</sub> flue-gas capture and geological storage demonstrations for a coal-fired power plant at full commercial scale.

While each of the recommended CCS technologies and courses of action have been individually tested in real-world conditions, in the case of post-combustion flue-gas capture of CO<sub>2</sub> and its storage underground, there has yet to be a full commercial scale demonstration at a coal-fired power plant.<sup>23</sup>

Without greater certainty of the cost effectiveness and technical feasibility of large-scale capture and sequestration, few will risk investing sufficient private capital in CCS to sustain a meaningful level of deployment.

It is thus critical to lower these financial risks by conducting multiple real-world demonstration projects that entail capture of CO<sub>2</sub> at large power plants, the transportation of CO<sub>2</sub> via pipelines to storage sites, its injection into a range of geological formations, the long-term monitoring of those storage sites for safety, and the formulation of new funding models.

**2. Cost:** Generate an accurate estimate of the costs of CCS, engage in concerted efforts to reduce these costs and develop workable funding models.

It is important to generate an accurate estimate of the costs of CCS and potential scale, timelines, and pathways to cost reductions as soon as possible. Initial costs will be high, but to make abatement affordable and thus achievable, the cost of CCS needs to be brought down through actual experience in CCS demonstration projects.<sup>24</sup>

**3. Commercial deployment:** Accelerate research, development, and deployment of CCS technologies across new and existing coal-fired power plants.

In order to make a significant impact on global emissions, both the United States and China will need to scale up the deployment of CCS technologies across a large percentage of both new and existing power plants and start capturing and sequestering many millions of tons of CO<sub>2</sub>.

This raises questions about regulatory policy, legal frameworks, and operational practice that must be informed by the field by technical findings, providing businesses with the kinds of economic and regulatory certainty they require to make investment decisions in CCS technologies.

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## IV. A roadmap for U.S.-China collaboration

**A successful U.S.-China program of collaboration** must be built on mutual respect and recognition of both countries' expertise and incentives. But it must also lay the track for substantial emissions abatement and be able to evolve and grow over time. While the general purpose of this roadmap is to help bring about a new partnership between the United States and China, the immediate aim is to catalyze U.S. leadership by sketching out a concrete, collaborative new plan of action on CCS that the United States government could consider adopting as it confronts the twin challenges of remedying climate change and strengthening U.S.-China relations. This roadmap is also intended to complement, and not substitute, other ongoing bilateral and multilateral collaborations on CCS that China has with other countries.<sup>25</sup> By working in parallel, the hope is that the collective efforts will yield lessons that help accelerate CCS deployment globally.

The three-prong program below outlines a process that can start immediately to produce early milestones while working toward the longer-term goals of retrofitting existing plants and developing critical new financing structures.

### 1. Sequestration of available pure streams of CO<sub>2</sub>

- Rapidly implement demonstrations of geological carbon sequestration for existing low-cost, pure streams of CO<sub>2</sub> in China.

### 2. Retrofit research, development, and deployment

- Spearhead a major new collaborative research and development project on both the capture and the sequestration aspects of CO<sub>2</sub> produced by conventional coal-fired plants in both the United States and China.
- Identify potential large-scale pulverized coal combustion projects that are ready for retrofits in China and the United States.
- Outline a strategy to begin retrofitting plants in both countries, while at the same time continuing to find comprehensive ways to lower costs, improve effectiveness, and advance scale-up.

### 3. Catalyze markets for CCS

- Establish mechanisms to guarantee that companies that store carbon now will be paid a certain amount per ton at a point in the future, either by the private market for carbon or by the government in the event that market has not developed sufficiently.

The central elements of this roadmap help address many of the concerns and hurdles that have impeded the use of CCS as a meaningful technological answer to a crucial climate change challenge.

First, beginning relatively low-cost, concrete actions should allow both countries to start demonstrating new leadership in the near term.

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Second, accelerating the development of CCS practices, protocols, and standards should help provide businesses and governments the information they need to invest in and deploy CCS more confidently and swiftly in the future. Successful deployment can also help to keep energy costs low and accelerate the development of green-collar CCS jobs in key U.S. and Chinese regions and markets.

Third, the roadmap will lead to the creation of financial mechanisms to support large-scale projects at relatively low cost.

Finally, the roadmap will accelerate the reduction of cost and provide the performance experience needed to scale up the mass deployment of CCS rapidly enough to make a meaningful impact on emissions worldwide.

## 1. Sequestration of available pure streams of CO<sub>2</sub>

China is currently a global leader in coal gasification development and deployment, having already installed well over 100 large gasifiers of different designs for a variety of uses. These gasifiers are outside the power sector and are used to make chemical feedstocks or hydrogen for fertilizer, chemicals, and other related products. What makes these gasifiers relevant to this project is that they also create byproduct streams of CO<sub>2</sub> that are very pure. In essence, they produce “pre-captured” CO<sub>2</sub> that is relatively easier to capture and could provide an early success for collaboration between the United States and China.<sup>26</sup>

Cooperation between the United States and China could begin almost immediately at several sites where China has already completed feasibility studies and is planning some actual sequestration projects.

These “pre-captured” streams of CO<sub>2</sub> provide opportunities that are not available in the United States to store carbon at a relatively low cost of \$5-\$10 per ton of sequestered CO<sub>2</sub>, including the cost of compression, drilling, and monitoring. Over a five-year period, the total cost for each project would be approximately \$50-\$100 million.<sup>27</sup> The Chinese could cover the main costs of the energy penalty, compressors, drilling, geophysical survey, assessment, injection, and operation and maintenance—roughly 60 percent of each project.<sup>28</sup>

The United States could contribute \$20-\$40 million per project in China for science and technology, demonstration, and implementation of sequestration practices; advanced technical support; heavy equipment through support from U.S. technical and service companies; and input from universities and national labs. Five such projects, each sequestering 2 to 3 million tons of CO<sub>2</sub> per year, would not only provide a path-breaking test, but also reduce global emissions by roughly 10 to 15 million tons of CO<sub>2</sub> each year. The United States’ share of costs for the five projects would be between \$100 to \$200 million in total. The cost for each such sequestration project is far lower than the \$1 to \$3 billion price tag of a single post-combustion carbon capture retrofit project in China.<sup>29</sup>

Moreover, collaboration could begin almost immediately at several sites, most of which are located near key sequestration targets such as the Bohai, Songliao, and Ordos Basins and which are geologically similar to many U.S. basins.<sup>30</sup>

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For instance, Shenhua’s direct coal-to-liquids plant in Ordos, Inner Mongolia produces about 3.6 million tons of CO<sub>2</sub> per year and has been designated by the Chinese government to be the site for China’s first large scale CO<sub>2</sub> sequestration project.<sup>31</sup> If the Ordos sequestration project were to be undertaken in collaboration with U.S. experts and companies that have experience in this kind of operation, it could become a world-class project that showcases U.S.-China cooperation on CCS technology.

The synergies inherent in such a project would benefit both countries as well as the world at large. Collaboration would not only increase the probability of success and lower the cost of such projects, but would build shared knowledge of how to design, monitor, operate, and maintain these operations.<sup>32</sup> It would also demonstrate that large-scale sequestration is possible in China, sending an encouraging message to interested public and private entities elsewhere in the world. And such a collaborative platform would allow the United States and China to build practices, protocols, and new intellectual property rights agreements that could help catalyze the CCS industry in both countries and allow for the collection of scientific knowledge that would speed up the deployment of CCS worldwide.<sup>33</sup>

Since China already intends to carry out sequestration projects on its own, particularly in the field of enhanced oil recovery, it makes sense for China to collaborate with the United States to reduce costs and share risks. Collaboration would also accelerate opportunities to showcase commercial viability to the world by leveraging Chinese capabilities and leadership. And since these sequestration projects focus chiefly on practice, know-how and experience rather than specific technology and hardware, it is likely that the two countries could largely sidestep major intellectual property rights issues.

But most importantly, such collaborative sequestration projects would allow for a new kind of partnership that would not require overly burdensome new investment, and thus allow the United States and China to begin cooperating immediately.

## **2. Retrofit research, development, and deployment**

The predicted trajectory of global emissions makes it evident that the planet will never meet global abatement targets unless something is done about the way we burn coal. China has shown interest in outfitting its new coal plants with pre-combustion capture capabilities, mostly through Integrated Gasification Combined Cycle technologies. United States and China collaboration on this front could support a number of public and private partnerships to accelerate such IGCC demonstrations.<sup>34</sup>

Yet collaborating on new plants alone will not be sufficient to meet global abatement targets because it does nothing to “clean” existing plants. Both countries must ultimately deal with their existing fleet of conventional coal-fired plants in order to meet global targets, either by shutting down these plants or retrofitting them for CCS. Both countries have acknowledged this necessity and have begun strategic investments in research and development that would enable retrofits on existing plants.

Department of Energy Secretary Steven Chu’s recent announcement that the United States will engage in joint research with China offers a timely opportunity. As part of this

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venture, Washington and Beijing should jointly pursue an aggressive new series of intensive research and development projects centered on retrofitting coal-fired plants with low-cost, effective CCS technology. This R&D stage should begin immediately so that deployment of the technology can begin shortly after phase one is complete.

It is true that China has expressed reluctance to deploy CCS retrofits rapidly within its existing coal fleet.<sup>35</sup> Recent papers have pointed out that China's overriding interest in economic growth and energy security make CCS deployment not the first order of priority.<sup>36</sup>

This roadmap focuses on laying the groundwork for eventual broad-scale retrofitting by setting up the preconditions for future CCS deployment that is not inimical to China's present priorities. CCS has yet to be proven feasible and cost effective on a large scale. So, the goal is to enable research that attempts to reduce the cost of retrofitting and make CCS more efficient in order to create an environment over time in which both countries can determine, on the basis of the results of their collaborative R&D, whether broad-scale CCS deployment is a realistic course of action.

Incentives may change as key advances make the technology more or less appealing. It is also possible that the devastating costs of global warming will escalate to such a level that the cost of not mitigating emissions from burning coal will become so great for China to bear that options will need to be reassessed.

Determining project viability alone would require two to three years of front-end engineering design studies alone. Several years of planning and analysis would also then be needed to select potential retrofit projects likely to succeed in each country. It is also important to note that only about half of U.S. plants have sufficient heat rate and efficiency to warrant consideration.<sup>37</sup>

Given all of these factors, the first several years of discussion and experimentation on coal-fired plant retrofits should focus on three goals:

**1. Engage in a wide array of research and development initiatives on both the capture and sequestration sides of retrofitting coal-fired plants as soon as possible to lower costs, improve effectiveness, and scale up these technologies for global application.**

- Both countries should build upon the multidisciplinary research centers already announced by the U.S. Department of Energy and Chinese Ministry of Science and Technology. Such centers should gather and disseminate the lessons learned on technology, regulation, business models, financing, plant operations, and demonstration projects. This will enable the two countries to deploy CCS more rapidly when political and financial conditions permit.
- China and the United States should establish large-scale research and education campaigns that focus on the devastating long-term costs of climate change, the need for CCS to combat climate change, and the technical feasibility and safety of CO<sub>2</sub> sequestration.

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- On the capture side, key research is necessary in post-combustion capture (e.g., solvents, sorbents, membranes, ionic liquids) and oxy-fired retrofit technologies (e.g., solid-fuel combustion research, flame-shape design, flue-gas recirculation, O<sub>2</sub> separations) that focuses on reducing capital and operational costs in retrofitting existing plants.
  - On the sequestration side, research should focus on developing and demonstrating techniques for long-term monitoring of sequestered CO<sub>2</sub>, identifying potential hazards, protecting groundwater quality, and developing broad expertise in the relevant management practice.
  - Research should also include design, drilling, and technology transfer efforts as they pertain to CCS deployment.<sup>38</sup>

## **2. Identify plants in China and the United States that are strong candidates for large-scale retrofit demonstrations.**

- Screen the existing fleet of coal-fired plants to identify those in both countries that are strong candidates for retrofit demonstrations. Such plants would include subcritical pulverized coal plants (400 megawatts or larger, or about 2 million tons CO<sub>2</sub> per year) that have space, designs suitable for retrofitting, and sequestration resources nearby.
- Project selection would be followed by preliminary front-end engineering design studies to determine technical viability, possible failure modes, and likely cost. Such an effort would require access to plant engineering information and geotechnical information, and a transparent process to share results from studies.
- Plants selected for retrofit (and alternates) would be announced after two to three years of collaborative analysis. Researchers would have assessed potential retrofit technologies during this time and developed preliminary designs, leading to the development of formal plant retrofit designs and procurement estimations of heavy equipment needs.
- Groundbreaking and retrofit would begin at key sites within five years, with the goal of CO<sub>2</sub> injection commencing one to three years later.

## **3. Outline a broad, medium- to long-term strategy for retrofitting power-sector coal plants in China and the United States in a way that embraces the countries' respective political, industrial, and financial conditions and needs.**

- Devise a strategy for mutually establishing targets for growth, emission abatement, energy intensity, and price.
- Focus working groups on both technical and nontechnical aspects—political, regulatory, and legal—concerns in each country to develop mutually agreeable standards and best practices for power sector retrofits, geological sequestration, power plant management, and regulatory frameworks.

A careful structure will have to be crafted to protect the intellectual property rights associated with this type of cross-border sharing. Private companies should be allowed to negotiate their own intellectual property terms. They are in the best position to know how



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to protect their rights, assess the value of their intellectual property and understand the cost of not entering the collaborative market.

As an example, it might be possible for U.S. companies to set up a licensing fee for use of their technologies. The Jupiter Oxygen project in India solved the IPR problem by partnering with a local company and giving that company exclusive rights to a particular technology in exchange for a licensing fee.<sup>39</sup> Such a strategy effectively incents local companies to guard against rights infringements themselves, thus adding an additional layer of defense with eyes and ears on the ground.

It might also be possible to develop an insurance fund jointly backed by the United States and Chinese governments that insures U.S. companies who share their intellectual property in this critical area with China, much the way the Overseas Private Investment Corporation insures risky trade deals.

Both parties can likely generate a wide range of other creative solutions. But it may be that this challenge is not as inhibiting as some fear. After all, China may become a vast market for CCS. U.S. companies that want to be major players in this market will see the benefits of early collaboration with major Chinese players. Intellectual property risks will therefore be tempered by the marketplace's growing economic potential. Market allure will be sufficient in many cases to drive companies to formulate their own case-specific arrangements.

The United States and China will have to examine a broad range of issues relevant to their regulatory governance. It will be important as the collaboration becomes more concrete to discuss issues of liability, safety, measurement, and verification; project design and management; channels of communication; and eventual site closure. It will be important to negotiate these issues in detail down the road.

### **3. Catalyze markets for CCS deployment**

Lack of an economic return, and uncertainty around the timing and level of that return, are the key financing barriers that slow the advancement of CCS projects. Unlike many other technologies that help reduce greenhouse gas emissions such as nuclear, hydroelectric, wind, solar, biofuels, waste recycling, and energy efficiency, there is no established market—no body of paying customers—for companies that offer CCS equipment and services beyond some secondary sources such as oil production.

Our assumption is that such a market will eventually come into being through various cap-and-trade systems or a tax on carbon. So, the key financing challenge is building a bridge between today and a point in time when such a market for sequestered CO<sub>2</sub> exists. Without this bridge, private sector investment will flow into CCS projects slowly and tentatively at best. A bridge would enable the flow of private investments to grow stronger over time. Experience and innovation will lower the cost of sequestered CO<sub>2</sub>, resulting in an increased rate of supply at any given price. There are short- and medium-term solutions for building this bridge.

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**Short-term (Year 0 to 5): Use public funds to support U.S. companies to participate in sequestration projects in China while simultaneously providing a guaranteed return for private capital investments in CCS that could be redeemed at a future point.**

U.S. tax dollars would be allocated primarily to U.S. companies, constituting a form of economic stimulus—albeit one without great multiples since much of the work would take place in China. It would also be an investment in the competitiveness of U.S. companies pursuing a potentially lucrative global CCS market. Industry might “co-invest” in these projects because they would gain an advantage over competitors in the form of early experience in large-scale sequestration.

One strategy to simulate a market value for abated carbon ahead of its actual formation might entail provisions similar to those laid out in the American Clean Energy and Security Act. In this scenario, the U.S. would provide a guaranteed payment (perhaps \$60 per ton) for an initial fixed volume of CO<sub>2</sub> successfully sequestered, in China or elsewhere. Like in the Waxman-Markey legislation, the price per ton would vary depending on the fraction of carbon captured (i.e. higher support for 85% capture and lower support for lower capture rates). This guarantee could be structured as a time-triggered insurance payout, so that there would be no outlay of U.S. capital until 2020, for example, and then only if a market instrument were not yet available to monetize the successfully abated carbon. The U.S. government would essentially promise to pay in the future, if the market has not yet come into existence.

The number of tons of sequestered carbon could be limited to an amount large enough to encourage several demonstration projects over the next five years, but small enough so as not to “break-the-bank” in the unlikely event that there was no functioning market for sequestered carbon. We would suggest the funding be offered over a five year period for up to 1,500 MW of capacity.<sup>40</sup> Since this much capacity generates about 9 million tons per year, the maximum exposure (assuming a 100 percent capture and sequestration rate) would be about \$540 million per year (\$60 per ton multiplied by 9 million tons), in the event that no private market for abated carbon had developed by the specified time for payout.

In addition to mechanisms encouraging CCS in the power sector, we would also suggest an analogous mechanism for the industrial sector. There are numerous industrial operations in China that produce CO<sub>2</sub> as a by-product of their normal operations, and are now venting this carbon into the atmosphere. That CO<sub>2</sub> should be captured and stored underground in order to accelerate learning and develop capabilities in this area. Since the capture is already happening, the price to encourage storage can be much lower. We suggest funds for \$20 per ton of CO<sub>2</sub> stored up to the first 30 million tons. This represents a maximum exposure of \$600 million (\$20 per ton multiplied by 30 million tons) in the event there is no private market available.

Such a mechanism could also serve as a platform to eventually include a broader set of international stakeholders to participate in the stimulation and evolution of successful public-private partnerships around CCS deployment.

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**Medium-term (Year 6 to 10): Push for the inclusion of sequestered carbon in a new Clean Development Mechanism-type offset regime to create access to other capital pools**

The Clean Development Mechanism is the Kyoto Protocol's carbon offset system that allows developed countries to offset their emissions by paying for clean-energy projects in developing countries. CCS is not currently eligible for the CDM credits, but it should be leveraged to provide revenue to companies sequestering carbon. As of now, a wind farm built in a developing country might count as a carbon offset for a European emitter of greenhouse gases, but a CCS project does not.

CCS was excluded from CDM funding in part because of significant opposition to coal-based sources of energy.<sup>41</sup> Changing these requirements to include CCS will not be simple. But the United States and China should actively push for such inclusion in a new post-Kyoto CDM-like mechanism over the medium-term.

**Long-term (Year 11 and beyond): Global market for abated carbon**

The basic challenge to create a revenue source to pay for sequestered carbon is clear, as is the short-term solution: building a financing bridge between now and the day a functioning market for CO<sub>2</sub> comes into being. Once there is a value for carbon, the capital markets can then structure mechanisms to aggregate, apportion, and manage capital flows according to supply and demand.

The long-term solution to the financing challenge posed by CCS is, of course, a global market for abated carbon, whether that abatement happens in the United States, China, or elsewhere. This subject is being addressed elsewhere, so we confine our comments here to simply noting that a global market must eventually be realized; the financing bridge proposed herein must lead to something in the end.<sup>42</sup>

A group of experts would need to study and formulate the details of such a new financing infrastructure—answering how much to pay per ton of sequestered CO<sub>2</sub>; how many tons will be covered; when will the money be paid; and what requirements will be needed to monitor the sites to make sure the CO<sub>2</sub> stays underground. One such group, the World Economic Forum Business-Expert Task Force on Low-Carbon Prosperity, has offered several specific proposals for public-private investment models to catalyze investment from institutional investors that we summarize in Box A.

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## BOX A

### Accelerating Investment in Low-Carbon Technologies in Developing Countries

#### *Proposals from the World Economic Forum Business-Expert Task Force on Low-Carbon Prosperity*

For the full recommendations: [www.weforum.org/climate](http://www.weforum.org/climate)

Institutional investors, such as public and private pension funds, insurance companies, sovereign wealth funds, endowments and private banks offer the largest potential source of necessary long-term private investment in low-carbon technologies in developing countries.

Public-private investment models in which public credit enhancement and regulatory capacity building is combined with private institutional capital have the potential to unlock significant investment flows for low-carbon energy systems in developing countries.

#### **Proposals:**

##### **Multilateral Development Bank Low-carbon Challenge Funds:**

Public-private, low-carbon infrastructure investment funds in each developing country region which draw in equity from institutional end-investors such as pension and sovereign wealth funds and use a new generation of public finance (risk mitigation) mechanisms from multilateral and bilateral development finance institutions.

Multilateral and bilateral development finance institutions would bid out preferential access to regional packages of their public finance mechanisms to leading global (or regional) fund management firms, who would tender for the bids. Such a model could catalyze up to US\$ 10 billion per region per three-year cycle, ready for business by 2011.

##### **Regional Low-Carbon Cornerstone Funds:**

Regional cornerstone funds for low-carbon infrastructure would be created and administered by the IADB, AfDB, AsDB, EBRD and EIB or through establishment of specialized institutions modeled on the US Overseas Private Investment Corporation. They would raise anchor equity (e.g. US\$ 5 billion) from major institutional investors as well as official and philanthropic donors and then invite leading global and regional fund management firms to establish low-carbon energy funds, clean infrastructure funds, low-carbon building funds, green-tech funds, etc. by bidding for a distribution of part (e.g. US\$ 1 billion) of the anchor equity. This model could catalyze US\$ 50 to 75 billion per region each three years and could be ready for business before the start of the second commitment period in early 2013.

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**A note on enhanced oil recovery**

CO<sub>2</sub> can, and has long been, used for enhancing oil extraction from fields by displacing oil through the injection of pressurized CO<sub>2</sub> gas. CO<sub>2</sub> has other limited industrial uses that carry a positive secondary economic benefit. But demand from all of these potential CO<sub>2</sub> sinks is nowhere near enough to sequester the carbon dioxide emissions that must be mitigated to slow down the rate of climate change.

Some analysts in China believe that enhanced oil recovery, or EOR, has the potential to create and improve initial commercial opportunities for CCS in China. However, the market potential for EOR will likely be limited. China's seven largest oil fields can likely store only between 10-20 million tons CO<sub>2</sub> per year. This volume could be met in the near term with pure CO<sub>2</sub> streams from coal-to-chemical plants in a handful of locations. Such sources could be captured, transported, and used for EOR for \$5-10 per ton—mainly the cost of compression and pipelines—and might be suitable for near-term purchase agreements between PetroChina and CO<sub>2</sub> suppliers. But EOR cannot be counted on for large annual emissions reductions and will not incent more than a limited number of projects.

Yet the Chinese are very interested in EOR, in large part because of the incremental oil production that results. Thus, it might therefore be of tactical importance in initiating U.S.-Chinese collaboration to embrace some such projects.

The GreenGen project in Tianjin provides an example of that kind of platform, wherein real technical and economic findings and gains are likely within an enhanced oil recovery platform. Initial support could be used to provide funding for the start-up phase of collaborative projects.

These are only a few financing ideas. It has become increasingly clear through the process of writing this report that there is no ready-made solution to this issue; it is a challenge that will necessitate ongoing exploration. And since finance lays at the center of the CCS question, there is an urgent need to have a specialized working group tasked to focus specifically on the question of financing, which will be able to dig deeper and generate even more innovative options.

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## V. Clearing political hurdles in the United States and China

**The global nature of climate change** demands new forms of partnerships. These partnerships are necessary to accelerate CO<sub>2</sub> emissions reductions and the transition to a low-carbon economy, and do so while producing tangible and near-term benefits for all parties involved. There are political challenges to CCS collaboration despite the fact that both the United States and China ultimately stand to profit more through collaboration than through pursuing independent pathways.

### Obstacles in the United States

While support for action on climate change is growing in the United States, substantial obstacles still persist.<sup>43</sup> A complicating factor in the CCS debate is the United States' relationship with the major carbon emitting countries in the developing world, especially those with whom it has a competitive trade relationship.<sup>44</sup> Many Americans and their representatives refuse to support a price on carbon or mandatory emissions reductions for fear of creating a competitive disadvantage for the United States. Given the existing political climate in the United States, any collaboration with China will have to navigate a number of barriers to overcome such fears.

### **Congress will most likely oppose the use of U.S. tax dollars to fund collaborative projects in China unless they bring substantial co-benefits to American workers.**

The United States trade deficit with China and its continued reliance on Beijing to finance U.S. budget deficits are topics that tend to dominate the bilateral economic relationship. The fact that the Chinese economy appears to be recovering more quickly from the global financial crisis than that of the United States reinforces a perception of those imbalances and creates further resistance against funding collaborations.<sup>45</sup>

### **Congress's historic relationship with developing nations on climate change has been competitive and apprehensive.**

When the Clinton administration brought the Kyoto Protocol back to the United States, the Senate responded with the 1997 Byrd-Hagel Resolution (passing 95-0), which defiantly proclaimed that there would be no ratification of any international climate treaty that failed to include defined emissions commitments from developing countries, something not called for in the Protocol itself.

The House more recently passed this year's Foreign Relations Authorization bill (H.R. 2410), which included a specific provision requiring the State Department to ensure that international treaties do not weaken U.S. companies' intellectual property rights. It also made reference to both climate treaties and low-carbon technologies.<sup>46</sup>

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What's more, the Waxman-Markey American Clean Energy and Security Act of 2009, now passed by the House (but not the Senate), includes provisions that would essentially enact border tax adjustments on imports from countries that fail to implement legally binding controls on their greenhouse gas emissions. The bill would also require the EPA administrator to "annually prepare and certify a report to Congress regarding whether China and India have adopted greenhouse gas emissions standards at least as strict as those standards required under this Act."

### **The federal government must address public concerns surrounding CCS.**

Although "clean coal" is being widely hailed by many industry groups,<sup>47</sup> some environmentalists doubt the viability of large-scale sequestration, citing CCS's high cost and the lack of proven technology.<sup>48</sup> Sequestering carbon also raises potential environmental concerns—such as leakage, earthquakes, and negative interactions with groundwater—that have led to a recent upsurge in activism in other parts of the world and even protests against early sequestration projects in Europe.<sup>49</sup> The United States can expect similar opposition at home as sequestration projects begin. Yet it is also true that the public's attitude cannot evolve from suspicion to support unless and until there are U.S. CCS demonstrations greater than 300,000 tons per year.

### **Overcoming obstacles in the United States**

Any collaboration with China on CCS must address the concerns outlined above. Fortunately, despite these concerns, CCS has nonetheless managed to win substantial initial support among key U.S. stakeholders.

#### **Public sector**

The Department of Energy has begun substantial work cleaning up coal pollution by addressing both conventional pollutants and carbon emissions. Along with several utility companies, the DOE has invested in a number of CCS demonstration plants.<sup>50</sup> And the Obama administration has begun actively encouraging more domestic CCS deployment. The American Recovery and Reinvestment Act of 2009 allocates \$3.4 billion to CCS pilot projects, including \$1 billion to the FutureGen project in Illinois. ACES also supports CCS, providing financial incentives to eligible projects for the sequestration of CO<sub>2</sub> in the form of emissions allowances under the proposed economy-wide cap-and-trade scheme.<sup>51</sup>

#### **Commercial sector**

The commercial sector has substantial potential to develop, fund, and deploy CCS technology. Despite a sagging fourth quarter, private companies invested \$8.4 billion in "clean-tech" industries in 2008. Although relatively little went into CCS, this number is expected to grow as the recession ends.<sup>52</sup>

U.S. companies working in electric power technology, such as General Electric and American Electric Power, are generally supportive of CCS technologies. The U.S. Climate

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Action Partnership—an alliance of businesses and leading environmental non-governmental organizations including the Natural Resources Defense Council and Environmental Defense Fund—endorses policies furthering the development and deployment of CCS. And sensing which way political winds are blowing, many U.S. utilities are beginning to show an interest in investing in CCS retrofits because there may soon be substantial export opportunities for CCS technology.

### **Labor unions**

Large unions (such as the United Mine Workers of American and the International Brotherhood of Electrical Workers), as well as labor union federations (such as the AFL-CIO), have strong interest in seeing coal-fired power generation and related technologies to help gain a new life for coal-dependent jobs in a carbon-constrained world. There are approximately 397,000 permanent, full-time jobs in electric power generation and distribution in the United States and an additional 78,800 jobs in the coal mining sector.<sup>53</sup> Approximately 19 percent of workers in the mining industry were unionized in 2006.<sup>54</sup>

Moreover, a study completed by BBC Research and Consulting found that constructing one CCS plant would directly create between 13,000 and 14,000 job-years and 36,000 to 38,000 subsidiary job-years. Ongoing operation and maintenance functions promise to create an additional 1,200 to 1,300 more job-years throughout the economy.

And a study completed by the National Energy Technology Laboratory calculates that the development and deployment of advanced coal technologies would create up to 75,000 new job-years, primarily in manufacturing—growing to 200,000 per year by 2020. Given the effects of the recent recession, the promise of clean coal as a new technology understandably garners significant support from multiple sectors. This support is augmented by environmental groups such as the Clean Air Task Force and Natural Resources Defense Council and commerce groups such as the Apollo Alliance and the Council for American Competitiveness.

## **Benefits of CCS collaboration to the United States**

### **CCS collaboration could help accelerate eventual CCS deployment in the United States.**

American expertise in sequestration technology and research and development is well developed and ready to be immediately exported to China as part of a new program. Rapid Chinese deployment times and relatively fewer regulatory obstacles should enable the United States and China to explore CCS far more rapidly than they could independently. Our estimate is that, in the long run, knowledge gained from such collaboration can be applied to accelerate the deployment of CCS facilities in the United States by 5 to 10 years. This would follow from reduced timelines for several key enabling framework components: Accelerated development of protocols and practices in the United States and China on sequestration deployment; accelerated documentation of site criteria required for financial



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market engagement; demonstration of CCS deployment in key Chinese basins with a high degree of transparency and documentation; increased investment in cost-reducing capture technologies and an early start at resolving potential intellectual property concerns; identification of new sources for investment in projects in power-sector retrofits and new builds; and increased trust and relationship building between the two key nations in a globally manifested CCS industry.

This acceleration of CCS development will require sustained investments over the research and development period, platforms to share results, and a scientific program that can deliver the key geological and engineering information to all stakeholders quickly and conclusively.

And it is only by demonstrating sequestration technology on a large scale that we can definitively allay safety concerns in both countries.<sup>55</sup> At the same time, collaboration will help develop regulatory frameworks, risk profiles, technical findings, practices, and protocols that will encourage new potential operators, regulators, investors, and public stakeholders.

### **CCS collaboration could create U.S. jobs.**

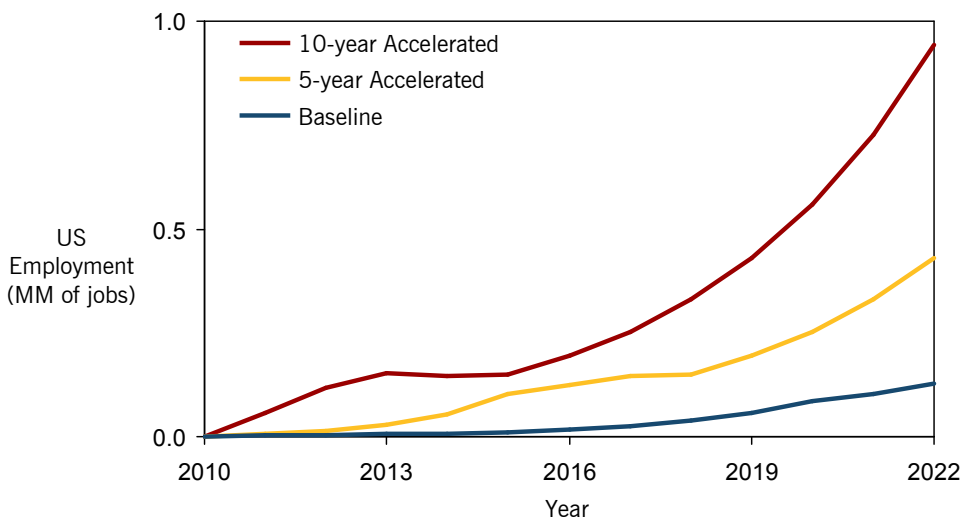
Collaboration would facilitate the entry of many U.S. stakeholders in a potentially massive CCS market in China. This would benefit U.S. labor markets by stimulating new opportunities at utility companies, energy companies and high-tech companies, thereby creating more U.S. jobs.

More importantly, CCS initiatives stand to create millions of new jobs in both skilled and unskilled areas during the construction and retrofit phase, as well as during ongoing operation. Our model makes working assumptions about how U.S.-China cooperation on CCS could accelerate the development and deployment of CCS technology and has considered each of these types of jobs as well as indirect jobs associated with CCS initiatives, based on industry data.<sup>56</sup> The acceleration of CCS efforts greatly improves the jobs picture when we examine the current baseline, five-year accelerated, and 10-year accelerated scenarios.

In the baseline scenario, we project CCS-related employment increasing slowly as new builds and retrofits take off, growing to 243,000 direct jobs and 473,000 indirect jobs globally in 2022. A five-year acceleration of CCS efforts drastically increases the amount of employment driven by CCS to approximately 819,000 direct jobs and 1.6 million indirect jobs globally in 2022. The more aggressive 10-year acceleration scenario results in over 1.8 million direct jobs and 3.5 million indirect jobs in 2022.<sup>57</sup>

We expect the U.S. share of these jobs to increase from a 2022 baseline scenario of 43,000 direct jobs and 84,000 indirect jobs to 145,000 direct and 285,000 indirect jobs with a five-year acceleration, and 318,000 direct and 625,000 indirect jobs with a 10-year acceleration.<sup>58</sup>

## Total U.S. Employment Associated with CCS, by Year



Source: Monitor analysis; BBC Research & Consulting "Employment and Other Economic Benefits from Advanced Coal Electric Generation with Carbon Capture and Storage (preliminary results)" February 2009 (<http://www.americaspower.org/content/download/1459/10428/file/BBC%20FINAL%20020709.pdf>); McKinsey & Co. "Pathways to a Low-Carbon Economy" Version 2 ([http://www.mckinsey.com/client-service/ccsi/pathways\\_low\\_carbon\\_economy.asp](http://www.mckinsey.com/client-service/ccsi/pathways_low_carbon_economy.asp))

### CCS collaboration could reduce U.S. electricity prices.

If the U.S. Congress passes a final climate bill that creates a price for carbon, and CCS is deemed to be an inevitable carbon abatement solution, ratepayers also stand to benefit from reduced electricity bills when CCS deployment is able to scale faster than it otherwise could without collaboration. CCS is increasingly viewed as a critical part of any eventual global carbon abatement effort, and the acceleration of CCS development could yield significant reductions in the electricity rates that would ensue under such a program. Some of the costs of abatement will be borne by utility companies, and some of those costs could be passed on to ratepayers depending on the structure of the pricing mechanism on carbon. The United States and China will almost certainly achieve CCS cost reductions more quickly by collaborating than by working independently. Our estimate of a five to 10 year acceleration of CCS deployment through cooperation shows that cost savings would be significant.

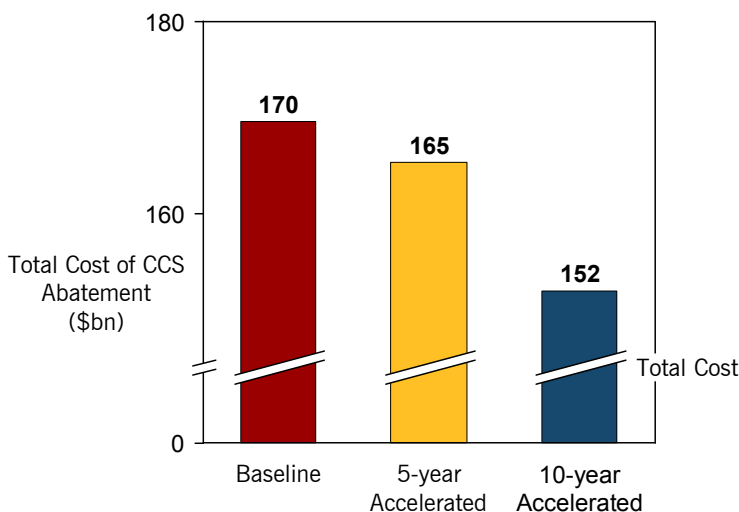
Current baseline estimates project the cost of CCS abatement to drop to \$95.58 per tCO<sub>2</sub>e by 2015, and drop further to \$55.14 per tCO<sub>2</sub>e by 2030.<sup>59</sup> Accelerating this cost curve will allow the overall CCS abatement effort to be achieved at lower cost.

In the baseline scenario, using the costs noted above, we project achieving a total global abatement of 3.65 Gt CO<sub>2</sub>-equivalent per year in 20 years at a total cost of \$959 billion. By accelerating the cost curve 5 years, the same total abatement can be achieved at a total cost of \$934 billion, saving \$25 billion.<sup>60</sup> A more aggressive 10-year acceleration costs a total of \$859 billion, saving \$100 billion.<sup>61</sup> The U.S. share of cost savings is approximately \$5 billion

in the scenario with a five-year acceleration, and \$18 billion with a 10-year acceleration.<sup>62</sup>

The accelerated cost curve both lowers total costs, and hence electricity prices, and reduces the time needed to achieve a given level of abatement. This results in greater emissions reductions beyond baseline estimates, which suggests that if we undertake efforts to accelerate the cost curve, CCS could form a larger portion of the overall abatement effort than currently assumed in the baseline estimates.

### CCS Abatement Cost (U.S. Share) for a total abatement of 3.65 Gt CO<sub>2</sub>e/yr



Source: Monitor analysis; McKinsey & Co. "Pathways to a Low-Carbon Economy"  
Version 2 ([http://www.mckinsey.com/clientservice/ccsi/pathways\\_low\\_carbon\\_economy.asp](http://www.mckinsey.com/clientservice/ccsi/pathways_low_carbon_economy.asp))

#### CCS collaboration could reduce costs for the United States.

Because several key components of CCS are cheaper in China than in the United States—including steel, cement, labor, and the savings from more rapid project completions—a focused joint effort could therefore reduce the cost of individual retrofit projects and construction time by as much as 50 percent. Moreover, by fostering a mutually beneficial, trusting relationship, the United States will also gain a better chance to learn from future Chinese developments and thus accelerate cost reductions in deployment at home.

#### Collaboration could allow the U.S. to share the risks.

Combining resources will allow the United States and China to share not only the benefits, but also the risks of failure, which will internationalize these risks. Some American companies have already weighed their business risks in the advanced coal sector and have come out in favor of being early movers in collaborating with China. Recent partnerships announced between Duke Energy Corp. and ENN Group and between Duke Energy and China

Huaneng Group highlight the opportunities being seized for risk-sharing and cost reduction through collaboration.<sup>63</sup> Additionally, KBR and Southern Company recently announced a deal with Beijing Guoneng Yinghui Clean Energy Engineering Co., Ltd. to license IGCC technology for use at Dongguan IGCC Power Plant in Guangdong Province. This deal will be the first commercial implementation of the TRIG technology for IGCC.<sup>64</sup>

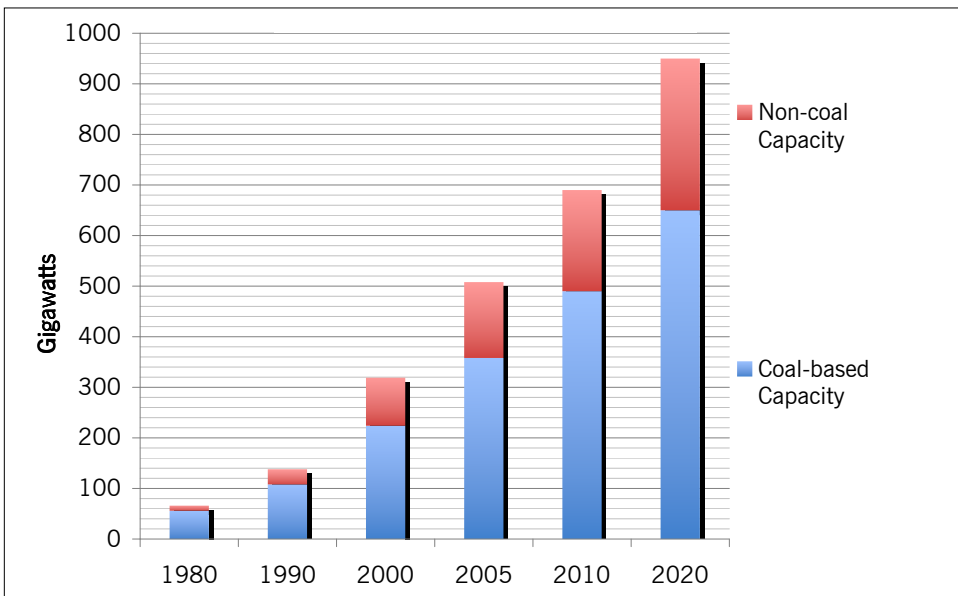
### Obstacles in China

China's primary commitment will continue to be to economic development and political stability, and it is depending on scientific innovation to reduce the environmental costs of its growth. However, the extreme pace of China's economic rise is making those costs prohibitive.

China became the world's largest annual emitter of greenhouse gases in 2007. While its emissions are only one-fourth those of the United States on a per capita basis and its cumulative historical emissions are similarly unequal,<sup>65</sup> due to rising urbanization and per capita incomes, China's energy demands will more than double from 2005 levels by 2030.<sup>66</sup> China has rich coal reserves and it will choose to burn even more coal to meet these new demands despite the fact that coal already contributes 80 percent of China's aggregate CO<sub>2</sub> emissions.<sup>67</sup> Indeed, China has been adding coal-fired power production capacity at an increasingly rapid rate.<sup>68</sup> Conservative studies estimate that China is now bringing online two 500 megawatt, coal-fired power plants every week, or an annual increase equal to the UK's entire power grid.<sup>69</sup>

### China power and coal builds

China has installed more than 500,000 Megawatts of coal capacity in the past 10 years



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Given this context, there are several obstacles CCS faces in China:

**China’s core interests are in energy security and economic development.**

Beijing recognizes the dangers of CO<sub>2</sub> emissions, but its overriding interest lies in maintaining continued rapid economic growth and energy security. Lacking sufficient oil and natural gas reserves of its own, China has become highly dependent on domestic coal and foreign oil imports.<sup>70</sup> But it has also devoted an impressive amount of economic resources to developing renewable energy and energy efficiency technologies to reduce its dependence on foreign oil.<sup>71</sup> Most joint U.S.-China energy projects to date have therefore focused on limiting greenhouse gasses indirectly by promoting energy efficiency and renewable energy.

Given China’s overriding concern of economic development, it is not surprising that CCS projects are viewed with a certain skepticism. After all, it is expensive to retrofit a plant with CCS technology and CCS plants require more coal to produce the same amount of electricity.<sup>72</sup> Understandably, China has also been far more concerned with sulfur dioxide, nitrogen oxide, and mercury pollution from coal-fired electricity generation—pollution with immediate health consequences—than with carbon emissions, which have long-term effects.<sup>73</sup> Therefore, because CCS is expensive, fails to diversify China’s energy sources, focuses on global rather than immediate and local environmental problems, and comes with technical uncertainties and an onerous “energy penalty,” Beijing has been cautious in committing to an aggressive program in this field.

**Chinese climate negotiators expect developed countries to assume greater responsibility for emissions reductions.**

Speaking on behalf of the G77, a consortium of developing countries, China often argues that since developed nations created the problem of climate change, they should inherit the primary responsibility for remedying it.<sup>74</sup> Indeed, China has even gone so far as to call on developed countries to reduce their emissions by 40 percent from 1990 levels by 2020, as well as to contribute 0.5 percent to 1 percent of their GDP to helping developing nations reduce their emissions, both of which are unlikely to happen.<sup>75</sup> Because China is wary of being singled out from other developing countries for heightened criticism and having a heavier burden imposed on it because of its dynamic growth, it has rejected the imposition of emissions caps.<sup>76</sup> Instead, China has preferred to set the bar low and overperform, lest it become hobbled by a “defined limit” that it may be unable to meet and that limit its growth.<sup>77</sup>

**Overcoming obstacles in China**

Any prospective CCS collaboration must recognize China’s underlying priorities of economic development and energy security, and successfully address the challenges of costs and other uncertainties in deployment. However, there are reasons to believe that various Chinese stakeholders would be receptive to collaborative overtures in the field of CCS, especially if these overtures are made with the right incentives and with the U.S. explicitly

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taking responsibility for its fair share of the historic burden. Opportunities for China include transfers of cutting-edge technology and technical expertise in a future market, external financial support, future green collaboration in other preferred areas,<sup>78</sup> as well as improved U.S.-China relations. Demonstrating and developing CCS technology could also help establish China as a leader in innovation, technology and climate change mitigation efforts.

**China has become increasingly proactive in addressing climate change and greenhouse gas emissions.**

Across the political, academic, and civic spectrums, Chinese leaders have begun to acknowledge both publicly and privately that climate change is a problem that must be taken seriously.<sup>79</sup> China has set aggressive targets for renewable energy, energy efficiency, nuclear power and transportation, and has been working to meet many of these domestic targets.<sup>80</sup> Although precise allocations of China's 4 trillion yuan stimulus package announced last year have been difficult to determine, one government source says roughly 580 billion yuan (just under \$100 billion) was allocated for climate change mitigation projects.<sup>81</sup>

What's more, China has been rapidly pioneering new technologies in solar, wind, and hydro power, and has become the world's largest user of hydro power and solar thermal heating and the fourth largest user of wind power in the world.<sup>82</sup> Indeed, China is moving at a remarkable pace in becoming a world leader in low-carbon power, all the while creating a large number of new green jobs.<sup>83</sup> These national priorities have at last begun influencing decision making at regional levels, as Beijing has begun to change the metrics by which it evaluates local leaders—mixing economic growth indices with environmental ones—thus incubating a new kind of environmental local leadership.<sup>84</sup>

A recent and quite hopeful report commissioned by China's National Development and Reform Commission and the State Council suggests that CO<sub>2</sub> emissions in China could slow by 2020 and peak by 2030 rather than 2050 with the right energy policies in place. The report also shows that this goal does not have to come at the cost of lowered economic growth. In fact, the report suggests that requisite investments to make China a global leader in low-carbon technologies could simultaneously help remedy climate change and boost domestic economic growth.<sup>85</sup> Such reports are only some of many examples of Chinese officials' willingness to address CO<sub>2</sub> emissions more proactively,<sup>86</sup> even while global conversations often remain quite politicized and polarized.

The 10th Standing Committee of China's Eleventh National People's Congress on August 27, 2009 confirmed a new call to arms on greenhouse gas emissions. The Standing Committee recognized that a response to climate change is "vital to human survival," and called on "the whole society to participate in a wide range of actions to address climate change."<sup>87</sup> Most recently on September 22, 2009, President Hu Jintao pledged at the United Nations General Assembly to reduce CO<sub>2</sub> emissions per unit of GDP from 2005 to 2020, one of the clearest indications to date of China's willingness to assume greater responsibility in global emissions reductions.<sup>88</sup>

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### **The Chinese government and commercial sector are making investments in CCS**

China has already made commitments to build large CCS demonstration plants and has explicitly acknowledged that the deployment of CCS in China's power sector is something that needs to happen in the future.<sup>89</sup> The Standing Committee of China's National People's Congress just recently proposed that now is the time to "encourage and support the use of clean coal technologies," including the use of CCS.<sup>90</sup> Investments in CCS have been made by NDRC, the Ministry of Science and Technology, and the Chinese Academy of Sciences. These include GreenGen in Tianjin, the sequestration component of Shenhua's direct coal-to-liquid plant in Ordos, Inner Mongolia, and the Thermal Power Research Institute/Huaneng post-combustion capture demonstrations in Beijing and Shanghai.<sup>91</sup>

NDRC and MOST investments in gasifier technology developments at TPRI and East China University have led to the licensing, construction, and deployment of large commercial gasifiers in China and the United States, and to the development of PCC technology at TPRI. China has used these investments to establish itself as an active player in the CCS field and a potential global competitor in advanced clean coal technology.<sup>92</sup>

The commercial sector in China has also begun to show interest in CCS, especially among the large state-run power and oil companies. The right incentives would help make these companies even more interested in obtaining and developing CCS technology and becoming more globally competitive in a future CCS market. After all, Chinese entrepreneurs have been extremely successful in capitalizing on China's transition to a low-carbon economy, specifically with regard to renewable energy and energy efficiency.

These public and private sector trends reflect the fact that attitudes toward CCS in China are neither homogenous nor immutable and that some experts and key decision makers in China are very supportive of CCS. The primary concerns relate to the energy penalty and the cost of CCS given that there is no price for carbon.<sup>93</sup> But this reluctance might eventually wane if the cost of CCS drops over time, if some form of price support for carbon develops in the foreseeable future, and if the U.S. is willing to play a more active leadership role.<sup>94</sup>

### **China aspires to enhance its global reputation as a responsible and peaceful rising power.**

Collaborating with the United States as an equal partner to help solve one of the world's most ominous crises would give China an unparalleled opportunity to assume global leadership.

Indeed, a new chapter is opening both in China's own development and U.S.-China relations with the 60th anniversary of the People's Republic of China and its three decades of "reform and opening" just passed. A joint project on CCS provides a logical and meaningful place to begin weaving a new narrative for Sino-U.S. relations over the next decade.

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## VI. Conclusion

**This year marked the 30th anniversary of U.S.-China rapprochement.** The two countries find themselves once again at a tipping point moment in history. While this important relationship will most certainly evolve in dramatic ways over the next few years, what is uncertain is how it will evolve.

At the same time that the United States and China are reaching to reformat their relations, the world is being confronted by an unprecedented challenge: global climate change. Our immediate short-term interests on the issue may not always seem to be in complete accord, but our long-term interests are unalterably aligned toward the need to collectively solve this daunting global problem.

One area that now presents itself as a logical starting point for collaboration is in carbon capture and sequestration for coal-fired power plants, which make up a structural part of both nations' energy systems. If United States President Barack Obama and Chinese President Hu Jintao could forge a partnership on this issue at their summit meeting in November, it would be an unprecedented step forward not only in the world's efforts to come to terms with climate change, but also in U.S.-China relations. We hope the roadmap outlined in this report can help enable leaders on both sides to seize this opportunity to bring their respective countries together in a meaningful new program of collaboration in this critical area of clean energy technology. Not only would such a step help test CCS as a workable answer to CO<sub>2</sub> mitigation and improve bilateral relations, but it would give a signal at the U.N. climate summit in Copenhagen this December that the U.S. and China are fully engaged in seeking a solution.

Now is the time to start the arduous, but not unhopeful, journey toward closer U.S.-China collaboration, and climate change is an important area for concerted joint effort. There will doubtless be many areas of disagreement that will have to be researched and negotiated, but the immediate challenge is to begin. Such a beginning could catalyze the United States and China to move forward in a convincingly collaborative way.



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## Acknowledgments

**The challenge of undertaking a project such as this roadmap**—the successor to the Asia Society and Pew Center on Global Climate Change’s “A Roadmap for US-China Cooperation on Energy and Climate Change”—has not only been to help formulate new and effective policy, but to also bring together a collegium of interested and well-informed specialists from civil society, business, science, academia, and government who will henceforth be able to continue collaborating. Those who have worked long and hard on this report share a deep concern about the effects of climate change on our planet and were thus willing to participate in a project aimed at sketching out a concrete course of action to address the emissions from coal-fired plants.

The project was started by the Asia Society’s Center on U.S.-China Relations and the Center for American Progress. Thanks are due to Asia Society President Vishakha Desai. Laura Chang and Albert G. Chang, who did much of the heavy lifting at the Asia Society, are due special thanks. They were assisted by John Delury, Leah Thompson, Andrew Smeall, Michael Zhao, Song J. Song and Ariane Wu.

At the Center for American Progress, thanks are due to President and CEO John Podesta, who traveled to Beijing to participate in Asia Society’s kick-off conference with Peking and Tsinghua Universities and China Meteorological Administration on climate change remedies in April 2009. And special thanks are due Julian L. Wong and Dan Sanchez who worked long and hard with Asia Society colleagues to research and write this report.

Without the input of our collegium of experts, it would have been very difficult to get this project “right.” This cadre of specialists came from almost every relevant field, and we thank them for all their help along the way. But a very special note of appreciation must be accorded S. Julio Friedmann, from Lawrence Livermore National Laboratory. Dr. Friedmann was extraordinarily generous in sharing his time and expertise, and in drafting key elements of this roadmap.

This report would have had a far less likely prospect of reaching completion without the extraordinary generosity of the Monitor Group who, through the good offices of Peter Schwartz at the Global Business Network, Monitor’s sister organization, worked tirelessly and pro bono to galvanize this effort to completion. Scott Daniels and Kurt Dassel headed the very committed and well-informed Monitor team and were ably assisted by Vivek Sekhar and John Benjamin Woo.

We do hope the recommendations of this roadmap will provide a starting point for the governments of both the U.S. and China—as well as all the other stakeholders who are essential to the success of any such public/private partnership—to begin effecting a meaningful collaboration in CCS.

Finally, projects like this cannot begin, much less come to successful fruition, without the financial wherewithal to undertake them. We were underwritten by some very generous support from Jon Anda, the Open Society Institute, the 11th Hour Project and Climate Works, which enabled us to carry out this venture. We are deeply grateful to them.

### **Orville Schell**

Arthur Ross Director,  
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### **Andrew Light**

Senior Fellow  
Coordinator, International Climate Policy  
Center for American Progress

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# Appendices

## List of Acronyms

<b>ACES</b>	American Clean Energy and Security Act of 2009 (H.R. 2454)
<b>AFL-CIO</b>	American Federation of Labor and Congress of Industrial Organizations
<b>CDM</b>	Clean Development Mechanism
<b>CCS</b>	Carbon Capture and Sequestration
<b>CO2</b>	Carbon Dioxide
<b>DOE</b>	U.S. Department of Energy
<b>EPA</b>	U.S. Environmental Protection Agency
<b>GDP</b>	Gross Domestic Product
<b>IEA</b>	International Energy Agency
<b>IGCC</b>	Integrated Gasification Combined Cycle
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>MIT</b>	Massachusetts Institute of Technology
<b>NDRC</b>	China's National Development and Reform Commission
<b>MOST</b>	China's Ministry of Science and Technology
<b>PCC</b>	Post-Combustion Capture
<b>ppm</b>	Parts per Million
<b>OPIC</b>	Overseas Private Investment Corporation
<b>TPRI</b>	Thermal Power Research Institute
<b>UMWA</b>	United Mine Workers of American
<b>UN</b>	United Nations
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change

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## Appendix A: Profiles of Selected CCS Projects in the U.S.

### CO<sub>2</sub> Capture Commercial Projects

Source: IEA Greenhouse Gas R&D Programme

#### Shady Point, Warrior Run, and Bellingham Cogeneration Power Plants

**Project Overview:** These plants generate electricity and produce food-grade CO<sub>2</sub> from flue gases

**Goals:**

- Commercial-scale, economical and environmentally-acceptable power generation coupled with CO<sub>2</sub> production

#### Great Plains Synfuels Plant (GPSP) CO<sub>2</sub> Capture and Compression

**Project Overview:** The GPSP is the only commercial-scale coal gasification plant in the United States that manufactures natural gas

**Goals:**

- To deliver CO<sub>2</sub> to the Weyburn unit in Canada

### CO<sub>2</sub> Capture R&D Projects

Source: IEA Greenhouse Gas R&D Programme

#### CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO<sub>2</sub> Capture

**Project Overview:** The CETC's pre-competitive collaborative R&D program in Ottawa, tackles the development of combustion and pollution abatement technologies for fossil fuels in oxygen (O<sub>2</sub>) and recycled flue gas (RFG) atmospheres for the purpose of producing high purity CO<sub>2</sub> streams that are capture ready for transport and storage

**Goals:**

- To develop energy-efficient integrated multi-pollutant control, waste management and CO<sub>2</sub> capture technologies for combustion-based applications
- To provide information for the scale-up, design and operation of large scale industrial and utility plants based on the oxy-fuel concept

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## **Physics and Chemistry of Coal-Seam CO<sub>2</sub> Sequestration and Coalbed Methane Production**

**Project Overview:** The research will ultimately provide guidelines for drilling of new CBM production wells and enable field engineers to determine if cases of poor CO<sub>2</sub> sequestration and/or low methane productivity can be attributed to non-ideal coal bed temperatures/ depths or, perhaps, to other factors

### **Goals:**

- To determine the temperature dependence of CO<sub>2</sub> sequestration and methane production.
- To determine adsorption isotherms for pure gases in a static system for coals of NETL interest.
- To develop a flow system to generate adsorption isotherms via numerical techniques established for data analysis

## **CO<sub>2</sub> Geological Storage R&D Projects**

Source: IEA Greenhouse Gas R&D Programme

### **American Electrical Power (AEP) Mountaineer Plant Research Project**

**Project Overview:** In November 2002, the U.S. Department of Energy (US DOE) announced a major new research project to begin studying the potential for geological storage of CO<sub>2</sub> at AEP's Mountaineer plant in New Haven, West Virginia, USA

### **Goals:**

- To answer the question of whether the rocks above the possible storage areas are sturdy enough and sufficiently free of interconnected fractures to assure that the CO<sub>2</sub> cannot gradually escape

### **Large scale CO<sub>2</sub> Transportation and Deep Ocean Sequestration**

**Project Overview:** Assessing technical and economic viability of large-scale CO<sub>2</sub> transportation and deep ocean storage

### **Goals:**

- To assess technical and economic viability of ocean storage using enhanced pipe-laying technology
- To resolve engineering challenges to oceanic tanker transport
- To develop appropriate offshore floating platform/barge for vertical CO<sub>2</sub> injection

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## **Laboratory Investigations in Support of Carbon Dioxide-Limestone Sequestration in the Ocean**

**Project Overview:** The project will carry our investigations into the preparation and characteristics of CO<sub>2</sub>/water/limestone mixtures for the ocean sequestration of CO<sub>2</sub>

**Goals:**

- To produce a series of emulsions comprising mixtures of liquid CO<sub>2</sub>, water and ground limestone
- To test and analyze such emulsions in terms of their chemical and structural characteristics
- To carry out modeling studies of behavior of emulsions after discharge into the ocean
- To produce the optimal mix of reagents such that a stable emulsion is formed with a density greater than that of seawater

## **CCS Power Generation Projects**

Source: Stephen Wittrig, Director of Advanced Technologies for BP

### **AEP Alstom Mountaineer (WV)**

**Developer:** AEP w/Alstom, RWE, NETL and BMI

**Size MW:** 30 MW

**Capture Process:** Post-combustion capture

**CO<sub>2</sub> Fate:** Sequestration (saline aquifer)

**Start-up:** 2009

### **AEP Alstom Northeastern (OK)**

**Developer:** AEP/Alstom

**Size MW:** 200 MW

**Capture Process:** Post-combustion capture

**CO<sub>2</sub> Fate:** EOR

**Start-up:** 2011

### **Antelope Valley (ND)**

**Developer:** Basin Electric; Powerspan (USDA loan)

**Size MW:** 120 MW

**Capture Process:** Post-combustion capture

**CO<sub>2</sub> Fate:** EOR (Pipe to Canada)

**Start-up:** 2012

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**W A Parish (TX)**

**Developer:** NRG Energy with Powerspan

**Size MW:** Hueneng 125 MW

**Capture Process:** Post-combustion capture

**CO<sub>2</sub> Fate:** EOR

**Start-up:** 2012

**Appalachian Power**

**Developer:** AEP

**Combustion:** IGCC

**Size MW:** 629 MW

**Capture Process:** Pre-combustion capture

**CO<sub>2</sub> Fate:** Undecided

**Start-up:** 2012

**FutureGen (IL)**

**Developer:** FutureGen Alliance, 9 international participants remain

**Combustion:** IGCC

**Size MW:** 275 MW

**Capture Process:** Pre-combustion capture

**CO<sub>2</sub> Fate:** Sequestration

**Start-up:** 2012

**AMPGS (OH)**

**Developer:** American Municipal Power-Ohio, Inc.; Bechtel Power Corporation;  
Powerspan

**Combustion:** IGCC

**Size MW:** 1000 MW

**Capture Process:** Post-combustion capture

**CO<sub>2</sub> Fate:** EOR

**Start-up:** 2015

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## Appendix B: Profiles of Selected CCS Projects in China

### CO<sub>2</sub> Capture R&D Projects

Source: IEA Greenhouse Gas R&D Programme

#### Near Zero Emissions Coal for China (NZEC)

**Project Overview:** The Phase 1 assessment will explore options for demonstrating CCS for coal-fired power generation in China

**Goals:**

- To explore options for the demonstration of CCS applied to a coal power plant in China
- To build knowledge and capacity on CCS in China

### CO<sub>2</sub> Geological Storage R&D Projects

Source: IEA Greenhouse Gas R&D Programme

#### Development of Coal bed Methane Technology/Carbon Dioxide Sequestration Project (CCCDP)

**Project Overview:** The project is addressing a number of issues leading to an ECBM/CO<sub>2</sub> sequestration demonstration project in China via transfer of Canadian technology

**Goals:**

- To undertake a programme of work leading to a demonstration project in China
- To produce an inventory of suitable coal beds
- To produce a detailed site selection process
- To carry out micro-pilot and large scale testing in selected areas
- To carry out evaluation and training exercises

#### EOR Application at Liaohe Oil Field in China

**Project Overview:** The project is examining the injection of boiler flue gas for enhanced oil recovery coupled with CO<sub>2</sub> sequestration in a Chinese oil field

**Goals:**

- To carry out injection trials using steam and/or flue gases in order to boost oil output and sequester CO<sub>2</sub>
- To develop the next phase of the project investigating CO<sub>2</sub> separation via membrane technology and enriching CO<sub>2</sub> levels in combustion flue gas through the use of recirculation technology

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## CCS Power Generation Projects

Source: Stephen Wittrig, Director of Advanced Technologies for BP

### CSIRO PCC Program

**Developer:** Thermal Power Research Institute (China); Huaneng Group and CSIRO (Australia)

**Combustion:** Coal Steam Power

**Size MW:** Huaneng Beijing host plant is 845 MW

**Capture Process:** Post-combustion capture retrofit

**CO2 Fate:** Carbonated beverages

**Start-up:** 2008

### Shanghai Shidongkou Second Power Plant

**Developer:** Huaneng Power International (project in Shanghai for Shanghai 2010 EXPO)

**Combustion:** Coal Steam Power

**Capture Process:** Post-combustion capture retrofit

**CO2 Fate:** Local sales, food and industry, possibly eventual offshore EOR

**Start-up:** Early 2010

### GreenGen

**Developer:** China Huaneng Group (51%) plus the other 4 State Power companies, Shenhua, China Coal, Peabody has applied to join

**Combustion:** IGCC

**Size MW:** 250 MW expanding to 650MW

**Capture Process:** Pre-combustion

**CO2 Fate:** Sequestration / EOR

**Start-up:** 250 MW IGCC plant in 2011, 650 MW IGCC with PC capture in 2013; add EOR CCS in approx 2015

### Shenhua CtL

**Developer:** Shenhua Group

**Capture Process:** Probably Rectisol (Coal conversion processes such as this plant capture the CO2 as part of the process and emit practically pure CO2)

**CO2 Fate:** Sequestration (saline aquifer and depleted oil fields)

**Start-up:** CtL operational CCS 2011



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## Endnotes

- <sup>1</sup> IPCC [International Panel on Climate Change] Working Group 1, *Climate Change 2007: The Physical Science Basis*, vol. 1 of IPCC Fourth Assessment Report (New York: Cambridge University Press, 2007). Parts per million (ppm) is the ratio of the number of GHG molecules to the total number of molecules of dry air.
- <sup>2</sup> NASA Goddard Institute for Space Studies, *GISS Surface Temperature Analysis: 2005 Summation* (New York: NASA Goddard Institute for Space Studies, 2006).
- <sup>3</sup> IPCC Working Group 1, *Climate Change 2007: The Physical Science Basis*.
- <sup>4</sup> IPCC Working Group 2, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, vol 2. of IPCC Fourth Assessment Report (New York: Cambridge University Press, 2007).
- <sup>5</sup> See Thomas Fingar, *Statement for the Record before the Permanent Select Committee on Intelligence and the Select Committee on Energy Independence and Global Warming*, House Of Representatives (Office of the Director of National Intelligence, 2008), [http://www.dni.gov/testimonies/20080625\\_testimony.pdf](http://www.dni.gov/testimonies/20080625_testimony.pdf).
- <sup>6</sup> *Ibid.*
- <sup>7</sup> *Ibid.*
- <sup>8</sup> Khalid Malik, *Project Launch Ceremony China Environmental Awareness Programme* (United Nations Development Programme, 2006), <http://www.undp.org.cn/modules.php?op=modload&name=News&file=article&catid=13&topic=6&sid=348&mode=thread&order=0&thold=0>.
- <sup>9</sup> China Environment Forum, *Environmental NGOs, Public Participation, and Governance* (Woodrow Wilson Center for Scholars, 2009), [http://wilsoncenter.org/index.cfm?topic\\_id=1421&fuseaction=topics.categoryview&categoryid=EE5586BC-9247-863E-B7C96B9489272423](http://wilsoncenter.org/index.cfm?topic_id=1421&fuseaction=topics.categoryview&categoryid=EE5586BC-9247-863E-B7C96B9489272423).
- <sup>10</sup> Department of Energy, Energy Information Administration (DOE/EIA), "Highlights," in *International Energy Outlook 2009* (IEO2009; DOE/EIA, 2009), <http://www.eia.doe.gov/oiaf/ieo/highlights.html>. The IEO2009 reference case projects an increase from 29.0 billion metric tons in 2006 to 40.4 billion metric tons in 2030.
- <sup>11</sup> James Hansen, "Tipping Point: Perspective of a Climatologist," in *State of the Wild 2008-2009*, ed. Eva Fearn (Washington, DC: Island Press, 2008), 6-15, 258-59. This estimate uses a carbon dioxide ceiling of 450 ppm.
- <sup>12</sup> See Asia Society's Center on U.S.-China Relations & Pew Center on Global Climate Change, *A Roadmap for U.S. China Cooperation on Energy and Climate Change*, January 2009, at <http://www.asiasociety.org/climate/> and Center for American Progress *A Global Imperative: A Progressive Approach to U.S.-China Relations in the 21st Century*, August 2008, at [http://www.americanprogress.org/issues/2008/08/china\\_report.html](http://www.americanprogress.org/issues/2008/08/china_report.html)
- <sup>13</sup> Renee Schoof, *Answer to U.S. Search for Clean Coal May Lie in China* McClatchy Newspaper September 24, 2009 <http://www.mcclatchydc.com/environment/story/76004.html>
- <sup>14</sup> For the role of CCS technologies in climate change mitigation, see, e.g., McKinsey & Company, *Global Cost Curve for Greenhouse Gas Abatement Measures* (McKinsey & Company, n.d.), <http://www.gltg.com.au/images/mckinsey-cost-curve.jpg>, and McKinsey & Company, *China's Green Revolution*, 2009, at [http://www.mckinsey.com/locations/great-erchina/mckonchina/reports/china\\_green\\_revolution\\_report.pdf](http://www.mckinsey.com/locations/great-erchina/mckonchina/reports/china_green_revolution_report.pdf).
- <sup>15</sup> See Memorandum of Understanding to Enhance Cooperation on Climate Change, Energy and the Environment between the Government of the United States of America and the Government of the People's Republic of China, July 28, 2009, at <http://www.state.gov/r/pa/prs/ps/2009/july/126592.htm>.
- <sup>16</sup> U.S. Department of Energy, "US-China Clean Energy Research Center announced," press release, July 15, 2009, at <http://www.energy.gov/news2009/7640.htm>.
- <sup>17</sup> Lisa Friedman, "A Sea Change in China's Attitude Toward Carbon Capture," *New York Times*, June 22, 2009, at <http://www.nytimes.com/cwire/2009/06/22/22climatewire-a-sea-change-in-chinas-attitude-toward-carbo-94519.html>.
- <sup>18</sup> See Tao Wang and Jim Watson, "China's Energy Transition: Pathway for Low Carbon Development," University of Sussex and Tyndall Centre for Climate Change Research, April 2009, at [http://www.sussex.ac.uk/sussexenergygroup/documents/china\\_report\\_forweb.pdf](http://www.sussex.ac.uk/sussexenergygroup/documents/china_report_forweb.pdf), which evaluates four low-carbon scenarios from now till 2050 consistent with stabilizing the global atmospheric content of carbon at 550 ppm of CO<sub>2</sub>-equivalent, three of which CCS is a critical part of the solution, requiring 67 to 90 percent of the Chinese fossil fuel power plant fleet to be equipped with CCS.
- <sup>19</sup> McKinsey's work on mitigation solutions shows that energy efficiency and renewable energy, although cheaper than CCS, do not have the mitigation potential to stabilize CO<sub>2</sub> concentrations at 450 ppm. See McKinsey, *Global Cost Curve, and China's Green Revolution*.

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- <sup>20</sup> See Scottish Centre for Carbon Storage, "Post-Combustion Capture," October 27, 2007, at <http://www.geos.ed.ac.uk/sccs/capture/postcombustion.html> and National Energy Technology Laboratory, U.S. Department of Energy, "Carbon Sequestration: CO2 Capture," accessed October 1, 2009, at [http://www.netl.doe.gov/technologies/carbon\\_seq/core\\_rd/co2capture.html](http://www.netl.doe.gov/technologies/carbon_seq/core_rd/co2capture.html)
- <sup>21</sup> U.S. Department of Energy, National Energy Technology Laboratory, Carbon Sequestration Atlas of the United States and Canada, 2nd ed., 2008, at [http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/atlasII/atlasII.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf).
- <sup>22</sup> Casie Davidson, "The Potential for CCS Deployment in China," Pacific Northwest National Laboratory, May 29, 2008, at [http://www.pnl.gov/gtsp/docs/2008/GTSP3\\_China.pdf](http://www.pnl.gov/gtsp/docs/2008/GTSP3_China.pdf).
- <sup>23</sup> This is an important distinction, because the concentrations of CO<sub>2</sub> in a power plant's flue are lower and therefore harder and more expensive to capture. CO<sub>2</sub> has been transported and successfully stored underground (e.g., in Sleipner, Norway, and Weyburn, Canada), but at about 1/3 the volumes that would be generated by a single large power plant. Demonstrations involving the injection of 10 times that amount (that is, the CO<sub>2</sub> from several power plants) are needed.
- <sup>24</sup> This can be done by identifying the most efficient current technologies, developing more efficient technologies for the future, identifying best practices in operations and integration, and so forth.
- <sup>25</sup> The joint UK-China Near Zero Emissions Coal initiative (see <http://www.nzec.info/>) and the Australia-China collaboration on post-combustion capture between Australian government research organization CSIRO and China's Thermal Power Research Institute (see [http://www.csiro.au/news/newsletters/Energy/0408\\_energy/HTML/PCC.htm](http://www.csiro.au/news/newsletters/Energy/0408_energy/HTML/PCC.htm)) are examples of bilateral CCS projects involving China. The Asia Pacific Partnership on Clean Development and Climate (see <http://www.asiapacificpartnership.org>) and Global Carbon Capture and Storage Institute in Australia (see <http://www.globalccsinstitute.com>) are examples of multilateral efforts in CCS that China is involved in.
- <sup>26</sup> For further recommendations on U.S. international sequestration collaboration, See Friedmann, S.J., and Newmark, R.L., "Ch 4 Commercial Deployment of Geologic Carbon Sequestration" in Clean Air Task Force, Coal Without Carbon: An Investment Plan for Federal Action, September 2009, at [http://www.coaltransition.org/filebin/pdf/Coal\\_Without\\_Carbon\\_Final\\_High-Resolution.pdf](http://www.coaltransition.org/filebin/pdf/Coal_Without_Carbon_Final_High-Resolution.pdf)
- <sup>27</sup> Friedmann, S.J., 2006, The scientific case for large CO<sub>2</sub> storage projects worldwide: Where they should go, what they should look like, and how much they should cost, 8th Greenhouse Gas Technology Conference, Trondheim, Norway
- <sup>28</sup> Chinese entities will likely over 60 to 80 percent of the project costs in local expenses, such as drilling, site characterization, geophysical surveys, pipelines, and compressors. The US would likely cover 20 to 40 percent, which would include field scientific and technical support, travel, simulation and analysis, injection planning support, and CO<sub>2</sub> injection monitoring and verification. For Chinese participation in a comparable US project, the costs would be reversed.
- <sup>29</sup> Most of the cost for projects is capital costs, and are reflected in the estimates printed here. There would be a non-zero operating cost as well – roughly \$5 to 10 million per year for "pre-captured" pure stream projects and \$40 to 200 million per year for retrofit projects. These are costs to be born by the operator, but could potentially be covered through one of the financial mechanisms discussed herein.
- <sup>30</sup> I. K. Newlands and R. Langford, CO<sub>2</sub> Storage Prospectivity of Selected Sedimentary Basins in the Region of China and South East Asia (Australian Government, Geoscience Australia, Record 2005/13).
- <sup>31</sup> Qingyun Sun, "CTL Development in China," U.S. China Energy Center, West Virginia University, April 24, 2008, at <http://files.asme.org/asmearg/Communities/Technical/Energy/16089.pdf>
- <sup>32</sup> A U.S.-China sequestration collaboration at Ordos could draw lessons from similar collaborative projects around the world, such as the In Salah (Algeria) sequestration project which is injecting around one million tons of CO<sub>2</sub> per year into gas reservoirs. In Salah began sequestering CO<sub>2</sub> in 2004 through a public/private partnership including BP (32%), Sontrach (35%) and Statoil (32%) and has set precedents for regulations and verification of CO<sub>2</sub> storage.
- <sup>33</sup> Umbrella organizations such as the Carbon Sequestration Leadership Forum (CSLF) might help facilitate collaborative research, information exchanges and networking. In particular, the policy group of the CSLF conducts research into legal, regulatory, and intellectual property rights issues that could help inform proposed U.S.-China sequestration collaboration. See <http://www.cslforum.org/index.html>
- <sup>34</sup> These projects could include collaboration over Now Gen (Duke Energy's new Edwardsport IGCC-CCS plant) and Green Gen in China (Huaneng's near-zero emission coal-fired plant). Such cooperation between the world's first two demonstration plants with near-zero emission would help accelerate further deployment, ensure a low-carbon success, create new jobs and demonstrate leadership in both Washington and Beijing.
- <sup>35</sup> Heads of major government agencies in China (NDRC, NEA, and Ministry of Commerce) and Vice-Premier Wang Qishan have argued that the additional heat, energy, and coal requirements for PCC will reduce power output, lower the rate of economic growth, and reduce coal availability for future generations.

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- <sup>36</sup> Richard K. Morse et al., *The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy* (Working Paper #88, Program on Energy and Sustainable Development, Stanford University, 2009), [http://iisdb.stanford.edu/pubs/22621/WP\\_88\\_Morse\\_He\\_Rai\\_CCS\\_in\\_China.pdf](http://iisdb.stanford.edu/pubs/22621/WP_88_Morse_He_Rai_CCS_in_China.pdf).
- <sup>37</sup> MIT Energy Initiative (MITEI), *Retro-Fitting of Coal-Fired Power Plants for CO2 Emissions Reductions* (MITEI, 2009), <http://web.mit.edu/mitei/research/reports.html>.
- <sup>38</sup> China's GreenGen project creates a platform for near-term action. In particular, China has not yet decided on a capture technology; by engagement, the U.S. could help a domestic company land the licensing agreement and contract for construction and integration. This would also be an opportunity for trust building, joint learning, and cooperation that would help with the success of FutureGen, CCPI, and other large RD&D investments in the U.S. A GreenGen/Future-Gen pairing is possible, with money, expertise, and technology flowing between both countries.
- <sup>39</sup> Jupiter Oxygen, telephone interview by Monitor Group, August 26, 2009
- <sup>40</sup> This is one-fourth of the 6,000 MW amount allowed for in the American Clean Energy and Security Act, which reflects the fact that China's per capita emissions are one-third that of the United States.
- <sup>41</sup> See Heleen de Coninck, "Trojan horse or horn of plenty? Reflections on allowing CCS in the CDM," *Energy Policy* 36 (2008), pp. 929-936, for a more complete discussion on the various arguments for or against including CCS into the clean development mechanism.
- <sup>42</sup> A series of documents are now in preparation by the World Economic Forum on financing for low-carbon technologies in the developing world, including China and India. These focus on architecture for the development of a series of OPIC-like development banks for clean energy. These documents will be released at the opening of the U.N. General Assembly in September.
- <sup>43</sup> Pew Research Center for the People and the Press, *A Deeper Partisan Divide over Global Warming* (Washington, DC: Pew Research Center, 2008), <http://people-press.org/report/417/a-deeper-partisan-divide-over-global-warming>.
- <sup>44</sup> See, e.g., Keith Bradsher, "China Builds High Wall to Guard Energy Industry," *New York Times*, July 14, 2009, B1.
- <sup>45</sup> See David Goldman, *Worst Year for Jobs since '45* (CNNmoney.com, 2009), [http://money.cnn.com/2009/01/09/news/economy/jobs\\_december/](http://money.cnn.com/2009/01/09/news/economy/jobs_december/).
- <sup>46</sup> See American Clean Energy and Security Act, H.R. 2410, Section 1120A.
- <sup>47</sup> See, e.g., American Coalition for Clean Coal Electricity, <http://www.cleancolusa.org/>.
- <sup>48</sup> See, e.g., Greenpeace International, *False Hope: Why Carbon Capture and Storage Won't Save the Climate* (Greenpeace International, 2008), <http://www.greenpeace.org/raw/content/international/press/reports/false-hope.pdf>
- <sup>49</sup> Public criticisms have delayed Royal Dutch Shell's efforts in Barendrecht, The Netherlands, and forced the suspension of Vattenfall's Schwarze Pumpe project in Spremberg, Germany. See Fred Pals, "Barendrecht's Stand Up to Shell's Plans to Bury CO2 (Update1)," *Bloomberg.com*, April 20, 2009, at <http://www.bloomberg.com/apps/news?pid=20601109&sid=agmq9zHTafTM>; Terry Slavín and Alok Jha, "Not Under Our Backyard, Say Germans, in Blow to CO2 Plans," *guardian.co.uk*, July 29, 2009, at <http://www.guardian.co.uk/environment/2009/jul/29/germany-carbon-capture>.
- <sup>50</sup> The U.S. has practiced enhanced oil recovery for more than 40 years, storing CO2 underground. It has focused primarily on Integrated Gasification Combined Cycle technology, but also on capturing and sequestering CO2, which involves advanced geological surveying technology. See DOE/NETL, *Carbon Sequestration through Enhanced Oil Recovery* (DOE/NETL, 2008), <http://www.netl.doe.gov/publications/factsheets/program/Prog053.pdf>.
- <sup>51</sup> See American Clean Energy and Security Act, H.R. 2452, Section 115.
- <sup>52</sup> Emma Ritch, *Record 2008 for Cleantech with \$8.4B in Investments* (Cleantech Group, 2009), <http://www.cleantech.com/news/4028/record-2008-cleantech-84b-investments>.
- <sup>53</sup> U.S. Department of Labor, Bureau of Labor Statistics (BLS), *National Employment Matrix* (BLS, 2007), <http://www.bls.gov/emp/empls.htm>.
- <sup>54</sup> SourceWatch, "Coal and Jobs in the United States," in *SourceWatch Encyclopedia* (Center for Media and Democracy, 2009), [http://www.sourcewatch.org/index.php?title=Coal\\_and\\_jobs\\_in\\_the\\_United\\_States](http://www.sourcewatch.org/index.php?title=Coal_and_jobs_in_the_United_States).
- <sup>55</sup> MIT Energy Initiative, *Retro-Fitting of Coal-Fired Power Plants for CO2 Emissions Reductions*, 2009, at <http://web.mit.edu/mitei/research/reports.html>.
- <sup>56</sup> See Douglas Jeavons, et. al., "Employment and Other Economic Benefits from Advanced Coal Electric Generation with Carbon Capture and Storage (Preliminary Results)," *BBC Research & Consulting*, February 2009, at <http://www.americaspower.org/content/download/1459/10428/file/BBC%20FINAL%20020709.pdf>.

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- <sup>57</sup> Indirect jobs are jobs created due to the purchase of goods and services by directly affected industries from other firms as well as purchases by employees of directly and indirectly affected businesses.
- <sup>58</sup> The U.S. share of the jobs created is estimated by multiplying the global job figures by 17.69 percent, which is the U.S. share of emissions resulting from coal consumption in 2006 based on data derived from Energy Information Administration, *International Energy Annual 2006*, at <http://www.eia.doe.gov/pub/international/iealf/tableh4co2.xls>. We expect that our calculations of the U.S. share of global jobs in the five-year and 10-year acceleration scenarios may be an underestimate. To the extent that the United States, as a result of this collaboration and other efforts is seen to be an early mover of CCS development and deployment, the United States may expect to create a larger share of global CCS jobs than other coal consuming countries.
- <sup>59</sup> See McKinsey & Co., "Pathways to a Low Carbon Economy," 2009, at [http://www.mckinsey.com/client/service/ccsi/pathways\\_low\\_carbon\\_economy.asp](http://www.mckinsey.com/client/service/ccsi/pathways_low_carbon_economy.asp).
- <sup>60</sup> Over a 15-year period
- <sup>61</sup> Over a 12-year period (ramping up plant construction is assumed to require an additional 2 years)
- <sup>62</sup> Like the global job figures (see footnote 5 and accompanying text), the U.S. share of the cost savings is estimated by multiplying the global cost saving figures by 17.69 percent, which is the U.S. share of emissions resulting from coal consumption in 2006. Again, as in the job analysis, this may be low estimate as a result of the United States' early movement in developing and deploying CCS technology compared to other coal consuming countries.
- <sup>63</sup> See "Duke Energy and China-based ENN Group Sign Clean Technology Agreement," press release, September 23 2009, at <http://www.duke-energy.com/news/releases/2009092301.asp>; and "Duke Energy Signs MOU with China Huaneng Group to Pursue Renewable and Other Clean-Energy Technologies," press release, August 10 2009, at <http://www.duke-energy.com/news/releases/2009081001.asp>
- <sup>64</sup> See "KBR Awarded Clean Coal Contract by Beijing Guoneng Yinghui Clean Energy Engineering Co., Ltd. for First Commercial TRIG™ Implementation Worldwide," press release, September 18, 2009, at [http://www.kbr.com/news/press\\_releases/2009/09/18/KBR-Awarded-Clean-Coal-Contract-by-Beijing-Guoneng-Yinghui-Clean-Energy-Engineering-Co-Ltd-for-First-Commercial-TRIG-Implementation-Worldwide.aspx](http://www.kbr.com/news/press_releases/2009/09/18/KBR-Awarded-Clean-Coal-Contract-by-Beijing-Guoneng-Yinghui-Clean-Energy-Engineering-Co-Ltd-for-First-Commercial-TRIG-Implementation-Worldwide.aspx)
- <sup>65</sup> See U.S. Senate Committee on Foreign Relations, *Broadening the Bilateral: Seizing the Opportunity for Meaningful Collaboration on Climate Change* (Senate Report 111-24, 2009), <http://foreign.senate.gov/China.pdf>.
- <sup>66</sup> 70 percent of China's emissions currently come from industry, and by 2030, 350 million Chinese, or 1.25 million per month, will move to urban areas, each requiring 3.5 times more energy to sustain than his or rural counterpart. This rise in China's energy demand would account for one-third of the worldwide increases in energy demand from 2005 to 2030. See U.S. Senate Committee, *Broadening*; see also Jerald J. Fletcher and Qingyun Sun, "CO2 Sequestration Options for the Shenhua DCL Plant: A Pre-Feasibility Study," West Virginia University, Natural Resource Analysis Center, April 1, 2007, at [http://www.nrac.wvu.edu/projects/sheia/publications/CarbonSequestration/WVU/Shenhua\\_Sequestration\\_Options\\_AnnexIIactivity\\_01Apr2007.doc](http://www.nrac.wvu.edu/projects/sheia/publications/CarbonSequestration/WVU/Shenhua_Sequestration_Options_AnnexIIactivity_01Apr2007.doc).
- <sup>67</sup> China has been the world's largest coal user since 1986; see Fletcher and Sun, *CO2 Sequestration Options*.
- <sup>68</sup> To meet the demand for electricity that is expected to accompany China's rapid growth, an additional 600 gigawatts of coal-fired capacity (net of retirements) is projected to be brought online in China by 2030. In the near term, the IEO2009 projections show a substantial amount of new coal builds, with 192 gigawatts of capacity additions between 2006 and 2010. See "Chapter 4—Coal," in DOE/EIA, *IEO2009*, 2009, at <http://www.eia.doe.gov/oiaf/ieo/coal.html>.
- <sup>69</sup> If by 2050 every country in the world were to cut its emissions by 80%, China's projected emissions alone—driven primarily by coal—would increase average global temperatures by a dangerous 2.7%. See Massachusetts Institute of Technology, "The Future of Coal: Summary Report," 2007, at [http://web.mit.edu/coal/The\\_Future\\_of\\_Coal\\_Summary\\_Report.pdf](http://web.mit.edu/coal/The_Future_of_Coal_Summary_Report.pdf).
- <sup>70</sup> China has 1.4% of the world's oil reserves and 1.2% of the world's gas reserves; see Fletcher and Sun, *CO2 Sequestration Options*.
- <sup>71</sup> In 2008, sustainable energy investment in China grew to \$15.6 billion, an 18% increase. See Sustainable Energy Finance Initiative (SEFI), "Global Trends in Sustainable Energy Investment 2009 Report" 2009, at <http://sefi.unep.org/english/globaltrends2009.html>. In 2008, sustainable energy investment in China grew to \$15.6 billion, an 18% increase.
- <sup>72</sup> See MIT, *Retro-Fitting*.
- <sup>73</sup> See Gov.cn, *The 11th Five-Year, 2006*, at [http://www.gov.cn/english/special/115y\\_index.htm](http://www.gov.cn/english/special/115y_index.htm), which calls for a 10% reduction in chemical oxygen demand (COD) and SO2 from 2005 levels by 2010.

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- <sup>74</sup> People's Republic of China, National Development and Reform Commission, Implementation of the Bali Roadmap: China's Position on the Copenhagen Climate Conference, 2009), [http://en.ndrc.gov.cn/newsrelease/t20090521\\_280382.htm](http://en.ndrc.gov.cn/newsrelease/t20090521_280382.htm) ("Developed countries shall take responsibility for their historical cumulative emissions and current high per capita emissions to change their unsustainable way of life and to substantially reduce their emissions and, at the same time, to provide financial support and transfer technology to developing countries").
- <sup>75</sup> See U.S. Senate Committee, Broadening.
- <sup>76</sup> Ibid.
- <sup>77</sup> Science and International Affairs, Georgetown University, interview by Monitor Group, July 30, 2009.
- <sup>78</sup> Energy Technology Innovation Policy (ETIP) Research Group, Tufts University, telephone interview by Monitor Group, August 13, 2009".
- <sup>79</sup> See U.S. Senate Committee, Broadening. The report notes the agreement among political and military leaders, energy executives, scientists, students, and environmental experts.
- <sup>80</sup> Ibid.
- <sup>81</sup> GOV.cn, "China calls for more efforts to tackle climate change," July 10, 2009, at [http://www.gov.cn/english/2009-07/10/content\\_1361669.htm](http://www.gov.cn/english/2009-07/10/content_1361669.htm).
- <sup>82</sup> Julian L. Wong and Andrew Light, "China Begins its Transition to a Clean Energy Economy: China's Climate Progress by the Numbers," Center for American Progress, June 4, 2009, at [http://www.americanprogress.org/issues/2009/06/china\\_energy\\_numbers.html](http://www.americanprogress.org/issues/2009/06/china_energy_numbers.html)
- <sup>83</sup> Xinhua, "China injects "green power" into economy," August 18, 2008, at [http://www.chinadaily.com.cn/bizchina/2009-08/18/content\\_8583270.htm](http://www.chinadaily.com.cn/bizchina/2009-08/18/content_8583270.htm).
- <sup>84</sup> See U.S. Senate Committee, Broadening.
- <sup>85</sup> Fu Jing, "Emissions to Peak at 2030: Report," China Daily, August 18, 2009, [http://www.chinadaily.com.cn/china/2009-08/18/content\\_8580379.htm](http://www.chinadaily.com.cn/china/2009-08/18/content_8580379.htm).
- <sup>86</sup> See Wong and Light, China Begins.
- <sup>87</sup> Gov.cn. China Legislature Ends Session, Adopts Armed Police Law, Climate Change Resolution (Gov.cn, 2009), [http://english.gov.cn/2009-08/28/content\\_1403439.htm](http://english.gov.cn/2009-08/28/content_1403439.htm).
- <sup>88</sup> Julian L. Wong and Isabel Hilton. "Hu Speaks- What Next?" Chinadialogue, Sept 24, 2009 <http://www.chinadialogue.net/article/show/single/en/3262-Hu-speaks-what-next>
- <sup>89</sup> In 2005, CCS was integrated into China's "National Medium and Long-term Science and Technology Development Plan towards 2020." In China's 11th Five-Year Plan (2006-2010), the National High Tech Program ("863" Program) also includes support for CCS.
- <sup>90</sup> See Standing Committee of the National People's Congress—Climate Change Resolution, August 27, 2009 at [http://www.npc.gov.cn/huiyi/cwh/1110/2009-08/27/content\\_1516122.htm](http://www.npc.gov.cn/huiyi/cwh/1110/2009-08/27/content_1516122.htm) ("加快应对气候变化领域重大技术特别是节能和提高能效、洁净煤、可再生能源、核能及相关低碳等技术的研发和推广，探索发展碳捕获及其封存..." [English: To accelerate the research, development and deployment of major climate technologies particularly in the fields of energy conservation and energy efficiency, clean coal, renewable energy, nuclear energy and related low carbon technologies; to explore the development of carbon capture and sequestration....])
- <sup>91</sup> The following Web sites provide information about these projects: GreenGen Project, <http://www.green-gen.com.cn/en/index.asp>; TPRI, Key R&D Programs Funded by Government Authorities in Recent Years, <http://www.tpri.com.cn/eng/important.htm>; Shenhua Group Corporation Limited, [http://www.shenhua-group.com.cn/english/kjyf\\_2.html](http://www.shenhua-group.com.cn/english/kjyf_2.html).
- <sup>92</sup> See Friedman, "Sea Change."
- <sup>93</sup> Remarks by David B. Sandalow, U.S. Assistant Secretary of Energy for Policy and International Affairs, at the Center for American Progress, July 22, 2009.
- <sup>94</sup> Unless developed countries set up some sort of new multilateral offset fund to begin paying for those industries that capture and sequester CO<sub>2</sub>, an eventuality which is not soon likely on a meaningful scale.

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