Research Paper No. 2048 (R)

Toward Electric Cars and Clean Coal: A Comparative Analysis of Strategies and Strategy-Making in the U.S. and China

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September 2010

The Fall 09 S373 Bass Seminar
Strategic Thinking in Action – in Business and Beyond

TOWARD ELECTRIC CARS AND CLEAN COAL: A COMPARATIVE ANALYSIS OF STRATEGIES AND STRATEGY-MAKING IN THE U.S. AND CHINA*

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Revised September 2010

*This monograph incorporates contributions of the MBA Class of 2010 students in the 2009 Bass Seminar at the Graduate School of Business, Stanford University. Special thanks go to Debra Schifrin, our Research Associate, as well as to Stanford's Program on Energy and Sustainable Development (PESD) for sharing their most recent research on clean coal in China.

Chapter 1
Introduction

The Fall 2009 S373 Bass Seminar
"Toward Electric Cars and Clean Coal: A Comparative Analysis of Strategies and Strategy-Making in the U.S. and China"

The Bass seminars at the Stanford University Graduate School of Business offer faculty and small groups of students the opportunity to interact in highly focused and intense ways on research topics of common interest. Our S373 Bass seminar "Strategic Thinking in Action – in Business and Beyond," has focused in the last several years on the energy situation facing the United States. The fall 2009 seminar focused on the development and adoption of the electric car and clean coal technologies in the U.S. and China. Together with the seminar participants we wanted to study the current strategies of both countries for dealing with these two issues, and we also wanted to study how they appproach the strategy-making process. This research paper describes the results.

Background for the 2009 seminar theme. In the course of our research for previous versions of the seminar we had been particularly struck by former Secretary of State George Schultz's observation: "Once more we face the vulnerability of our oil supply to political disturbances… How many more times must we be hit on the head by a two-by-four before we do something decisive about this acute problem?" [1] Secretary Schultz's concern strongly resonated with us because it reinforced our own concern with how seven U.S. Presidents since Dwight Eisenhower in the late 1950s had recognized the looming strategic threats of the nation's dependency on foreign oil, yet had allowed that dependency to grow unchecked over the next half century[2].

Our previous research also revealed that the transportation sector is an important consumer of foreign oil and the most vulnerable to a major disruption of the foreign oil supply because of its inability to rapidly shift to other energy sources.[3] Consequently, we focused our fall 2008 seminar research on the strategy and implementation of retrofitting one million pick-up trucks, SUVs and vans in the period 2009-2012 as the first "minimum winning game[4]" of a new U.S. energy strategy aimed at increasing energy resilience.[5]

Comparative analysis of two focal areas in 2009. We viewed retrofitting as a bridge toward moving the transportation sector from internal combustion engine (ICE)-based vehicles to fully electric vehicles. Hence, we wanted to focus part of the fall 2009 seminar on the development and adoption of the electric car. Given the importance of coal in generating electricity, with

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[1] Grove, A.S., Burgelman, R.A., and Schifrin, D. "US Dependence on Oil in 2008 and Beyond: Facts, Figures and Context," Stanford Business School Research Paper Series # 1997, September 2008.

[2] Grove, A.S., "Thinking Strategically," *Wall Street Journal*, January 22, 2007.

[3] Grove, A.S., Burgelman, R.A., and Schifrin, D. "US Dependence on Oil in 2008 and Beyond: Facts, Figures and Context," *ibid*.

[4] The first MWG is limited enough to be won with the available resources within the short-to-medium term, and sufficiently large that winning it provides a foundation for the next, more difficult MWG on the way to achieving the long-term strategic objective (think "base camps" along the route to the top of Mount Everest). Burgelman, R.A. and Siegel, R.E., "Defining the Minimum Winning Game in High-Technology Ventures." *California Management Review*, Spring 2007.

[5] Burgelman, R.A. and Grove, A.S., The Drive toward the Electric Mile – A Proposal for a Minimum Winning Game." Stanford Business School Research Paper Series # 2013, February 2009.

attendant global warming and pollution isssues, we decided to focus the other part of the seminar on the development and adoption of clean coal technologies. Since strategies dealing with the development and adoption of electric cars and clean coal technology will depend heavily on the respective governments, this gave us the oppportunity to do a comparative analysis of the strategy-making of the U.S. and the People's Republic of China (PRC).

In summary, our pedagogical objectives were (i) to carrry out a comparative analysis of strategic industrial techno-economic-political dynamics; (ii) to do so with a focuse on the same problems and in the same time frame in contrasting economic-political systems; and (iii) thereby to provide students with a unique opportunity to learn about *national* and *transnational* governance.

Conceptual Frameworks

We started from the assumption that the various conceptual frameworks that we have applied in previous versions of the seminar at the level of companies and industries could also be usefully appplied at the national and transnational levels, consistent with the principle of "self-similarity across scale;" that is, patterns tend to remain the same regardless of the scale at which one looks at them[6]. In other words, we assumed that these same models might also shed novel light on strategy-making at the national and transnational levels.

Our first conceptual framework distinguishes between *induced* and *autonomous* strategic processes[7]. The induced strategy process exploits opportunities in the familiar environment. The top decision-maker sets the corporate strategy and induces strategic actions that are aligned with it. The autonomous strategy process explores new opportunities that are outside the scope of the existing corporate strategy, relate to new environmental segments, and are often based, at least in part, on new distinctive competencies. Autonomous strategic initiatives often come about fortuitously and somewhat unexpectedly. At the time of their origination, the relationship of autonomous strategic initiatives to the existing corporate strategy is indeterminate. To resolve the indeterminacy by amending the corporate strategy to integrate the autonomous strategic initiative into the induced strategy process going forward (or abandoning it) a process of "strategic context detemination" needs to be activated by senior executives with the support of top management.

Our second conceptual framework derived from our research on "cross-boundary disruptors"[8] to examine the possibility that strategic actions by the government of one nation might effectuate major changes in the strategic situation faced by another nattion. The third conceptual framework drew on research of one of our colleagues about the role of activists in facilitating or impeding radical innovation.[9]

Finally, we introduced a new conceptual framework that distinguishes three stages in technology development and adoption: (1) invention/discovery (from R&D to first pilot plant); (2)

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[6] Gaddis, J.L., *The Landscape of History: How Historians Map the Past*, Oxford University Press, 2002.

[7] Burgelman, R.A., "A Model of the Interaction of Strategic Behavior, Corporate Context and the Concept of Strategy," *Academy of Management Review*, January 1983.

[8] Burgelman, R.A. and Grove, A.S., "Cross-Boundary Disruptors: Powerful Inter-Industry Entrepreneurial Change Agents," *Strategic Entrepreneurship Journal*, December 2007.

[9] Rao, H., *Market Rebels: How Activists Make or Break Radical Innovations*, Princeton University Press, 2009. We thank Professor Rao for allowing us to use two of his book chapters before their publication.

translation/scaling (achieving 5-10 percent of the total market; and (3) becoming the norm (achieving more than 50 percent of the total market).[10] This framework suggests that the major hurdle in the process of technology development and adoption resides in the translation/scaling stage (stage two) and raises the question who will be ready and have the wherewithal to take on this risky task. The translation/scaling stage serves a similiar function as the process of strategic context detemination in the autonomous strategy process.

Application of the Conceptual Frameworks

Self-similarity across scale. As noted above, we assumed that applying conceptual frameworks that are helpful in producing insight in organization-level and industry-level strategic strategic change could also be applied to national and transnational strategy-making.

Induced strategic actions. This part of the strategy-making framework focuses on the comparative analysis of the top-down role of the US Government and the Chinese Government in driving their respective transportation industries toward the use of electricity as the dominant energy source, and their coal industries toward clean coal.

Autonomous strategic actions. This part of the strategy-making framework considers the possibility that the US and/or the Chinese Government will not be the main driver, but that they can advance the transformation - to the electric car and to clean coal - by making bets on novel bottom-up strategic initiatives that are emerging in their respective societies that challenge the existing state of affairs. In light of this, promising private and/local deployment experiments that could accelerate the validation of the viability of the electric car and clean coal would be examined. These experiments might involve collaboration between incumbent organizations, startup-up organizations and supporting governments.

Cross-boundary disruption. This framework considers the possibility that the transformation of the US and Chinese transportation industries and/or the movement toward clean coal will be achieved through market actions of agents of one nation effectuating major change in the industries of the other.

Nonmarket forces (advocay groups). This framework considers the extent to which non-market players - advocacy groups of various sorts - can play a key role in giving support to the electric car and clean coal initiatives, or block whatever movement is gaining momentum.

Technology development and adoption. This framework focuses on examining who, in the U.S and China respectively, will be in a position to be able and willing to drive the scaling of adoption of the electric car and of clean coal technology.

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[10] Grove, A. S., Introductory Lecture, fall 2009.

Organization of the Comparative Studies

We asked the seminar participants to organize themselves into four project teams: (1) Electric car in the US, (2) Electric car in China, (3) Clean coal in the US, and (4) Clean coal in China. Each project team was charterd with using the conceptual frameworks to examine the dynamics that are shaping the rate of adoption of their focal area (electric car or clean coal) in their geography (US or China), and reach conclusions about when and how success of their focal area in their geography will be achieved. Each group was expected to produce a project paper (10-15 pages) presenting and discussing the group's findings.

Structure of the Monograph

The present monograph reports the findings of the four research projects undertaken by the seminar participants, as well as our efforts to develop a more general understanding of governmental strategy-making in the U.S. and China.

Chapter 2 summarizes how we set the stage for carrying out the comparative resarch during the seminar.

Chapter 3 presents, first, a summary of our substantive research findings regarding the different strategies of the U.S. and China with respect to the development and adoption of the electric car and clean coal technologies; and, second, some predictions about the U.S. and the Chinese governments' strategic actions about these two issues in the next five-to-ten years based on our insights into their different approaches to strategy-making.

Chapters 4-7 present the edited project research reports prepared by the seminar participants.

Chapter 8 concludes the monograph. It highlights the importance of recognizing "bounded execution capabilities" in the face of difficult technical challenges associated with electrification of the transportation sector and the development of clean coal technologies, and identifies three conditions for resolving the challenges associated with transnational strategic leadership.

Chapter 2

Setting the Stage for the 2009 Seminar: Preparatory Research

To provide a solid background for ourselves and for the seminar participants, we produced two research notes in advance of the seminar. The first research note covered the global electric car industry, and the second one compared the clean coal strategies of the U.S. and China.[11]

Global Electric Car Industry

In 2009, the U.S. had about 250 million cars on the road, only 40,000 of which were electric vehicles. Most of these had a range of 20 miles, a speed of 25 miles per hour, and were generally used for fleet applications, checking parking meters, and transporting people and clubs across golf courses.

But the global electric car industry was poised to leap forward. Start-ups as well as established automakers were jumping into the electric car, hybrid retrofitting, and battery- making industries. VC firms were investing hundreds of millions of dollars in promising start-ups, while existing companies were spending billions of dollars designing new cars and battery technology as well as building new battery plants. Some companies already had electric cars on the road, while others were pushing to have electric cars and so-called "plug-in hybrid electric vehicles" (PHEV) available by late 2009 or 2010.

The U.S. government in 2008 began to talk about the energy crisis in earnest in response to both skyrocketing gasoline prices and a national mood that favored decreasing the U.S.'s dependence on foreign oil. When President Barack Obama entered office in 2009, he made energy independence one of his core issues, and his administration allocated billions of dollars to promote electric vehicle manufacturing and development of advanced batteries for those vehicles.

The Chinese government in 2008 wanted to turn the country into a global leader in hybrid and electric cars within three years. Within that time, each of the country's passenger vehicle makers would be required to have a licensed new energy vehicle on the market. China also wanted to hit battery capacity that would be equal to 1 million units of battery-powered automobiles in operation. Municipal governments in 13 "test" cities were offering up to $8,800 in subsidies to taxi fleets and local governments for hybrid and all-electric vehicles. Subsidies for private purchases, however, were only expected to be added later in 2009.

Other governments were even more active partners. In Israel, for example, the government was working with Silicon Valley start-up Project Better Place and established car companies Renault and Nissan to bring the electric car to Israel, and had committed to offering substantial tax incentives to consumers who would buy electric cars. Denmark was also working with Renault and Nissan, and with Project Better Place, to build a country-wide electric car network with 20,000 recharging stations powered by wind turbines. In Japan, the government pledged to install

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[11] Schifrin, D., Burgelman, R.A., and Grove, A.S., "The Global Electric Car Industry in 2009: Developments in the U.S., China, and the Rest of the World." Stanford Business School case SM-175, September 2009; and Schifrin, D., Grove, A.S. and Burgelman, R.A., "Clean Coal in the U.S. and China – An Industry Note." Stanford Business School case SM-183, October 2009.

power outlets throughout public areas in certain cities and towns, and planned to encourage private companies to give discounts on loans, insurance and parking to electric car owners.

In light of this state of affairs of the emerging global electric car industry, we wanted the seminar participants to examine how the structure of the electric car industry would likely take shape in the U.S and China during the next decade. We were particularly interested in gaining deeper understanding of the strategy-making process used by each country in pursuing this same issue.

Clean Coal in the U.S. and China

Our research found that the U.S. had the largest recoverable coal reserves in the world, with about 260 billion short tons, enough to last 225 years at 2009 consumption rates. Russia followed with 170 billion short tons, then China with 125 billion short tons. However, China was by far the largest coal producer and consumer; it produced more than two and a half times the amount of coal as the U.S.—the world's second-largest producer—and consumed twice as much. China's coal consumption had skyrocketed since 2000, while U.S. consumption had stayed relatively flat.

Not surprisingly, in 2009 coal was a crucial source of global energy, accounting for almost 30 percent of the world's primary energy production. In the U.S., coal generated about 23 percent of total energy, and 50 percent of electricity. In some parts of the world those proportions were much higher. In China, coal generated 70 percent of the country's total energy and 80 percent of its electricity. China was adding, on average, one new coal-fired power plant every week. However, coal-powered plants were environmentally unfriendly and were cited as a major contributor to climate change. In 2006, global CO_2 annual emissions from the consumption of fossil fuels equaled 29 billion metric tons, 12 billion of which came from coal consumption.

A set of several new technologies referred to as "Clean Coal" had the potential to reduce some of the harmful effects of coal. In 2009 the term "clean coal" usually meant Carbon Capture and Storage (CCS), also called Carbon Capture and Sequestration. In the CCS process, CO_2 was captured by gases produced from fossil fuel combustion, compressed, transported and injected into the ground for permanent storage. A key accompanying technology was Integrated Gasification Combined Cycle (IGCC) which turned coal into synthetic gas (syngas), making it easier to capture CO_2 for storage.

Clean coal plants were expensive to build, with a price tag of $800 million to $1 billion per plant. At the demonstration phase, it cost $130 to keep a ton of emissions from the atmosphere. Theoretically, this could drop by two-thirds once CCS was deployed on a mass scale. Estimates for the amount of CCS investment needed to make a substantial contribution to climate change ranged from $15 billion to $30 billion by 2020.

In addition, the pollution-control equipment could equal the size of the rest of the coal plant. These new machines had to be fed with heat and electricity, which used more fuel. To use CCS, plants needed to increase coal consumption by 20-25 percent to produce the same amount of electricity. Other challenges included CCS technology uncertainty, regulatory uncertainty, and liability issues over sequestration. There was also an argument that making conventional coal plants more efficient would do more to reduce CO_2 emissions than CCS technology.[12]

Clean coal had outspoken advocates on both sides, and had become a hot political topic across the globe. Many environmentalists believed there was no such thing as clean coal, and that the dangers and harmful effects of coal mining and coal-powered plants could not be mitigated by new, as yet unproven, technology. They were also concerned about the safety of storing carbon dioxide underground. However, clean coal was gaining momentum with the aid of many governments; at the Hokkaido Summit in 2008, G8 leaders supported the launching of 20 large-scale CCS demonstration projects around the world by 2010. President Obama had made supporting clean coal an election promise and was putting billions of dollars behind efforts to make clean coal plants a reality.

By the time of the seminar, it was clear that the implementation of clean coal technologies was only in the beginning phase, with construction of new clean coal plants and retrofits for existing plants still in the planning and pilot stages.

In light of this state of affairs, we wanted the seminar participants to examine how the emerging structure of the clean coal industry would likely take shape in the U.S and China during the next decade. We were again particularly interested in gaining deeper understanding of the strategy-making process used by each country in pursuing a similar issue.

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[12] The identification and elaboration of this important point can be found in Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009.

Chapter 3

Summary of Current Strategies and Prognosis of U.S. and Chinese Strategy-Making

The four student reports (chapters 4-7 in this monograph) are studies based on a research design that compared the strategies and the strategy-making processes of the U.S. and Chinese governments with respect to the development and adoption of the electric car and clean coal technologies. The aims of the present chapter are twofold. First, we summarize, in the next section, the substantive research findings of the four studies concerning the current U.S. and Chinese *strategies* with respect to the electric car and clean coal. Second, we further analyze, in the following section, our findings about U.S. and Chinese governmental *strategy-making processes*. Informed by that analysis, we make a prognosis of U.S. and Chinese governmental strategic actions concerning the electric car and clean coal technology in the next five-to-ten years. We end the chapter with some overall conclusions and their implications.

U.S. and Chinese Current Strategies: A Summary of Research Findings

A key premise of our seminar is that the reality of strategy is manifest in *strategic actions* rather than assertions (strategic rhetoric). Hence, we asked the students to pay special attention to strategic actions; that is *consequential actions* demonstrating real commitment[13] on the part of the U.S. and China with respect to the development and adoption of the electric car and clean coal technologies. Below we summarize what we believe are these real current strategies.

Current U.S. strategy related to the electric car and future needs. The study reported in chapter 4 of this monograph confirmed that widespread electric car adoption in the U.S. is necessary to reduce America's reliance on imported fossil fuel, reduce the nation's largest source of carbon emissions, and ensure national transportation security. The study's findings suggest, however, that the government's current strategy, focused on becoming the technology leader in the electric car market, is unlikely to make any significant impact on achieving that result. Instead of such a technology "push" strategy, this study recommends a market "pull" approach, which would entail the government creating incentives for companies to put electric cars in the hands of consumers and for consumers to purchase electric cars. Such policies should include an electric car technology production tax credit, more stringent CAFÉ standards, and on the consumer side, continuing tax credits and non-monetary incentives such as access to HOV lanes. In other words, U.S. government policies should be aimed at building demand for electric cars. Also, the U.S. should invest in Li-ion battery R&D, assure IP ownership, and allow some participation in the advancement of battery technology and production. In addition, the U.S. should clearly target power electronics and systems integration as realistic targets for U.S. leadership.

China's strategy related to the electric car and future needs. In contrast, the study reported in chapter 5 finds only limited support for electric car adoption in China by government agencies such as MIIT and MOST, and essentially none by consumers. Instead, electric car production is an issue of automobile sector competitiveness, as Chinese manufacturers target the U.S. for export of full electric cars as well as batteries. This study also finds that China is well positioned to lead in these areas due to government support for automotive production, China's comparative

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[13] Burgelman, R.A., *Strategy is Destiny: How strategy-Making Shapes a Company's Future*, New York: Free Press, p. 4.; Grove, A.S., *Only the Paranoid Survive*, New York: Double Day, 1996.

advantage in low-cost manufacturing at scale, and leadership in battery technology. In fact, China is now the world's dominant Li-ion battery manufacturer, and the Chinese Academy of Science currently leads the world in energy storage and Li-ion peer-reviewed publications. The leadership position of China is likely to persist as over time Li-ion battery manufacturing will be commoditized.

U.S. strategy related to clean coal and future needs. The study reported in chapter 6 finds that international expectations, activist groups and the desire to continue to utilize its sizeable coal reserves drive the U.S. to investigate the **scaling** of Carbon Capture and Storage (CCS). While the study finds that this technology in its current state appears too expensive to deploy, the U.S. government needs to ascertain the potential learning effects of this technology. To do that requires scaling up of a number of utility-scale demonstration projects. The study argues that data from these projects is extremely important in determining the feasibility of future actions, and should be shared as broadly as possible among domestic technology developers and selected international partners.

China's strategy related to clean coal and future needs. Again in contrast, chapter 7 reports that up to this point, China has only pursued energy initiatives that provide immediate economic benefits, reflecting the clear priority of that country on economic growth and its impact on social stability. Based on recent research by the Program on Energy and Sustaintable Development at Stanford (PEDS),[14] this study reports that China will be very unlikely to implement carbon capture and sequestration unless it is funded by the West. China's desire for cheaper energy has lead to the building of high-efficiency ultra-supercritical plants, which make a contribution to clean coal developments. The study reported in chapter 7 suggests that given these complementary approaches, effective U.S.-China collaboration and information exchange needs to be a central part of the two societies' efforts. Independently, the study also found that the Chinese government is not a monolithic entity. Consequently, successful collaboration will depend on the ability to identify and work with the appropriate governmental agencies – regional, central – that are more in tune with this approach.

U.S. and Chinese Strategy-Making Processes: A Prognosis

Our four studies also provided insight in the *strategy-making processes* of the U.S. and China. The differences between the strategy-making processes of the two nations can be further discussed in terms of two key dimensions: (1) the degree to which top management's strategic decision-making power is concentrated rather than distributed throughout the organization, and (2) the degree to which top management is able to get all the relevant parties to execute

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[14] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009.

simultaneously rather than sequentially. Appendix 1 briefly discusses four types of strategy-making processes generated by these two dimensions.[15]

Using these two dimensions of strategy-making processes and taking into account the contextual differences facing the U.S. and Chinese governments, we develop the following predictions about the evolution of the strategy-making processes of each government in relation to the development and adoption of the electric car and of clean coal technologies.

Future U.S. strategy-making related to the electric car. Having currently some 250 million cars on the road implies enormous U.S. dependence on foreign oil. Hence, the electrification of the transportation industry is inexorably becoming a high national security priority. The urgency of this, however, will depend critically on the price of foreign oil. Hence,

> <u>Prediction 1a</u>: If the price of oil moves and stays above $150/Bbl, a clear and present national security threat will move the U.S. government to concentrate strategic decision-making and to force all relevant parties to simultaneously help implement a national strategy of scaling up electrification of the transportation sector in the next 5-10 years (a move toward the “rational actor” model).
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> <u>Prediction 1b</u>: If the price of oil stays below $150/Bbl, the U.S. government will continue to allow strategic decision-making to remain widely distributed with various interested parties simultaneously competing for government resources in the next 5-10 years (stick with the “internal ecology” model).

Future Chinese strategy-making related to the electric car. Chinese strategy-making with respect to electrification of its transportation sector is likely to be triangular in the next five-to-ten years. Firstly, through past investments China has achieved world leadership in battery technology and manufacturing, which provides it with a competitive advantage to capitalize on the potentially enormous opportunity of supplying the emerging global electric car industry. Hence,

> <u>Prediction 2a</u>: The Chinese government will concentrate strategic decision-making power and vigorously orchestrate simultaneous action of all relevant parties involved in implementing an export strategy to supply batteries to the U.S. and Europe as these regions are forced to scale up their electric car industries in the next 5-10 years (move toward the “rational actor” model).

Secondly, as it becomes an industrial and military superpower, needs to develop higher-value employment opportunities for its vast and increasingly educated labor force, and needs to accommodate the population’s demands for affordable means of transportation, China will be

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[15] These are: (i) the “rational actor” model (concentrated strategic decision-making and simultaneous action), (ii) the “bureaucratic” model (concentrated strategic decision-making and sequential action), (iii) the “internal ecology” model (distributed strategic decision making and simultaneous action), and (iv) the “garbage can” model (distributed strategic decision-making and sequential action).

strongly motivated to develop its own internal combustion (ICE)-based automotive industry. Hence,

> Prediction 2b: The Chinese government will concentrate strategic decision-making power and vigorously orchestrate simultaneous action of all relevant parties involved in implementing the development of an automotive industry that can market very cheap (<$3,000) ICE-based cars to its own population and perhaps other parts of the developing world (Vietnam, Thailand, and others) in the next 5-10 years (move toward the "rational actor" model).

Thirdly, having only some 37 million cars on the road for a population 4.5 times that of the U.S. implies that electrification of the Chinese transportation sector is still a very low priority. This suggests that the strategy-making process of China will most likely not pay much attention to electric car adoption in the foreseeable future. Hence,

> Prediction 2c: If the price of oil moves and stays above $150/Bbl, the Chinese government will continue to concentrate strategic decision-making power with respect to electrification of the transportation sector but will also allow the various government bureaucracies to compete among each other for resources and influence, which will delay adoption of the electric car during the next 5-10 years (stick with the "bureaucratic" model).

Future U.S. strategy-making related to clean coal. With enormous domestic coal reserves and very large reserves of natural gas, the U.S. government does not face a clear and present danger resulting from foreign resource dependence for its energy needs (beside transportation). There is, however, growing activist pressure to reduce CO2 emissions. Hence,

> Prediction 3: The U.S. government will weakly concentrate strategic decision-making power and weakly orchestrate scale-up of clean coal technologies for the next 5-10 years (continue with a "half-hearted rational actor" model), unless some serious externality (e.g., a natural catastrophe) forces strong commitment (and a move toward the "rational actor" model).

Future Chinese strategy-making related to clean coal. With 70-plus percent of its energy generation derived from coal, and with still lower energy intensity than the U.S., China has no strong motivation to pursue clean coal with its own resources. It can play a "game of chicken" with the developed world in order to obtain such resources. It helps the central government to keep this game going by allowing different of its various bureaucracies to battle for getting external resources. Hence,

> Prediction 4: The Chinese government will concentrate strategic decision-making but will also allow the various government bureaucracies to compete among each other for resources, which will delay adoption of clean coal during the next 5-10 years (stick with the "bureaucratic" model), unless the U.S. and Europe are willing to provide China with

significant financial incentives to scale up somewhat faster (move toward a "half-hearted rational actor" model).[16]

Conclusions and Implications

Based on our analysis of current U.S. and Chinese strategies and our prognosis about the strategy-making process of each country with respect to the development and adoption of the electric car, our overall conclusion is that the transformation of the U.S. transportation sector is likely to continue during the next 5-10 years, but probably more slowly than currently anticipated. The key driving force will not be the U.S. government, but rather major incumbent automakers, such as Nissan and Renault, who have secured internal access to critical new battery technology as well as cooperative agreements with national, regional and local governments in different parts of the world which are important for supporting infrastructure development. Only if oil prices again rise rapidly and stay at very high levels will the electric car adoption process in the U.S. accelerate. In that case, the early global movers may have significant advantages, based on economies of scale and economies of learning, to capitalize on a rapidly expanding US market opportunity. We also conclude that the Chinese electric car market opportunity during the next 5-10 years will remain quite small, but that the leadership of Chinese companies in battery technology and manufacturing will open up strong export opportunities if indeed the US electric car market takes off more rapidly.

Similarly based on our analysis of current U.S. and Chinese strategies and our prognosis about the strategy-making process of each country with respect to the development and adoption of clean coal technologies, our overall conclusion is that nothing will force global action and that, consequently, the major moves toward reduction of emissions will not happen in the next decade. This conclusion seems to be in line with the outcomes of the United Nations climate summit in Copenhagen last December, viewed by many as disappointing.[17] The last-minute accord, driven particularly hard by President Obama right before returning to Washington D.C., contains no deadline to draft a legally binging treaty, no clear requirements to cut emissions, and only vague references to helping countries cut back on deforestation. China, among other major developing nations, resisted calls to cap their emissions and agreed only to continue those domestic environmental initiatives that they view to be in their economic interest.

While it is frustrating to have to come to grips with the slowness with which large-scale global change is likely to happen, it should perhaps not be surprising. One of the clear lessons from our studies is that "self-similarity of scale" with respect to strategy-making processes - i.e., the applicability of organizational-level conceptual frameworks to the national and transnational levels - breaks down at the transnational level because, in contrast to the organizational and nation levels, there is no natural "peers-plus-one" mechanism in place to force change on the

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[16] This prediction is again usefully informed by the conclusions reached in Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009.

[17] See, for instance, Ball, J. "Summit Leaves Key Questions Unresolved – U.N. Effort in Copenhagen Sets Stage for Further Haggling Over Emissions Caps, Funds for Poor Nations, *Wall Street Journal*, December 21, 2009, p. A17.

different independent parties involved.[18] Only when one of the independent nations is able to contribute a disproportional amount of key resources needed for the collectivity's shared interests to prevail in the face of a "clear and present danger" does a transnational strategic decision-making authority inexorably arise. This type of situation was evident, for instance, in the changing strategic relationship between the U.S and the U.K. during WWII:

> "The American emphasis on the war in the west was also finally becoming pronounced. (…) As well as producing armaments for herself, the United States also produced 27 percent of all munitions used by Commonwealth forces in 1943 and 1944. Overall, Lend-Lease aid to the UK reached a total value of $27 billion, plus an added $6 billion of purchases made in the US before the Act was passed. *It was another factor giving ever increasing weight to Roosevelt's and Marshall's views in the councils of the Western Allies over those of Churchill and Brooke*." [19]

However, to the extent that independent nations realize that strategy involves maintaining a favorable balance between their dependency on external forces and their capacity to influence these forces[20] - in order to avoid strategic subordination - they will try to avoid the circumstances leading to the emergence of a transnational strategic decision-making (peers-plus-one) authority.

At least some observers believe that this is the sort of resistance that the U.S. is experiencing at the end of the first decade of the 21st century.[21] While it may be too soon to write off the U.S. as the leading nation of the world - it clearly retains strategic dominance in certain areas - it will nevertheless be necessary for its government to devise innovative approaches for dealing with situations that increasingly involve real strategic interdependence.

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[18] Grove, A.S. and Burgelman, R.A., "Modeling Nation-Level Strategic Change," Unpublished manuscript, April 2009.

[19] See Roberts, A. *Masters and Commanders: How Four Titans Won the War in the West, 1941-1945*, New York: Harper Collins, p. 468 (emphasis added).

[20] Burgelman, R.A. Strategy *is Destiny: How Strategy-Making Shapes a Company's Future*, New York: Free Press, 2002, p. 362.

[21] Rachman, G. "America is losing the free world." *Financial Times*, January 5, 2010, p. 9.

Appendix 1: Models of Strategy-Making in Complex Organizations

In chapter one, we discussed a model of the organizational strategy-making process that distinguishes between induced and autonomous strategic initiatives to compare strategy-making in the U.S. and PRC. As noted there, top management sets the corporate strategy and induces strategic actions by lower-level leaders that are aligned with it in order to exploit opportunities in the familiar environment. The autonomous strategy process, in contrast, explores new opportunities that are outside the scope of the existing corporate strategy, relate to new environmental segments, and are often based, at least in part, on new distinctive competencies. An important top management responsibility and challenge is to balance resource allocation to the induced and autonomous strategy processes over time; in particular the scaling up and vectoring of resources related to autonomous initiatives that demonstrate viability (a process we call “strategic context determination”).

Taking into account the existence of induced and autonomous strategy processes, the overall strategy-making process of a complex social system can be further characterized in terms of two key dimensions: (1) the degree of *concentration (versus distribution) of strategic decision-making powe*r, and (2) the degree to which *strategy execution involves all relevant parties simultaneously (or sequentially)*. The combination of these two dimensions makes it possible to integrate into one conceptual framework four organizational decision-making models previously developed in the literature. Figure 1 shows these four strategy-making processes.

Figure 1: Models of Strategy-Making*

		Strategic Decision-Making Power	
		Concentrated	**Distributed**
Mode of Execution	**Simultaneous**	**RATIONAL ACTOR Model****	**INTERNAL ECOLOGY Model******
	Sequential	**BUREAUCRATIC Model*****	**GARBAGE CAN Model*******

*Burgelman, R.A., *Strategy is Destiny: How Strategy-Making Shapes a Company’s Future*, New York: Free Press, 2002: 4-6.

** Also called “Model I” in Allison, G. and Zelikow, P., *Essence of Decision: The Cuban Missile Crisis*, 2nd. Ed., New York: Addison Wesley Longman, 1999.
*** Also called “Model II” in Allison and Zelikow, *ibid*.
**** Burgelman, R. A., “Internal ecology of strategy-making and organizational adaptation: Theory and field research.” Organization Science, 1991: 239-262. The internal ecology model is perhaps closest to Allison and Zelikow’s Model III: “governmental politics.”
*****March, J.G. and Olsen, J.P., *Ambiguity and Choice in Organizations*, Bergen, Universitetsforlaget, 1976.

Rational actor model. A comprehensively rational top management (individual leader or leadership team) formulates the overall strategy and is able to get all the interdependent actors in the organization to simultaneously engage in the actions necessary to implement it. In this model, there is strong alignment between strategy and action. It is often viewed as the ideal type. However, it may be most effective to respond to environmental dynamics that can be reasonably well anticipated and influenced. It may also be the best model for coping with a “clear and present danger” or for exploiting an extraordinary opportunity. While a comprehensively rational top management is in principle able to effectively balance induced and autonomous strategy processes for some period of time, they are likely to eventually start favoring the induced strategy process.

Bureaucratic model. In this model the overall strategy is still formulated by a comprehensively rational top management, but implementation is less immediate because various parts of the organization are independent of each other and translate the strategy in terms of the logic of their own operations before taking action to implement it. This model has advantages in slow moving environments because each part of the system has time to optimize its strategic actions in light of the overall strategy. In rapidly changing environments, however, it will lead to sluggish execution of the overall strategy. While autonomous strategic initiatives will undoubtedly spring up in different parts of the system, scaling them up will be difficult. By default, the induced strategy process will become dominant.

Internal ecology model. This model views organizational-level strategy as the result of successful strategic initiatives of interdependent actors (individuals or groups), who are in a position to commit the organization and who continuously try to do so. In this model, strategy-making is a highly dynamic process that capitalizes on anticipated and unanticipated variations in the internal and external environments. It views the strategy-making process as constituting an opportunity structure for strategic leaders in the organization, but one in which individual opportunity seeking is constrained, to some extent, by the imperative of organizational survival. This model is most effective in highly uncertain, opportunity-rich environments. The autonomous strategy process is likely to be dominant here. Coherence of system-level strategic action depends on the characteristics of the internal selection environment.

Garbage can model. In this model, strategy-making results from various independent actors taking action as a function of the sequence in which problems, solutions, and decision opportunities arise. The effectiveness of system-level strategic action depends on the sequence in which problems, solutions, and decision opportunities arise. There is neither an explicit or implicit overall strategy, nor a clear ecological survival force, serving as reference point for determining whether an initiative is induced or autonomous. Hence, by default the autonomous strategy process dominates. Arriving at a coherent overall strategy for the organization is to a large extent governed by chance. The normative implication of this model is to “just hang in there and keep trying.”

We realized that this conceptual framework might be useful to predict U.S. and Chinese government strategy-making in the two energy-related areas.[22]

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[22] Note that in the context of our four studies we did not encounter applications of the garbage can model. However, regarding other alternative energy sources, numerous experiments in solar, wind, nuclear, coal sequestration, and so on, continue with no clear winner in sight. Our prediction therefore is that the U.S. government will remain stuck in the “garbage can” model; that is, the government will keep supporting, on a relatively small scale, various technological advances as they come along, but without making any major commitments.

Chapter 4

OUTLOOK FOR ELECTRIC VEHICLES IN THE UNITED STATES*

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* This chapter was prepared by Amal Dorai, Sam Fort, Boris Gimond, Eli Gregory, Ben Lenderman, Elizabeth Martin and Graeme Waitzkin.

OVERVIEW OF US AUTOMOBILE INDUSTRY

The American transportation industry today faces a perfect storm of economic, geopolitical, and environmental concerns that threaten its future. The decline of the US automobile industry, the country's increasing dependence on foreign oil imports, and global warming have spurred the Obama Administration to publicly commit the country to developing alternative transportation methods and alternative energy sources as a way of combating these problems and setting a new path for the US transportation sector and economy as a whole.

The most-discussed aspect of the United States transportation sector is the 50-year decline of the Big Three automakers (GM, Ford, and Chrysler) relative to Japanese and European manufacturers. In 1961, the Big Three sold 85 percent of new passenger cars in the US; by 2008, that had declined to 47 percent. This decline is a longstanding phenomenon, and the recent bankruptcies are only the most catastrophic symptom of a problem that should have been dealt with decades ago. However, even in its current wounded state, the American automobile industry is "too big to fail." Automobile sales are $740 billion per year, which represents 5.6 percent of the total economy; when including indirect effects of the industry such as parts sales and support industries, the automobile sector is fully 8-10 percent of the US economy. The consequences of a total industry failure would devastate not only the major automobile states in the Midwest and South, but would quickly spread to the entire economy in its currently vulnerable state.

The geopolitical concerns around the politics of oil are as important as economic considerations in shaping American policy. US oil production has fallen 45 percent since 1985, while imports have risen 320 percent, coming mainly from the Middle East. In 1985, domestic production was 9 million barrels per day and imports were 3 million barrels; today, production is 5 million barrels and imports are 10 billion barrels. The entire US economy is essentially at the mercy of the Middle Eastern OPEC countries.

Finally, the worldwide issue at the center of transportation is the inexorable march of global warming, and the difficulty of coordinating strategies to combat it before it drastically impacts quality of life on this planet. The contentious issue in this arena is between the largest polluters, some of whom are highly developed economies (most notably, the US) and some of which are developing economies (most notably, China). Each of these blocs demands that the other take a leadership role in sacrificing short-term economic growth to address global warming, and the stalemate has delayed any meaningful actions by the global community.

Electric transportation has been put forward as a way of addressing all three of these problems. Internal combustion engines deliver only 20 percent of their consumed energy to their wheels, and can only consume oil-based fuels, while electric vehicles are themselves nearly 90 percent efficient, and are limited only by the efficiencies of the many methods used to generate the electric power used.[23] Costs of electric cars have come down dramatically since the failed late 1990s EV-1 experiment by General Motors, led largely by improvements in lithium-ion batteries which are expected to continue at an ~8 percent pace per year.[24] Even if coal, the dirtiest power

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[23] Tesla Motors.

[24] Jefferies & Co. Equity Research.

generation technology, is used to generate the electricity used, electric cars cause only half the CO2 emissions of a modern hybrid-electric vehicle like a Toyota Prius. If renewable energy is used to power the car, the transportation can literally be emissions-free. It is this promise of creating a new industry to boost economic growth, while also reducing emissions, which can break the traditional economic/environmental “tradeoff” and create a win-win situation for the country that assumes leadership in electric transportation.

We believe that the electrification of the transportation industry will happen whether or not the US is involved, and that electric vehicle adoption can and will be a strategic component of the United States’ strategy as an economy and a nation. However, the federal government will have to combine a strong long-term vision with tactical execution skills in many different arenas to ensure that America takes a leadership position in this nascent but critical electric vehicle (EV) sector.

STATED GOALS OF US GOVERNMENT

In August 2009, when talking about the Recovery Act, Energy Secretary Steven Chu clearly outlined the three main goals pursued by the government in its energy policy “These are incredibly effective investments that will come back to us many times over – by creating jobs, reducing our dependence on foreign oil, cleaning up the air we breathe, and combating climate change.”[25]

Ensure energy and oil independence in America

A few days after going into office, on January 26 2009, President Obama called for the country to become energy independent, saying the reliance on imported oil posed threats to the country’s security.[26]

However, recent history has shown that the goals stated by the governments can be significantly different from the outcomes in terms of energy dependency. In response to the 1973 oil crisis, US President Richard Nixon launched a foreign oil imports reduction program called Project Independence. However, instead the US has steadily increased its oil imports as a percentage of consumption, and today oil represents over $500 billion per year in imports, or nearly 5 percent of annual US GDP that we are essentially sending abroad.

Increase GDP

The recent crisis of the automobile industry has raised the question of the viability of manufacturing cars in the US. The massive subventions allocated by the Recovery Act to domestic electric car projects tend to prove that the current administration heavily relies on this technology to at least maintain the automobile industry’s contribution to the GDP. "For our nation and our economy to recover, we must have a vision for what can be built here in the future

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[25] US Department of Energy.
[26] www.Whitehouse.gov.

- and then we need to invest in that vision," said Vice President Biden. "That's what we're doing today and that's what this Recovery Act is about."[27] .

Furthermore, by subsidizing a number of battery manufacturers, the Government has demonstrated its vision that new economic giants will potentially emerge from the electric car supply chain.

Reduce emissions

A few days before the opening of the Copenhagen Climate Conference, US officials announced that the country will reduce its emissions "in the range of" 17 percent below 2005 levels by 2020, giving the world the clearest blueprint yet of US strategies to cut back.

To support this goal, President Obama has, among other initiatives, set the objective of putting one million plug-in hybrid vehicles on the road by 2015.

EVs TO HELP ACHIEVE THESE GOALS

To solve the enormous transportation and energy security problems America currently faces, we believe the solution is to drive the transition from an ICE-based transportation system to an electric vehicle-based one. The development of a strong EV industry in America accomplishes the stated goals above in three ways.

First, a conversion to electric vehicles eliminates America's reliance on other countries for oil imports. With EVs, the US can fuel its vehicles with electricity instead of petroleum. All of the power generated can come from within America's borders, given the strong supply of electricity generating resources. Simultaneously we can drastically reduce the current account deficit and reduce the potential threat of oil-producing countries to national security.

Second, if the US is able to become a leader at producing EVs domestically, America will be able to re-establish its power as a manufacturing center and create thousands of jobs to replace the ones that were lost in the recent recession. Given how important the auto industry is to the United States, being a leader in the auto sector with innovation in electric vehicles will be an important boost to America's economy.

Third, a conversion to electric vehicles will have an enormous positive effect on reducing CO_2 emissions, as EVs are far less polluting than their ICE counterparts. The emissions produced by an ICE vehicle amount to approximately 1.3 billion tons of CO_2 per year. Assuming electricity is produced by our current mix of generation assets (48 percent coal, 22 percent gas, 30 percent other), an all-electric vehicle fleet would emit approximately 460 million tons of CO_2, or 2/3 less than ICE-based vehicles. Furthermore, if this electricity is produced from renewable sources such as wind and solar (such as is the plan for Better Place), the emissions from EVs drop to zero. Besides cleaning smog-filled skies and reducing the effects of global climate change, we

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[27] Recovery Act Announcement, US Department of Energy.

also have the opportunity to assert America as an environmental leader and lead by example for other countries that are contemplating their own policies to combat climate change.

EV Economics

The most significant driver of demand for EVs in our view is making electric vehicles cost–effective compared to the current ICE alternatives. As such there are two main variables that will drive the value proposition of EVs to consumers: the price of batteries, which is the most significant single expense currently in building an EV (~40 percent for the Nissan Leaf), and oil prices, which is the most significant recurring cost for automobiles. We see three potential scenarios for the direction of these variables going forward.

Scenario 1: Status Quo

In our first scenario, battery prices stay where they are today (approximately $750/kWh) and oil prices remain low ($50/barrel, or approximately $2/gallon at the pump). This is an approximation for the status quo. As shown in **Exhibit 1**, Scenario 1, in terms of cumulative annual cost of ownership, this scenario is never compelling for a consumer as prices for a hybrid or fully-electric vehicle is never cost-competitive with the ICE alternative.

Scenario 2: Status Quo Battery, Oil Price Spike

In our first scenario, battery prices stay where they are today (approximately $750/kWh), however oil prices spike to approximately $150/barrel (~$5/gallon at the pump), or close to where prices were in the middle of 2008. As shown in **Exhibit 1**, Scenario 2, in terms of cumulative annual cost of ownership, cumulative annual cost of ownership for EVs and PHEVs eventually becomes more compelling than ICE cars, however the breakeven point is 5 or more years out, which may not be compelling enough to drive consumer adoption.

Scenario 3: Battery Technology Breakthrough

In the second scenario, oil prices remain low ($50/barrel), however innovation in battery development leads to a breakthrough that drops battery prices to half of what they are today (to approximately $375/kWh), which is a price that we believe is very achievable in the next several years given historical cost reductions and current innovations in development. As shown in **Exhibit 1**, Scenario 3, cumulative annual cost of ownership for EVs and PHEVs eventually becomes more compelling than ICE cars, however the breakeven point is 5 or more years out, which in our view is likely not compelling enough to drive widespread consumer adoption.

Scenario 4: Battery Technology Breakthrough and Oil Spike

In our final scenario, we continue to assume that innovation leads to $375/kWh battery prices, however in this case through increases in oil prices driven by supply/demand imbalances and/or an additional carbon/gas tax in America, price at the pump goes to $5/gallon (equivalent to ~$150/gallon oil). As in **Exhibit 1**, Scenario 4, cumulative annual cost of ownership is significantly favorable for EVs and PHEVs, with a breakeven point of less than 2 years. This value proposition we believe is extremely attractive to customers and would lead to virtually a complete transition to EVs from ICE.

INDUCED ACTIONS TO SPUR EV INDUSTRY

The analysis above shows that the current cost of batteries is prohibitive for mass consumer adoption. Analysis by the Rocky Mountain Institute (RMI) yields an experience curve for production of lithium-ion batteries, however.[28] As manufacturing increases, “learning by doing” will result in a significant price drop: the cost of these batteries is expected to drop by half over the next ten years. Although batteries are prohibitively costly at the present, increased production will drive the industry down this experience curve. As prices drop, demand will continue without additional government incentives. Support will be needed to bring the industry to this point.

From innovation to mass adoption

At a high level, the automotive industry can be divided into four phases:
1. Research and development
2. Product scaling
3. Mass production
4. Consumer adoption

To drive the industry and allow for technical leadership, financial support is needed at every level. Seed money is needed to fund R&D and break current technology barriers, and fuel efficiency regulations are necessary to drive automakers research initiatives on their own. As new technologies are developed, automakers will require additional funding for the capital-intensive scaling process. As the market is ready for mass adoption, funding will be required for mass manufacturing facilities. Finally, incentives will be needed on the consumer side to increase adoption. The United States government currently has initiatives along these four stages. Here we review the induced and autonomous initiatives in place and compare them to relevant private and public spending on similar programs.

Seed phase: Research and Development

At the seed stage, government funds have been provided for battery research and development. The DOE has allocated $11M in funding for division among seven battery technology start-ups and universities, for improvement of battery material performance and decreasing cost (See **Exhibit 2** for breakdown).

To bring this amount in perspective, leading battery manufacturer A123 received $32 million in their first round of funding alone. They have received over $200 million in funding to achieve their position in the battery industry today. Manufacturers such as Ford and Toyota typically

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[28] Anderson, D., “Status and Trends in the HEV/PHEV/EV Battery Industry,” presentation at U.C. Berkeley in Summer 2008, Rocky Mountain Institute.

spend from \$5 - \$8 billion annually on R&D.[29] Compared to these figures, \$11 million is not significant.

In addition to providing seed money, the government can stimulate interest in R&D by providing production incentives such as CAFE multipliers. Under new federal regulations, vehicle manufacturers will have to meet fleet averages of 35.5 mpg for all new cars sold. As the current average fuel economy of new vehicles sold is roughly 27 mpg, this will require investment in new technologies for improvements in fuel efficiency. An “EV multiplier” is currently being considered for these standards. Under this system, PHEVs and EVs would be averaged in as 0 mpg vehicles (despite having zero emissions), and the number of EVs produced would be multiplied by 1.2 or 2 to determine the fleet average fuel efficiency. The multiplier would provide an additional incentive for manufacturers to incorporate these vehicles into their product lines, despite their high cost.

It is estimated that it will cost auto manufacturers an average of \$1,100 per vehicle to improve a traditional internal combustion vehicle to meet these standards.[30] The average additional production costs of a PHEV with a 40 mile range are \$9,262; those of an EV with 100 miles of range are \$15,860. If an automaker decided to meet the new standards by adding PHEVs and EVs to his fleet (while keeping the efficiency of all other vehicles the same), the number of vehicles they would need to add depends on the CAFE multiplier. The table illustrates this effect below.

	CAFE multiplier		
Vehicle type	1	1.2	2
ICE	75%	79%	86%
PHEV/EV	25%	21%	14%

As a lower number of non-traditional vehicles will be needed with these multipliers, the average cost to meet the standard per vehicle will be reduced. The effect of the multipliers on average cost can be seen in the table below, in addition to the chart in **Exhibit 3.**

	CAFE multiplier		
Cost	1	1.2	2
ICE	\$1,100	\$1,100	\$1,100
PHEV-40	\$2,270	\$1,972	\$1,293
EV-100	\$3,887	\$3,377	\$2,215

Maintaining a fleet of traditional internal combustion engine vehicles results in average costs of \$1,100 per vehicle. Meeting the standards by adding PHEVs or EVs to a fleet is much costlier in all three multiplier scenarios. It can be assumed that with current battery prices, CAFE multipliers will not provide sufficient incentives for an increase in EV production.

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[29] “Viknesh VIjayenthiran,” Ford’s R&D budget second biggest in the world,” *Motor Authority,* October 8, 2007, Ford 2009 annual report, Toyota Motor Corporation.

[30] Ken Bensinger, “Obama Administration Unveils Fuel Economy Rules,” *Los Angeles Times,* September 16, 2009.

Product Scaling and Mass Production

Scale becomes the next phase of development. Under the Advanced Technology Vehicle Manufacturing Program, the US DOE allocated funds to develop manufacturing facilities for advanced vehicles and components. Of these funds, $2.6 billion was allotted for electric vehicles, including $529 million for Fisker facilities and $465 million for Tesla. Of the money allocated to Tesla, $100 million will go towards battery manufacturing facilities, allowing production of 30,000 units per year by 2013.[31] Loans provided to Fisker will allow for production of 15,000 cars per year.[32] With annual U.S. auto sales of more than 10 million vehicles, 30,000 units will amount to less than 3 percent. (See **Exhibit 4** for a breakdown of Advanced Technology Vehicle Manufacturing allocation).

In addition to these loans, government funds of $2.5 billion have been provided for battery and advanced vehicle manufacturing facilities. Under the same program however, $5.9 billion in loans were allocated to Ford alone for manufacturing of advanced internal combustion engines.

Consumer Adoption

The final stage of industry is consumer adoption. DOE and the National Renewable Energy Laboratory (NREL) studies have shown that only 14 percent of consumers systematically consider fuel economy economics when purchasing new vehicles.[33] Other studies have shown that when consumers do consider fuel savings, it is often over a time span of only a few years,[34] as opposed to 10 years or the full life of the vehicle. EVs currently have a higher up-front cost, but allow for fuel savings throughout the vehicle life. The failure of consumers to consider potential savings provides a significant barrier to adoption, requiring government intervention to support the industry.

Support in this area can be provided in the form of purchase tax incentives, infrastructure investments, funding for government fleet purchases, and non-monetary consumer incentives. Of the 2009 Federal Stimulus package, $2 billion was provided for individual purchase tax incentives. Individual private purchase incentives for PHEVs and EVs come to $7,500 per vehicle; an additional $600 million was allocated for purchase of government vehicles.

An analysis of the effect of the tax credits can be done by assuming that consumers will change purchase decisions when the net-present value (NPV) over five years is roughly $1,000. It is assumed that the point at which they will switch is normally distributed around this value, as consumers consider several other factors in the decision to purchase a vehicle. The distribution

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[31] Josie Garthwaite, "Tesla Wins $465M in DOE Loans; Nissan Gets $1.6B for Electric Cars," earth2tech, June 23, 2009.
http://earth2tech.com/2009/06/23/tesla-wins-465m-in-doe-loans-nissan-gets-1-6b-for-electric-cars/

[32] Josh Mitchell and Stephen Power, "Gore-Backed Car Firm Gets Large U.S. Loan," *Wall Street Journal*, September 25, 2009.

[33] David L Green, "The Market for Fuel Economy: How Does it Work?" *BESD Seminar.* Oak Ridge National Laboratory, 2008.

[34] Ibid

and cumulative density function of an assumed demand function is shown in **Exhibit 5**. Given this assumption and the learning rate assumptions from RMI as stated earlier, calculations show that the price effect of the tax credit will significantly affect adoption, as shown in the charts in **Exhibit 6**.

Adoption in this scenario has a snowball effect: as increased demand drives increases in manufacturing, battery prices drop, thereby increasing demand. Based on this analysis, we determine that the purchase tax incentives of $7,500 per vehicle will have a significant influence in increased adoption.

AUTONOMOUS ACTIONS TO FURTHER INDUCED ACTIONS

Induced actions from the US government will help in terms of providing the funding and political support necessary to drive the EV industry forward in America. However these measures are meaningless without complementary autonomous actions from startups, private investors, and industry players that will build the companies and technologies we need to drive our electric vehicle future. More specifically, we must have the support of the following constituents: venture capital and private equity investors, auto OEMs, U.S.-based battery companies, and infrastructure players such as major US utilities.

Venture Capital Investing

The autonomous actions of venture capital and private equity investors are crucial to the success of the EV industry in America, as these firms will be the leaders in identifying the technologies and market segments where there exists the greatest potential for value creation in the US economy. Venture investors have been focused on the electric vehicle and advanced battery market since early this decade, however given the capital intensive nature of these businesses, many fewer startups in these sectors have been funded compared to less capital intensive internet and software startups. Venture investing in lithium-ion batteries, the only proven form of advanced battery for EV, has been relatively modest compared to investment in other industry segments.

The future prospects for private investors to increase funding in EVs and advanced batteries is improving given government grants and loan guarantees, however our judgment is that investors will need to see several high-returning exits in this industry before they commit significant additional capital to these sectors.

Automakers

Autonomous actions from the big three U.S. automakers will also be critical in establishing America as a worldwide leader in EVs, given their enormous R&D budgets, established manufacturing infrastructure and years of experience in the industry. To date, GM, Ford and Chrysler have each developed their own EV initiatives. The resources and output they have committed to these efforts remains lackluster, however. For example, GM has committed several billion dollars to developing the plug-in hybrid Chevy Volt, but the company only plans to produce 30,000 of these cars for the first two years after launch, equivalent to 0.18 percent of the company's total sales. Ford has announced plans to create a 100-mile battery-electric vehicle in 2011, but has also only committed to produce 10,000 in its first year. In November 2009, Chrysler decided to effectively disband its electric-drive initiative due to executive order from its new owner, Fiat. Given the dramatic downturn in the US auto industry, the focus on cost-cutting and restructuring under bankruptcy, and the uncertain future around consumer demand for electric cars, our judgment is that the big U.S. automakers will not lead the U.S. to become the world leader in electric vehicles unless more incentives are provided by the government to support EV growth.

U.S. battery makers are another important player whose autonomous actions will drive the U.S. EV industry. Currently there is simply a dearth of US-based companies that have the technology and capabilities to provide batteries for electric vehicles. A123 Systems, based in Massachusetts, is one such provider that has had recent success through an initial public offering in October of 2009. A123 has received loan support from the federal government, which we believe is a step in the right direction, and the company has signed contracts with Chrysler to provide the batteries for their electric vehicles, however the recent Fiat takeover at Chrysler has put this partnership at risk. Johnson Controls, another US-based company, has formed a joint venture with French battery company Saft, however much of the manufacturing of these batteries will take place abroad. All other significant lithium-ion battery companies, including LG Chem, BYD, Sanyo, and others are based abroad and currently have greater scale than their U.S. competitors. Our judgment is that this area has deservedly garnered more focus from the federal government, however must be supported to a greater extent. If we are successful in transitioning our country to electric vehicles from current ICE models, it does little good for us as a country if we are merely replacing our reliance on oil produced abroad to a reliance on batteries produced abroad.

Electricity Infrastructure

Assuming that consumers are convinced of the benefits of EVs, significant cost reductions in battery manufacturing occurs and auto manufacturers are able to design cars that consumers desire, the final outstanding question is whether or not the electricity infrastructure of the United States is capable of handling the increase in demand for electricity from EVs.

Generation Capacity

Given the demand profile for electricity in the United States, significant effort will likely be taken by grid operators to encourage EV charging to occur during the evening when excess capacity is highest and prices are lowest. Even though this is the likely outcome, it is instructive to understand the current balance between electricity supply and peak demand and the number of EVs that could be supported under a scenario where each EV in service connected to the grid at times of peak demand.

As of 2007, the United States had approximately 967 GW of installed generation capacity.[35] At the same time, peak demand was 782 GW revealing excess capacity of 186 GW. Without regard

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[35] All figures relating to capacity and demand were provided by the Energy Information Administration

for excess capacity requirements, this 186 GW would represent 37.2 million EVs.[36] Taking into account a 15 percent capacity margin, 13.5 million EVs could be added to the peak demand under current generation capacity. Going forward it is projected that approximately 60 GW of net capacity will be added by 2015, representing the capacity for an additional 10 million EVs. Given projected adoption rates, it is assumed that utilities will be able to add additional generation capacity as needed. As a result of these findings, we have determined that generation capacity is not considered to be a limiting factor for EVs.

Transmission and Distribution

There are currently 1.6 million miles of transmission and distribution lines in the United States. While determining the exact transmission capacity of the network is difficult, we do know that congestion on the network has been steadily increasing over the last decade. In 1998 there were 305[37] Transmission Loading Reliefs[38] (TLRs) and in 2008 that number had increased to approximately 3,300.[39] Over roughly the same time line, 2000-2010, Investor Owned Utilities will have invested over $80 billion in their T&D assets, but it is obvious that a 10x increase in TLRs over the last decade is not sustainable and significant investment will be needed to overcome the current deficiencies in the grid.

According to a report prepared for the Edison Electric Institute,[40] it is estimated that from 2010 to 2030, close to $900 billion will need to be spent on T&D (66 percent spent on distribution assets) to integrate renewables into the grid and to accommodate new technologies such as EVs. As an example of the type of investment in distribution that will likely be needed with the adoption of EVs, one can look at the neighborhood transformer, which currently operates near capacity and supports between 6-12 homes. The average home in the United States consumes 10,500 kWh per year and the use of an EV can be expected to add somewhere on the order of 7,500 kWh of demand per EV.[41] This additional consumption is likely to stress these transformers significantly and additional investment will be required to ensure that neighborhoods do not suffer frequent blackouts.[42] Interviews with utility employees indicate that utilities are aware of these issues and are committing significant resources to resolve them.[43] Given projected adoption rates, it is assumed that utilities will be able to update transformers as

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[36] Assumes that each car requires 5kW when charging, 25 kWh battery and a 5 hour charge.

[37] New York State Energy Research and Development Authority
http://www.nyserda.org/publications/report06-13.pdf

[38] A TLR Procedure is a mechanism that allows reliability coordinators to mitigate potential or actual operating security limit violations and the number during a time period provides a sense of congestion within the network.

[39] North American Electric Reliability Corporation (NERC), Transmission Loading Relief, trend chart.
http://www.nerc.com/docs/oc/scs/logs/trends.xls

[40] http://www.eei.org/ourissues/finance/Documents/Transforming_Americas_Power_Industry.pdf

[41] Each charge requires 25 kWh and each EV is charged 300 times per year.

[42] David Herron, "Planning for the Coming Wave of Electric Vehicles," *San Francisco Examiner,* September 17, 2009.
http://www.examiner.com/x-14333-Green-Transportation-Examiner~y2009m9d17-Planning-for-the-coming-wave-of-electric-vehicles

[43] Interview with Christian Keller on November 2, 2009; interview with former PG&E employee John Stanfield on November 17, 2009.

needed. Given these findings, we have determined that transmission and Distribution is not considered to be a limiting factor.

Charging Stations

The final component of the EV charging infrastructure is the actual EV charging stations. There are currently three companies leading the build-out of the charging station infrastructure. Better Place is likely the best known of the three, but at present they have only announced partnerships with a small number of states and have not installed any of their charging or swap stations. Two other companies, Coulomb and eTec have installed stations in several cities in the United States and the Department of Energy recently granted eTec $100 million to install more than 15,000 charging stations in a partnership with Nissan and the states of AZ, CA, OR, TN and WA.

The cost for each charging station various from approximately $5,000 for a Coloumb station to between $1,500 and $2,500 for an eTec station. The forecast of sales of PHEVs results in approximately 5 million PHEVs on the road by 2020. If we conservatively assume a cost of $2,500 per station and 2 stations per car, the cost of building the charging station infrastructure is $25 billion over the next 10 years, which pales in comparison to the amount that will be spent on generation and T&D assets over the same period. Given these findings, the construction of the charging station network is not considered to be a limiting factor.

THE ROLE OF ACTIVISTS

Activists will likely not play an important role in EV adoption in the US. In general, most activists are in favor of EV adoption, but only a few will have enough influence to help drive change and create widespread adoption of EVs. In our view, the most significant activists that will affect US EV industry are the United Auto Workers and environmental activist groups.

The United Auto Workers are somewhat spilt in their views towards the rise of EVs in the U.S. Some U.A.W members feel that EVs would harm the status quo and jeopardize an already failing industry. Other U.A.W members look at EVs as an opportunity to breathe new life into a dying industry in the US. This group has moderate influence in the decision to adopt EVs and is likely to play a moderate role in determining EVs future in the United States.

Environmental activists are highly organized groups in the EV landscape. Most are proponents of EVs and vary widely in their effectiveness. Some activist campaigns originating from these groups have been widespread and highly effective, however overall their effectiveness in changing the automotive landscape has thus far been moderate at best. However with climate change increasing in global awareness, their leverage may grow leading to these groups becoming much more influential in the future.

WILL WE GET THERE WITH THE CURRENT STRATEGY?

Consumer Adoption

Many signs indicate that the US vehicle market will see a large growth in electric vehicles. The first potential influence is the price of fuel: an increase could allow EVs and PHEVs to be cost competitive with traditional ICE vehicles. The second is the price and quality of batteries: current research efforts by Nissan's alliance with NEC and start-ups such as Amprius are likely to result in a technological breakthrough. The third is government incentives and intervention. The current tax credits are spurring quicker adoption, which result in lower prices as a result of the "learning by doing" effect. In an attempt to meet stated greenhouse gas emission targets, the Obama administration is likely to modify the CAFE system or increase current tax credits in favor of PHEVs and EVs. Finally, autonomous market actions have already begun in response to a new consumer demand for "green" products, such as the Toyota Prius.

Government Investment

Looking at the US government investment in EV technology and EV infrastructure, it appears that while the latter is likely to yield tangible positive results, it is unclear that the former will lead to global technical leadership. Infrastructure investments are both large (~$4.5 billion) and diverse (spread around to regional power authorities). Most importantly, these infrastructure investments are not reliant on technology development, as dollars will flow to projects around upgrading smart grid systems and further build out of physical infrastructure, both known technologies. Unlike infrastructure investments, the outcome from EV technology investments is less clear. While $11million in early science grants and $2.6 billion in production scaling loans for EVs may yield technology advancement, these amounts are insignificant when compared to competitive battery and automobile R&D budgets.

Industry: EV Technology

Currently, foreign battery technology (primarily from China and Japan) is more sophisticated than U.S. domestic production. As long as batteries remain such a higher percentage (~40 percent) of electric vehicle cost, it is likely that foreign players will dominate the EV market. However, as battery costs decline as projected and become essentially a commodity component in EV manufacturing, technology sophistication in battery production will be less of a competitive advantage and a highly fragmented battery supply will likely emerge. In such an environment, one can expect a continuation of the current status quo of the current automobile market fragmentation with no clear dominant company, composed of players from Japan, Korea, U.S. and Europe with both start-up entrants like Tesla, Fisker or Coda, and new foreign players like BYD and Tata.

Industry: EV Infrastructure

As discussed, as much as $900 billion of grid investment is needed over the next 20 years, along with the build out of a widespread charging network for EVs. The US government has allocated approximately $4.5 billion to upgrade parts of the grid through the stimulus package, but it is expected that the responsibility for future investment will be met by autonomous actions of Investor Owned Utilities on the grid side. While these investments are not primarily directly for EVs, grid upgrades will have significant ancillary benefits for EVs including smart metering and grid stability. With regard to charging infrastructure, it is very likely that a combination of grass roots efforts by start-ups and local governments will deliver a charging station network for EVs.

RECOMMENDATIONS FOR AMERICA'S ELECTRIC VEHICLE FUTURE

The current U.S. transportation industry is on an unsustainable course - the reliance on imported fossil fuels and the subsequent carbon emission indicate that a movement towards EV adoption is necessary for U.S. transportation security. The default approach for the U.S. to achieve transportation security is to become the world leader in EV technology. Accordingly, government policies are aligned to support technology leadership in the form of grants for early stage science and loans for existing manufacturers to scale production. The U.S. may eventually be a technology leader, but currently that outcome remains unclear given U.S. technology sophistication in comparison to foreign competitors. Given the market size and projected increases in oil prices, it is more likely that the U.S. will need to become the EV adoption leader.

As such, in order to become a leader in the adoption of EVs, policy makers at all levels of government should consider the following policy goals:

Higher gasoline taxes

Of net importing OECD countries, the United States has the lowest gasoline taxes in the world. By artificially raising the price of oil through a gasoline tax, the government can move more rapidly towards price parity between ICE vehicles and EVs.[44] The obvious obstacle to this recommendation is the political difficulty in passing new taxes. An alternative to raising the national tax might be autonomous movements by motivated state governments to raise gasoline tax to increase state revenues while making their state home to a growth industry like electric vehicles.

Improved CAFÉ standards

In an upgrade the Energy Independence and Security Act (2007) the Obama administration has set a requirement of 35 mpg average for the fleet by 2016. At today's fleetwide average of 25 this represents representing a 40 percent improvement over today's CAFÉ standards.[45] While this is an aggressive target, by simply removing SUVs and light trucks from the product portfolio would achieve this goal, leaving the transportation sector still reliant on foreign oil sources,

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[44] Australian Institute of Petroleum.
http://www.aip.com.au/pricing/internationalprices.htm

[45] Brent D. Yacobucci, "Automobile and Light Truck Fuel Economy: The CAFE Standards." Congressional Research Service Report for Congress, May 7, 2008,

albeit more efficient. Like the exceptions provided in the current CAFÉ standards for flex fuel vehicles, higher weighting for EVs and PHEVs could incentivize auto manufacturers to produce higher volumes.

Demand-side incentives

Non-monetary incentives to own electric cars can help spur demand without taking additional public funds. Incentives like free access to HOV lanes and preferred parking can increase adoption, particularly in high congestion areas.

Incentives for consumer focused businesses

Similar to loan guarantees for EV related science, the government can implement targeting financing or tax incentives for business built around EVs and corresponding infrastructure. Such programs can induce the creation of new businesses or the movement of existing companies, like utility providers, service stations, or retail businesses towards EV related products.

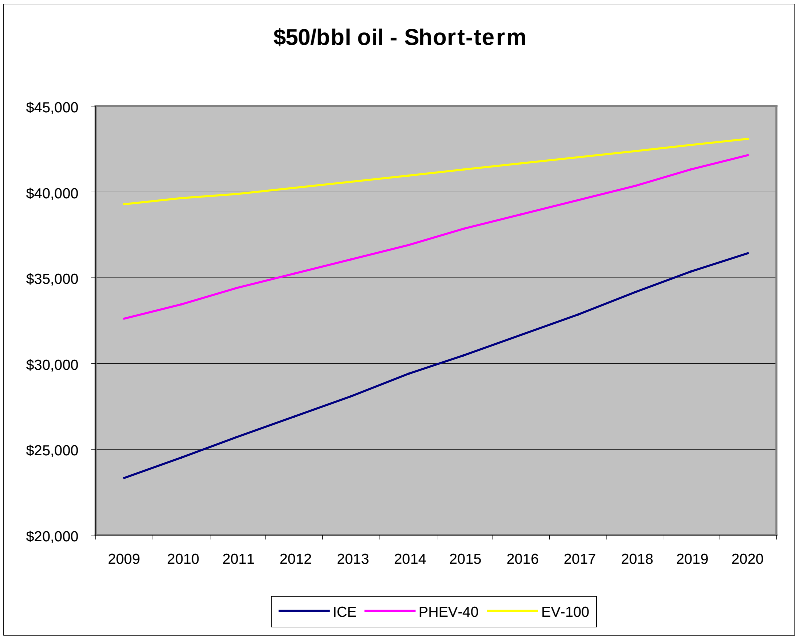
Increase consumer tax credit

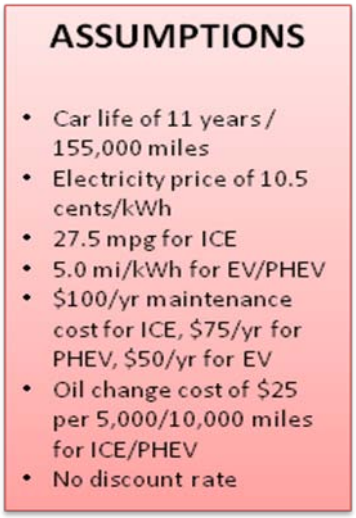
The current maximum consumer tax credit of $7,500 often just makes up for the extra cost associated with an EV battery as compared to its ICE counterpart. Any increase in this tax credit could create an advantageous situation for consumers of EVs and would speed EV adoption.

Exhibit 1
Oil and Battery Price Scenarios

Graphs represent Total Annual cost of Ownership; i.e. vehicle is assumed purchase at the end of 2009, and incremental annual costs (fuel, maintenance, etc.) are added cumulatively over the life of the vehicle

Scenario 1





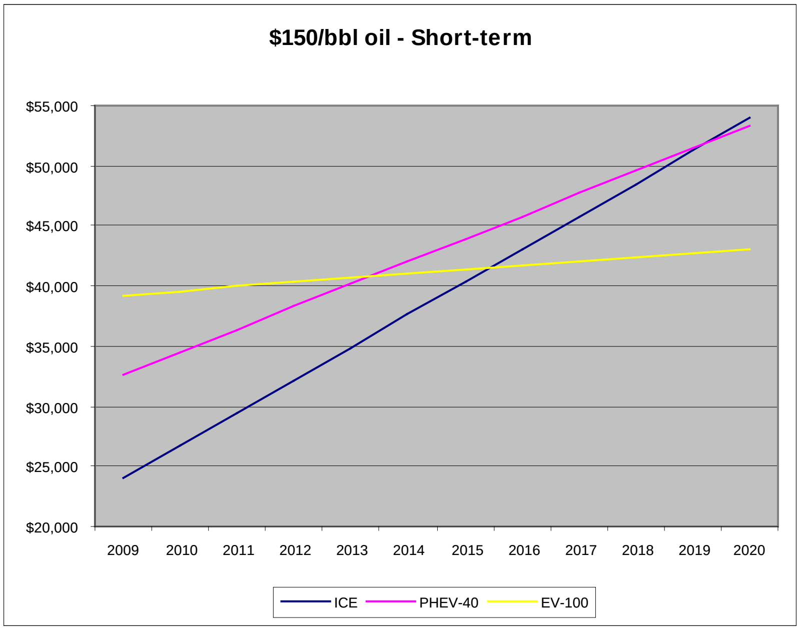
ASSUMPTIONS

- Car life of 11 years / 155,000 miles
- Electricity price of 10.5 cents/kWh
- 27.5 mpg for ICE
- 5.0 mi/kWh for EV/PHEV
- $100/yr maintenance cost for ICE, $75/yr for PHEV, $50/yr for EV
- Oil change cost of $25 per 5,000/10,000 miles for ICE/PHEV
- No discount rate

Source: Created by research paper authors.

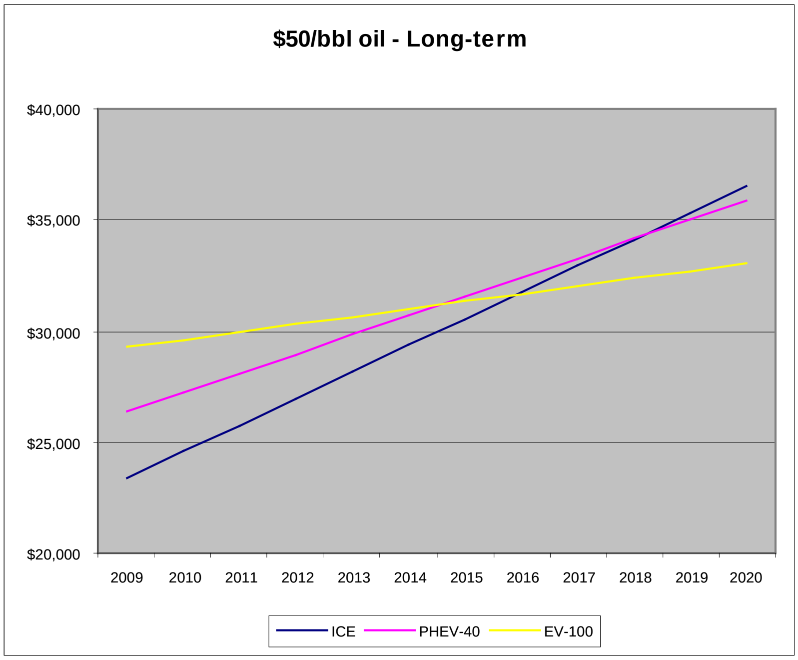
Exhibit 1 (continued)
Oil and Battery Price Scenarios

Scenario 2



Source: Created by research paper authors.

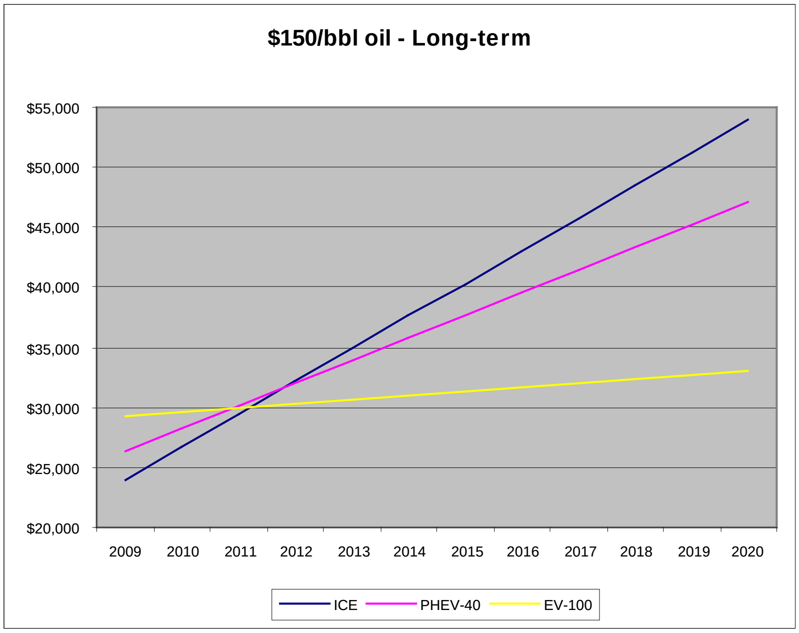
Scenario 3



Source: Created by research paper authors.

Exhibit 1 (continued)
Oil and Battery Price Scenarios

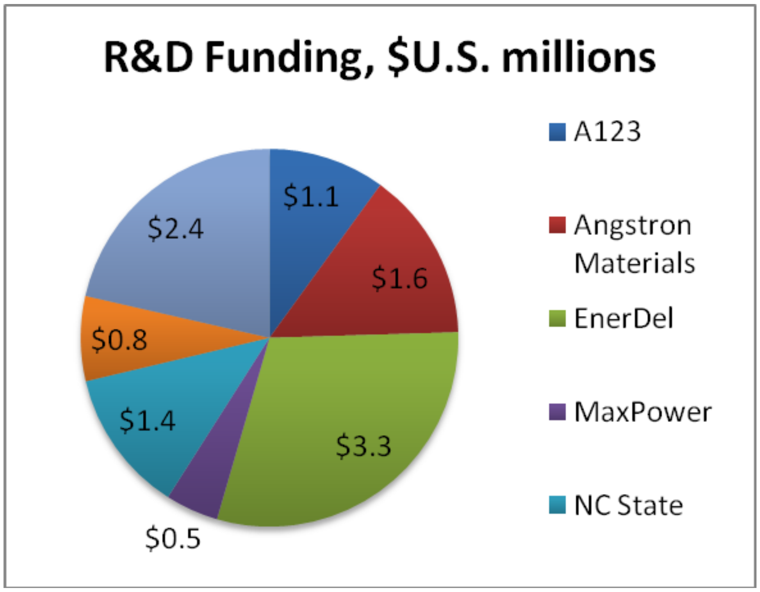
Scenario 4



Source: Created by research paper authors.

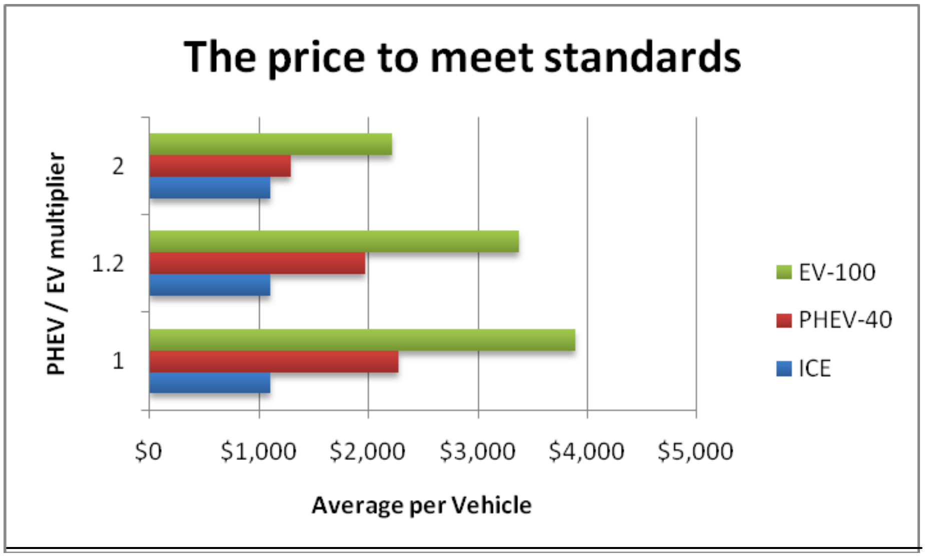
Exhibit 2

Breakdown of $11B in R&D Funding from US Government



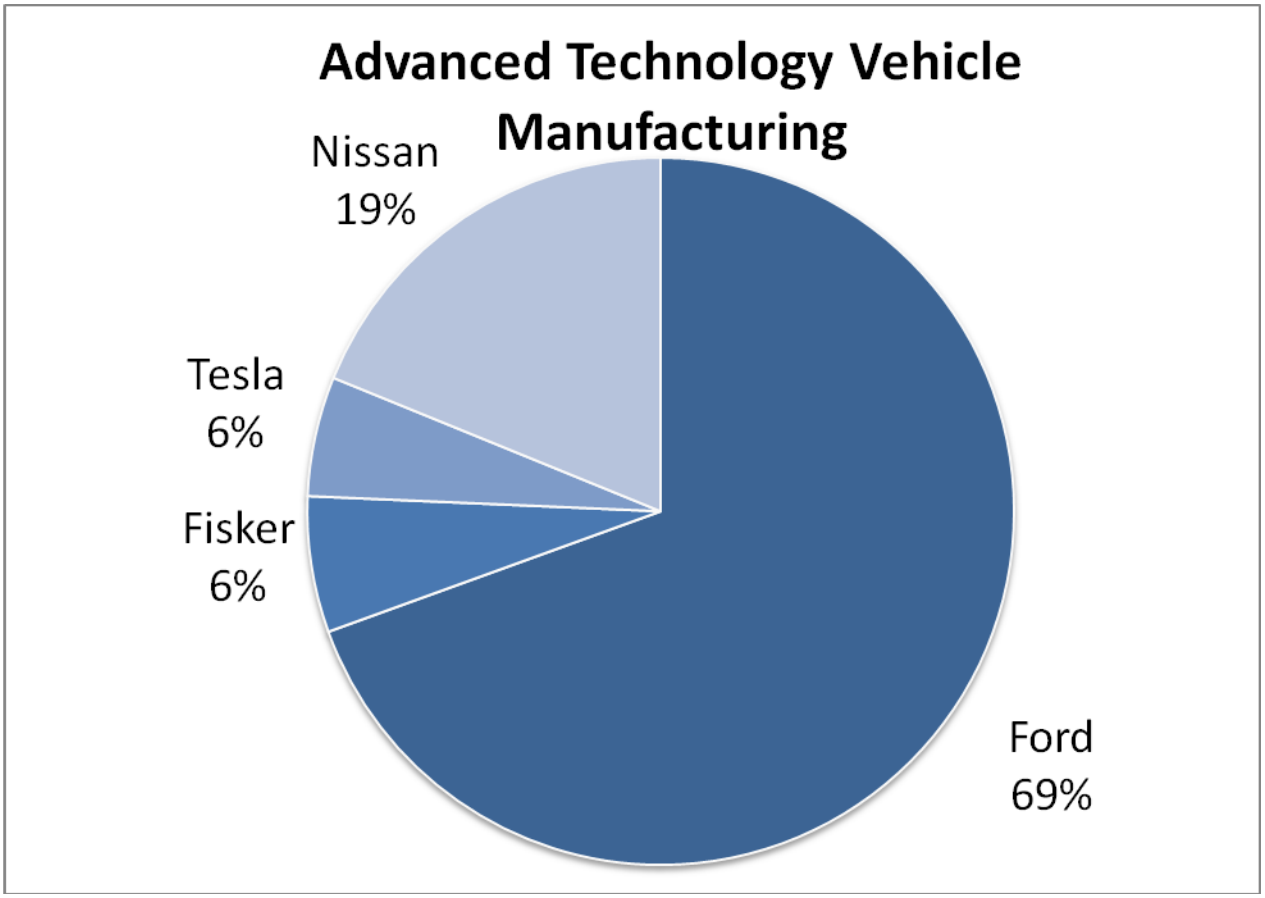
Source: U.S. Department of Energy

Exhibit 3
Effect of Multipliers on Average Cost



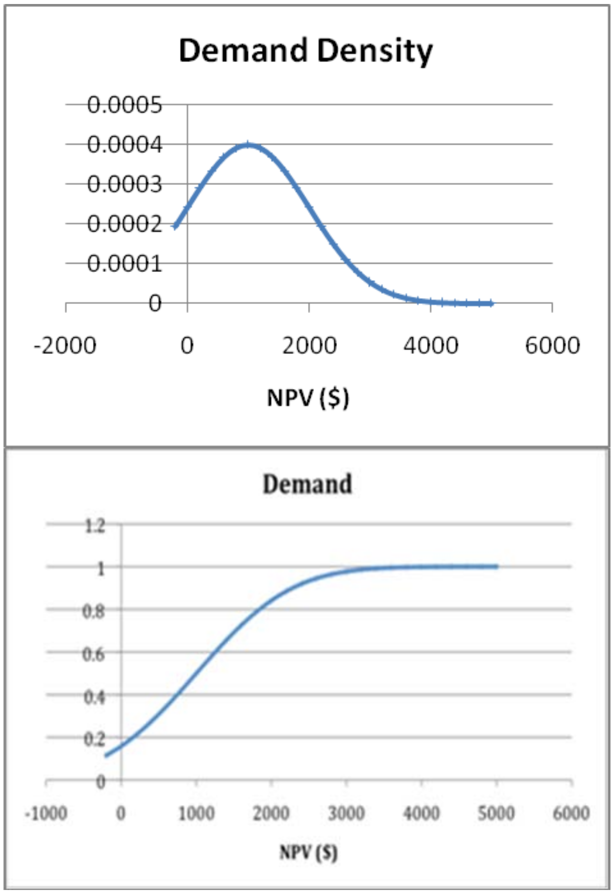
Source: Created by Research Paper authors.

Exhibit 4
Breakdown of Advanced Technology Vehible Manufacturing Allocation



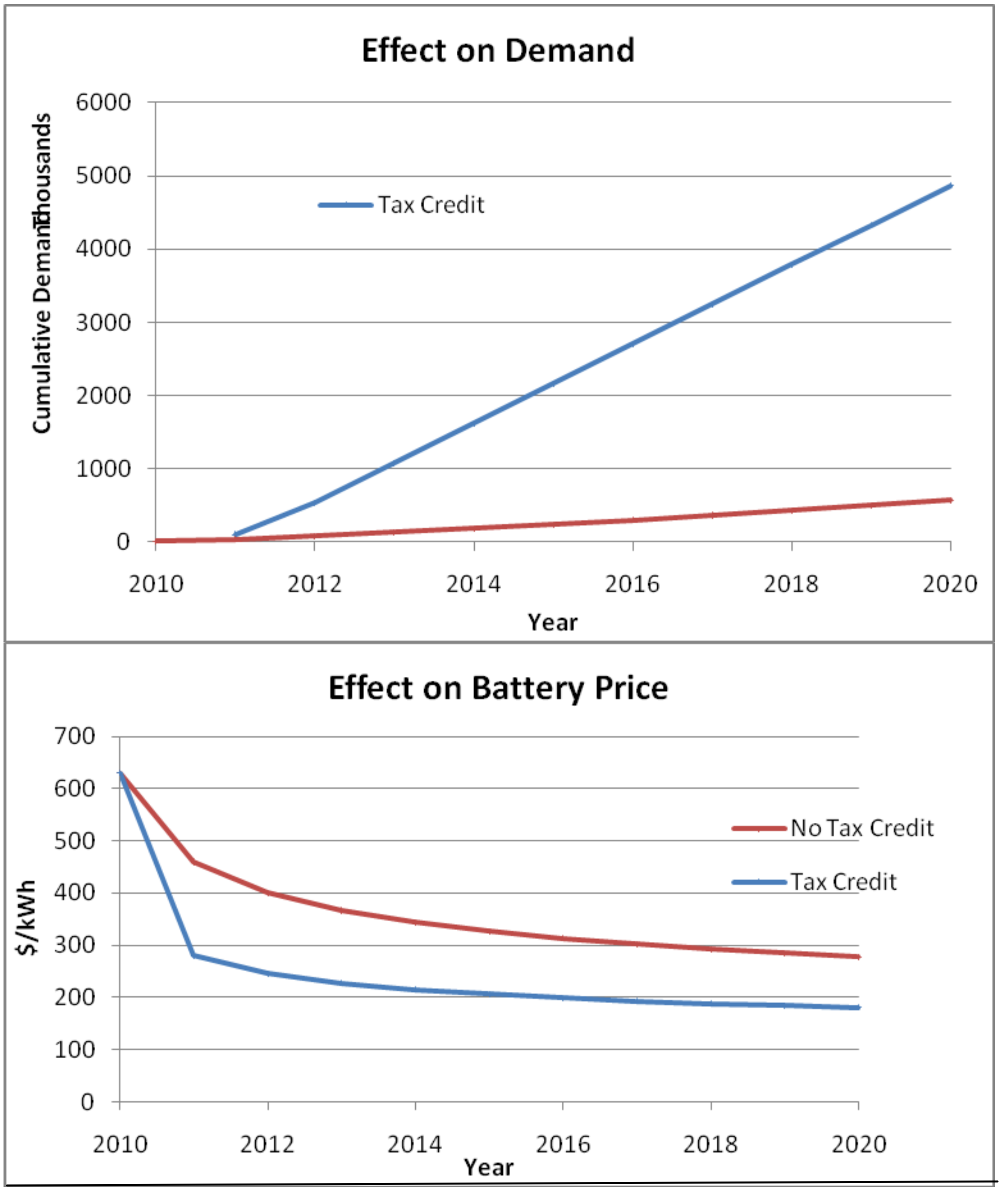
Source:Advanced Technology Vehicles Manufacturing Loan Program, U.S.Department of Energy.
http://www.atvmloan.energy.gov/

Exhibit 5
Demand Profile for EVs



Source: Created by research paper authors.

Exhibit 6
Tax Credit Impacts on Adoption



Source: Created by research paper authors.

Chapter 5

PLUGGING IN: THE DYNAMICS OF ELECTRIC VEHICLE ADOPTION IN CHINA*

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* This chapter was prepared by Anna Fang, Bofei He, Yohei Iwasaki, Ling Jin, Emily Ma, Michael Ovadia and Thomas Rigo

INTRODUCTION

Over the past decade, China's rapid economic growth has led to an even greater expansion of CO_2 emissions, air pollution and oil consumption. The Chinese economy's contribution to global warming, to social unrest through environmental degradation and to strategic vulnerability through oil imports has not gone unnoticed. For the first time, in 2007, improving environmental quality became a key strategic initiative in the National Development and Reform Commission's Five-Year plan.[46]

The central government's new focus on environmental issues has given advocates of electric automobiles (EV) hope that China will provide global leadership in EV adoption. However, in China, as in the rest of the world, the EV market remains unable to overcome the upfront costs necessary to reach large scale production and adoption. Large scale adoption is not commercially feasible because the cost of batteries that deliver similar performance to internal combustion engines (ICE) is relatively high, while the fully-costed price of owning an ICE automobile remains low. In order to make EVs economically attractive for consumers, the government must provide incentives for EV adoption or manufacturers must deliver rapid innovation that will dramatically reduce the cost of batteries. This paper plans to address these dynamics of potential EV adoption in China by answering two key questions:

1) Are conditions in China currently ripe for near-term EV adoption?
2) In the future, what are the necessary conditions for widespread EV adoption in China?

In order to answer the first question, we analyze three aspects of current conditions in China. We examine:

- The willingness of the Chinese government to take actions to stimulate EV adoption.
- The influence of "activists" to push the government into action.
- The potential for EV adoption through autonomous corporate action with a cross-boundary disruptor (XBD).

Looking beyond the current conditions, we attempt to form a view on the status of EV adoption in China in 2020. In order to approach this task rigorously, we establish three potential scenarios. The purpose of the scenario analysis is to parse out the necessary conditions for EV adoption in China and evaluate the potential of these conditions coming to pass by 2020. The key scenarios we considered were:

- *The status quo* **–** China, a country dominated by coal-based energy, continues to subsidize gas prices and provides limited incentives for EV adoption.
- *Global environmental concern* – Global environmental concern drives an emission reduction regime, but China maintains a "developing country" exempt status and oil prices stay low.

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[46] National Development and Reform Commission (NRDC) People's Republic of China website. http://en.ndrc.gov.cn/

- *High oil prices and global environmental concern* – Global environmental concerns drive an emissions reduction regime globally and oil prices spike.

This analytical process uncovers the conclusion that mass EV adoption in China requires high oil prices *and* technological development *and* government support through consumer subsidies in order to reach scale. Unfortunately, EV adoption is not a strategic priority for the Chinese government in the intermediate future. As a result, the future of EV adoption in China depends on both export markets providing an initial avenue for scaling up EV production and dramatic technological change through a cross-boundary disruptor.

ASSESSING GOVERNMENT EFFORTS TO STIMULATE EV ADOPTION

A Brief Word on Chinese Government Functions and Imperatives

Before analyzing the current status of Chinese government efforts to scale EV adoption in China, a brief overview of Chinese government functions is in order. The decision-making processes of the Chinese government are dramatically different than its American and European counterparts and its workings must be understood in order to follow the logic and conclusions of this paper.

China's government consists of the Communist Party of China, which rules through a one-party system. The party's and the government's highest organ of power is the National Congress of the Communist Party of China. The Congress meets approximately every 5 years as the National Development Reform Commission (NDRC) to set national priorities and direct policy. All aspects of long-term Chinese EV policy ultimately lie in the hands of the NDRC.[47]

China is governed on a day-to-day basis by the Secretariat (Hu Jintao) and the nine-member Politburo Standing Committee, who meet on a weekly basis. The Politburo Standing Committee is made up of party chiefs of major cities, heads of the Central Military Commission and other influential members of the Communist Party. Decision-making at the Politburo level is rumored to be made by consensus. It is important to note that the Politburo leadership is also the leadership of the NDRC. As a result, the Five-Year Plans serve as planning guidelines and the Politburo executes those guidelines on an ongoing basis. The Politburo would oversee EV policy implementation at a high, centralized level.[48]

Policy implementation at a local level is driven by a mélange of ministries and local governments. Key ministries affecting EV development include MOST and MIIT. The role of each of these ministries is discussed in greater detail at a later point, but the key lesson is that multiple ministries have overlapping functions and vie for influence in implementing policy guidelines. Meanwhile, local governments also potentially influence EV adoption by setting auto licensing requirements, local business subsidies and restrictions on products sold locally. Ministers and local government officials are often businessmen and technocrats rather than

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[47] National Development and Reform Commission (NRDC) People's Republic of China website. http://en.ndrc.gov.cn/

[48] The Central People's Government of The People's Republic of China website. http://english.gov.cn/

bureaucrats. As a result, the local implementation of central policy guidelines can be characterized by pragmatic approaches that are distorted by the interests of local power holders.[49]

Finally, the Chinese government's central objective – like that all governments – is survival. With the one-party system, however, "survival" means survival of the Communist Party. At its current state of development, the Communist Party's hold on central power is dependent on mitigating social unrest and national security. Social unrest is mitigated by raising the standard of living (monetary and environmental) and by providing employment. National security is maintained through an effective standing army and access to natural resources to supply the economy and military.

A Brief Word on the Chinese Transportation System

As with its government, China's transportation system is organized differently from that of the U.S. or Europe. In order to draw the reader through our analysis and conclusions, it is vital that the reader carries with them a base-line knowledge of the Chinese transportation system.

The core difference between the U.S. and European transportation systems and the Chinese one is the prevalence of automobiles. In China, there are .028 cars per person, rather than 1 and .5 cars per person in the U.S. and Europe.[50] The key mode of personal transportation in China remains the bicycle with 450 million units in 2008.[51] And other significant modes of personal transportation include the electric scooter with 100 million units and the motorcycle with 90 million units. The automobile pales in comparison with only 38 million cars on the road. Meanwhile, commercial transportation is dominated by rail (representing 51 percent of ton-miles) and waterways (27 percent of ton-miles). Truck transportation constitutes 21 percent of ton-miles with 11 million trucks in operation.[52]

The emphasis on rails and light personal transport in China yields a transportation system that is a negligible consumer of energy in the Chinese economy (7 percent) and producer of CO_2 emissions (7 percent). However, the transportation sector does represent 38 percent of China's oil consumption. A closer look at the transportation sector's oil consumption reveals that automobiles represent only 19 percent of the total, while buses and trucks are responsible for slightly more than half of China's transportation oil use.[53] Thus, in order to understand Chinese policy making imperatives around the EV, it is critical to acknowledge that automobiles are, in

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[49] Erica S. Downs, "China's 'New' Energy Administration: China's National Energy Administration Will Struggle to Manage the Energy Sector Effectively," *China Business Review*, November-December 2008. www.chinabusinessreview.com

[50] Central Intelligence Agency website. www.cia.gov.

[51] Jonathan Weinert, et al. "The Transition to Electric Bikes in China: History and Key Reasons for Rapid Growth." UC Davis Institute of Transportation Studies, 2005

[52] "An Overview of China's Transport Sector – 2007,"World Bank Working Paper.

[53] Feng An, "Chinese Transportation Markets and Policy in a High Oil Price Environment," 3rd Transatlantic Energy and Climate Change Policy Workshop, March 30-31, 2006, Auto Project on Energy and Climate Change (APECC).

the near and intermediate term, a tertiary contributor to China's environmental problems and a relatively unimportant consumer of China's natural resources.

Assessing the Role of Government Action in Inducing EV Adoption

The rapid adoption of EVs in the near-term (5 years) requires induced action by the Chinese government. The government not only has to play a potential role in making EVs financially attractive to consumer, but the government must also deploy massive grid capacity investments and charging stations. At the current time, the Chinese government's efforts to induce EV adoption remain limited and the government has adopted a "wait-and-see" approach through allowing autonomous development of corporations and technologies dedicated to the EV arena.

If one observes the Chinese government's recent actions, it is clear that there is little interest in the Communist Party to push large scale adoption of EVs in the Chinese markets. At the national level, the 2007 Five-Year Plan provides no quantitative measures of emissions or transportation pollution reduction. Instead, the document is focused on diversifying and reducing the emissions intensity of the Chinese economy. This "emission intensity" language suggests that the central government's focus is not on the small impact that EVs would have on the environment, but rather on the massive impact that shifting Chinese reliance on industry in favor of higher value and lower-polluting industries such as services would have on the Chinese quality of life.[54] The recent stimulus package provides another data point for central government priorities. The $586 billion Chinese stimulus package included $1.5 billion towards low carbon emission vehicles – including hybrids and plug-in hybrids. This figure pales in comparison with the allocation to improving energy efficiency in the rail system ($98.7 billion) and the electricity grid ($70 billion). Similarly, funding efforts for EVs at the ministry-level in China have been minimal. MOST, the ministry responsible for directing R&D in China has set aside $106 million annually for developing hybrids and EVs.[55] MIIT, the ministry responsible for directing established industries such as the automotive industry, recently announced a technology revitalization program that include $1.5 billion for the automotive industry in general.[56]

China's observed strategy of minimal involvement in the EV arena dovetails with the priorities articulated by government agencies in the media. Thus far, goal setting for EVs has been de minims. The most recent government target for "new energy cars" has been set at 0.5 million by 2011.[57] However, most of these vehicles are budgeted to be government fleet and special vehicles. This target is unimportant within the Chinese planning behemoth and "new energy cars" includes hybrids, plug-in hybrids and EVs. This limited goal is also in-line with a recent speech given by the NDRC at a People's Republic of China EV Conference. The speaker stated: "The State Council doesn't want to regulate EV production capacity; that should be left to the market…rather we expect major auto makers to get fully prepared in EV technologies by 2011

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[54] National Development and Reform Commission (NRDC) People's Republic of China website. http://en.ndrc.gov.cn/

[55] Transition to hydrogen-based transportation in China: Lessons learned from alternative fuel vehicle programs in the United States and China Energy Policy Volume 34, Issue 11, July 2006, Pages 1299-1309 Hydrogen.

[56] Ibid.

[57] Yu Dawei, "China Should Speed Up New-Energy Vehicle Development," *Caijing*, April 28, 2009. http://english.caijing.com.cn/2009-04-28/110155209.html

and come up with EV specification standards."[58] This statement clearly indicates that the Chinese government is not focused on directing production resources to the EV industry, but rather is taking a "wait-and-see" attitude towards EV technological and manufacturing development. As a result, the large scale subsidies and necessary infrastructure upgrades that are necessary for near-term EV adoption in China will not be forthcoming.

ASSESSING THE ROLE OF ACTIVISTS IN EV ADOPTION

"Activism" Redefined in the Chinese Context

While the Chinese government is apprehensive about allocating resources to EV adoption, it is possible that "activist" entities within the political economy can push the government into action. In the U.S. and Europe, activists are characterized by non-market actors, such as NGOs, lobbyists, consumer groups and associations.[59] In China's one-party political economy, this definition is stale. Chinese laws require the registration of all organizations with the government and rules forbid the public gathering of large groups of people – making it difficult for non-market actors to exert influence over government and corporations.[60] Given the Chinese context, a more appropriate definition of the term "activist" would focus not on non-market actors that influence the government as a whole or corporations, but rather on those entities that can influence the NDRC.

Government Ministries as Activists

Setting aside corporations, the two key activist organizations affecting the adoption of EVs within China are the Ministry of Industry and Information Technology (MIIT) and Ministry of Science and Technology (MOST). While MOST is focused on directing R&D efforts, MIIT is dedicated to regulating and developing major industries. MOST was founded in 1998 and has been involved in directing Chinese battery R&D efforts since its inception.[61] MIIT is a recently formed ministry (2008) that is responsible for regulation and development of major industries, including the automobile industry.[62] Once the EV manufacturing supply chain matures, it is slotted to fall under MIIT's supervision as well.[63] Since battery technology is critical to the development of EVs, the two ministries have been competing for leadership in defining EV R&D and regulation – an area of potential future national interest and funding.[64]

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[58] 工信部主持召开了规格极高的"2009中国电动汽车产业发展国际论坛"期间，日产与工信部和武汉市政府签署了两项协议书，包括为工信部制定包括充电网络建设和维护，促进电动车大规模使用的综合规划，同时在2011年在武汉首先推出电动车

[59] "What is an Activist," http://www.activistrights.org.au/cb_pages/what_activist.php

[60] The Central People's Government of the People's Republic of China website. http://www.gov.cn/flfg/2005-08/05/content_20965.htm

[61] http://news.sohu.com/20090907/n266519740.shtml

[62] "PRC Government Structure Report. http://www.uschina.org/public/china/govstructure/govstructure_part5/12.html

[63] http://info.auto.hc360.com/2008/07/091445291562.shtml

[64] http://www.yangtse.com/sytj/syqc/200907/t20090714_670621.htm

Evidence of this competition has emerged in 2009. In April 2009, for example, MIIT – despite its mandate to only focus on major industries – hosted a global forum exclusively dedicated to setting standards for future EV development.[65] The forum was considered a milestone for the EV industry, since it set the tone for the future growth of the industry as a potential major player in the Chinese market.[66] From this forum, Nissan (and the DongFeng Nissan JV) emerged the winner in this critical first round of EV standard-setting in China. Furthermore, Nissan was named the exclusive strategic partner in a memorandum of understanding between MIIT.

MIIT's patronage of Nissan is a clear effort to lay-out a series of standards, which will define the status quo in advance of any NDRC decision-making. This standard-setting is also an evident play to wrest influence away from MOST. It is worthy of note that the prominent battery manufacturer, BYD, which falls under MOST's supervision was not even invited to the forum.[67] Nevertheless, MIIT took the opportunity to classify BYD's Li-on battery technology as "intermediate phase", while classifying Nissan's battery technology as "mature phase". Again, the implications of this early "phase" standard-setting has tremendous implications for defining the development of EVs in China and the status quo that the NDRC will have to work within. EVs with "intermediate phase" batteries can only be sold to 14 "test" cities in China in small scale. Meanwhile, Nissan's exclusively designated "mature phase" battery technology can be sold with EVs anywhere in the Chinese market. [68]

MIIT's actions on behalf of Nissan and the automobile industry may lie in the heritage of MIIT leadership. The former chairman of the DongFeng Nissan JV, Yu Miao is currently the vice minister of MIIT. Mr. Yu, is far more than a vice minister – he is a business celebrity who garners greater name recognition than BYD's CEO Wang Chuanfu. Mr. Yu created JVs with Honda and Nissan, and pioneered quality automobile mass production in China.[69] As a result, it would not be surprising to continue to see MIIT favoring players in the automotive industry in driving EV adoption and standard setting in advance of any specific decision-making at the NDRC level.

The Local Government as Activist

As with government ministries, local governments can play a role pushing forward policies that define the status quo and force the NDRC's hand in supporting the adoption of the EV. While MIIT advocates for China's automobile producers, BYD has a strong ally in the city of Shenzhen. Indeed, BYD is headquartered in Shenzhen, which was the first city to open-up to the world during the 1978 reforms and currently has the highest per-capital GDP of any city in China.[70] Shenzhen's political influence should not be underestimated since its economic power is that of several provinces combined. With the possibility of BYD building a "Detroit" for the

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[65] Ibid.
[66] Ibid.
[67] Ibid.
[68] http://www.yangtse.com/sytj/syqc/200907/t20090714_670621.htm
[69] http://auto.sina.com.cn/z/drltreaty/index.shtml
[70] "Shenzhen," Wikipedia website.
http://en.wikipedia.org/wiki/Shenzhen

EV market in Shenzhen, the municipal government has lobbied the NDRC to cast favor on the company.[71]

Thus far, the Shenzhen government has not only provided BYD with a test market in the government's vehicle fleet, but the municipality has also established a strategic partnership with the China Development Bank on behalf of BYD. This partnership is significant because the China Development Bank is the investment bank representing central government and it arranges investments in major SOEs and infrastructure. It is crucial to recognize that the last time the Shenzhen municipal government established this type of partnership it was with Huawei – a local start-up which became the second largest telecommunication manufacturer in world.[72] Hence, Shenzhen is positioning BYD to receive favor from the NDRC as it determines funding and development of the EV in China.

Activists Opposing the Adoption of EVs

While MIIT, MOST and certain local governments seek to promote EV adoption, powerful activists exist within the Chinese political economy that seek to block the adoption of EVs. The overlapping responsibilities between ministries, local governments and corporations create a dynamic where uncertainty over responsibilities produces a power vacuum for large entities to exert control. One such area is the energy sector. As a result, the state-owned energy companies represent powerful autonomous actors who are well-represented in ministries, the NDRC and other organs of influence within the Chinese Communist Party.[73]

Unfortunately for proponents of the EV, utilities and oil companies have stated little interest in widespread EV adoption. Major Chinese oil companies are not interested in seeing a key source of revenue threatened – PetroChina and Sinopec derive 47 percent and 34 percent of their sales from gas and diesel.[74] While utilities may benefit from increased demand for power, they have shown little motivation to make the investments to upgrade their plant and provisioning technologies for EVs. A central reason for this behavior is that utilities are evaluated by the government on reliability. Given the lack of government interest in inducing the EV effort as a whole, utilities have been reluctant to initiate the large and complex investments necessary to support widespread EV adoption.[75] Hence, the oil and utility industries are two powerful agents in the political economy that seek to block or to slow the adoption of EVs in China.

Within the Chinese political economy, the strongest forces of activism on the NDRC are seen in large state-owned enterprises, the ministries and the local governments. While MIIT can set standards that will affect adoption, local governments can bring tremendous economic resources to bear in order to push a given company into a position of favor with the NDRC. Meanwhile, large state-owned enterprises with direct membership in NDRC decision-making can divert

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[71] http://blog.qq.com/qzone/622007689/1229357735.htm

[72] http://sjoem.com/news/news-53032.html

[73] Erica S. Downs, "China's 'New' Energy Administration: China's National Energy Administration Will Struggle to Manage the Energy Sector Effectively," *China Business Review*, November-December 2008.

[74] Petrochina 2008 Annual Report
http://www.petrochina.com.cn/resource/EngPdf/xwygg/ew_20090415_annual_report.pdf;
http://english.sinopec.com/download_center/reports/2007/20080406/download/AnnualReport2008.pdf

[75] Erica S. Downs, loc. cit.

government resources away from inducing EV adoption. Looking strictly at the activists forces, the future outcome of the EV market is unclear at the present time.

IF NOT INDUCED – THEN AUTONOMOUS?
CROSS-BOUNDARY DISRUPTION POTENTIAL IN THE CHINESE EV MARKET

While MIIT has stated its support of Nissan over BYD as the frontrunner of China's EV industry, the local efforts of the Shenzhen government to support the battery manufacturer BYD cannot be ignored. A closer look at the political and economic dynamics suggests that conditions are ripe for BYD to become a cross-boundary disruptor in EV automobile manufacturing. In examining BYD's potential as a cross-boundary disruptor, it is necessary to assess seven conditions set out by Burgelman and Grove.[76] These conditions are outlined below:

External Industry-Level Conditions

- Is the industry in decline?
- Is there a large market opportunity?
- Is there a confluence of market and non-market forces

Internal Company-Level Conditions

- Does the company possess a culture of innovation?
- Is the company resource rich?
- Is the company hungry for growth?
- Does the company possess bold leadership?

External Industry-Level Conditions
Innovation stasis in the automotive industry

Since Henry Ford's introduction of the Model T car at the beginning of the 20th century and the mass adoption of the internal combustion engine passenger car that followed, there have been very few revolutionary concepts that have been introduced successfully to the marketplace. With gradual consolidation, the top five players in the world automotive industry (Toyota, GM, Volkswagen, Ford and Honda) manufactured over 40 percent of all passenger cars in 2008.[77] While these industry players have dabbled in alternative vehicles, other than Toyota's success

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[76] Robert A. Burgelman and Andrew S. Grove. "Cross-Boundary Disruptors: Power Inter-Industry Entrepreneurial Change Agents," *Strategic Entrepreneurship Journal*, October 2007.

[77] World Motor Vehicle Production 2008.
http://oica.net/wp-content/uploads/world-ranking-2008.pdf

with the Prius, to date, none have managed to successfully transfer their plug-in or full electric vehicle technology from their R&D labs to the marketplace. Given that sales of traditional ICE cars are still strong and growing, and that auto manufacturing processes have been optimized to produce such cars, these incumbent players have had little incentive to convert their operations entirely to produce a revolutionary type of alternative energy vehicle. This has opened up the opportunity for startups such as Tesla Motors, not burdened with existing infrastructure, to leapfrog these incumbents, attempt to overcome the overwhelming minimum efficient scale associated with auto manufacturing, and produce a viable full electric vehicle.

Market Opportunity for Battery Manufacturers

In 2008, 69.5 million vehicles were produced. Of these, 55.8 million are cars (the remaining vehicles are light and heavy commercial vehicles and buses).[78] Consider the extreme scenario in which all 60 million cars are full electric Tesla Roadsters, each requiring 6831 commodity-grade lithium-ion batteries currently available.[79] This would require over 400 billion batteries. Compare this to the 2008 demand for lithium-ion batteries worldwide at 3.5 billion.[80] Even a 10 percent conversion of the world auto production to electric vehicles would increase the demand for existing commodity batteries several-fold. Without considering improvements in battery technology and fixing prices, a straightforward increase in demand volume is a boon to battery manufacturers worldwide.

Confluence of Non-Market Forces – National Policy, Batteries, EVs and Employment

The Chinese battery industry is of strategic national importance because of its potential for growth and differentiation. China has plateaued as the dominant world exporter of commodities such as footwear and apparel.[81] Given this market position, central and local governments are likely actively seeking opportunities to produce high value-added products that leverage their manufacturing bases and employ their labor markets. Indeed, from this perspective, batteries are an attractive product for manufacture because their production can be both capital and labor intensive.[82]

Not surprisingly, China is becoming an increasingly important global production base for lithium-ion batteries. Not only does China dominate the world export share for batteries overall,[83] it is capturing the world export share faster than any other country.[84] In 2005, the

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[78] Ibid.

[79] Tesla Motors website. http://www.teslamotors.com/blog2/?cat=19

[80] China Business Intelligence website. http://www.researchinchina.com/Htmls/Report/2009/5686.html

[81] International Cluster Competitiveness Project, Institute for Strategy and Competitiveness, Harvard Business School, *https://secure.hbs.edu/iccp/index.jsp*.

[82] Robert S. Huckman and Alan MacCormack, "BYD Company, Ltd." Harvard Business School Case, April 2, 2006.

[83] Source: International Cluster Competitiveness Project, Institute for Strategy and Competitiveness, Harvard Business School. Lighting and electric equipment cluster (battery subcluster).

[84] Source: International Cluster Competitiveness Project, Institute for Strategy and Competitiveness, Harvard Business School. Lighting and electric equipment cluster (battery subcluster).

value of China's total battery exports topped $4 billion, compared with less than $1 billion for the United States, and less than $3 billion for Japan.[85] Having surpassed Japan as the major producer of lithium-ion batteries in 2007,[86] China produced 1.5 billion of the 3.5 billion lithium-ion batteries demanded by the global markets in 2008.[87]

Home to major lithium-ion battery manufacturers BYD, BAK and B&K, Shenzhen produced 70 percent of all of the lithium-ion units produced in China with the majority of units produced by BYD.[88] While there are over a hundred lithium-ion battery companies in China, BYD is clearly the largest player in China and has become the dominant player by supplying consumer electronics and mobile phone manufacturers such as Apple and Nokia with battery units.[89] Hence, in examining the potential for the Chinese battery manufacturing industry to produce a cross-boundary disruption, it is only meaningful to consider BYD as a potential disruptor.

Confluence of Non-Market Forces- City of Shenzhen: Complementary goals

Shenzhen was China's first special economic zone and continues to be a hub for high-tech manufacturing and innovation. The city ranks first in foreign trade volume and, coupled with the local absence of incumbent traditional auto manufacturers, Shenzhen provides an ideal hotspot for the development of an electric vehicle manufacturing base.[90] In addition, Shenzhen's local government has already provided a combination of generous subsidies and EV pilot programs.[91] Indeed, with 130,000 workers, a highly desirable portfolio of high-tech products and a rapidly growing presence on the world stage after Warren Buffett's purchase of 10 percent of the company, BYD is one of Shenzhen's crown jewels.[92] While BYD may not have the stated support of the central government, it is arguable that the support of a strong regional government with aligned interests is enough and perhaps more nimble than lobbying politicians in Beijing.

Confluence of Market Forces – EV batteries: Two divergent development strategies

Two strategies have emerged in reducing the range and power-to-weight ratios for EV batteries. The first strategy is to invent, develop and successfully manufacture, in high volume, a very high power-density battery specifically for EV use. The second is to develop and manufacture an integration system that employs commodity lithium-ion battery technology used in consumer electronics – as Tesla Motors has done.[93] Both of these strategies are complementary to BYD's

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[85] Source: International Cluster Competitiveness Project, Institute for Strategy and Competitiveness, Harvard Business School. Lighting and electric equipment cluster (battery subcluster).

[86] "China Surpasses Japan as World's Largest Lithium-ion Battery Maker," *EV World*, July 29, 2008. http://www.evworld.com/news.cfm?newsid=18789

[87] China Li-ion Battery and Its Raw Materials Market Report, 2008-2009, China Business Intelligence website http://www.researchinchina.com/Htmls/Report/2009/5686.html

[88] Rough estimate based on total output of China and sum of outputs from BYD, BAK and B&K.

[89] BYD Annual Report 2008.
http://www.bydit.com/doce/investor/notify_show.asp?year=2008&sort=Annual%20Report

[90] Shenzhen Government Online. http://english.sz.gov.cn/economy/200911/t20091120_1229164.htm.

[91] Wang Zhen, "Shenzhen plans subsidy for hybrid cars," Caijing, June 16, 2009.
http://autos.globaltimes.cn/china/2009-06/437233.html

[92] Marc Gunther, "Warren Buffett Takes Charge," *CNN Money*, April 13, 2009. http://money.cnn.com/2009/04/13/technology/gunther_electric.fortune/

[93] Tesla Motors Company website. http://www.teslamotors.com.

core capabilities. BYD has a competitive advantage with respect to the former strategy as it has the R&D and process engineering capability to systematically explore and prototype disruptive battery technology.[94] BYD also gains with respect to the latter strategy as it currently holds 30 percent of the lithium-ion battery market.[95] Given these two complementarities, the electric vehicle serves as a strategic channel through which BYD can focus its existing capabilities to capture new markets.

Internal company-level conditions

In addition to satisfying the external industry level conditions for a cross-boundary disruptor, BYD's internal company-level conditions also meet the criteria.

- **Culture of innovation:** BYD has a culture of entrepreneurship and innovation. Lacking the capital normally required to start a battery manufacturing firm, BYD invented new battery chemicals that are less sensitive to humidity which eliminated the need for a costly humidity-controlled environment, and developed new processes to optimize the manufacturing of batteries via manual labor. Compared to its competitors, BYD continues to invest disproportionately (3 percent of revenues) in product and process R&D to this day.[96]

- **Resource Rich:** Flush with a capital infusion from the equity markets in 2009, BYD is well positioned to rapidly accelerate its development and manufacturing of electric vehicles. BYD has experienced double digit growth in revenues and net profits for the past few years, decelerating only slightly in the past year due to the recession[97] (See **Exhibit 1**).

- **Hungry for growth:** While BYD still has room to grow its lithium-ion battery business in the consumer electronics market, cell phone and laptop batteries have been largely commoditized and the industry is saturated. To maintain its current pace of growth, BYD must stoke the demand for its commodity products to grow its manufacturing and sales volume as margins wither, while developing a market for premium products in its pipeline.

- B**old Leadership:** Wang Chuan Fu, the man at the helm, has publicly stated his desire and commitment to conquer the world. Behind the scenes, he has established a culture of healthy debate and questioning, which is extremely rare and unique for a Chinese company.[98] The same confidence and ambition that led Mr. Wang and BYD to the number one spot in batteries in less than a decade will propel them to overcome their weaknesses (e.g. lack of B2C sales and marketing capabilities) and tackle the electric vehicle industry.

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[94] Robert S. Huckman and Alan MacCormack, "BYD Company, Ltd." Harvard Business School Case, April 2, 2006.

[95] BYD Annual Report 2008.
http://www.bydit.com/doce/investor/notify_show.asp?year=2008&sort=Annual%20Report

[96] Robert S. Huckman and Alan MacCormack, "BYD Company, Ltd." Harvard Business School Case, April 2, 2006.

[97] Marc Gunther, "Warren Buffett Takes Charge," *CNN Money*, April 13, 2009.
http://money.cnn.com/2009/04/13/technology/gunther_electric.fortune

[98] Based on personal experiences. Phone interview with Liam Casey, CEO of PCH International.

BYD clearly has the potential to play the role of a cross-boundary disruptor in the Chinese EV market. With respect to the propagation of industry change (See **Exhibit** 2), BYD's actions have already impacted the automobile industry by generating media excitement and increasing consumer awareness worldwide. However, whether or not BYD becomes the dominant player in the global market is yet to be seen. Given the price point of its cars ($40,000 USD for the E6 is beyond reach for most Chinese consumers, even middle-income Shenzhen residents) and the external conditions it faces in its home market, BYD is much more likely to succeed first in providing batteries for export EV markets and then in penetrating its home market with its batteries and its EVs.

Conclusions on the Near-term Dynamics of EV Adoption

After evaluating induced government policies, the efforts of activists and the potential for cross-boundary disruptors, the near-term prospects for EV adoption in China look dim. The strong government spending and incentives that have been responsible for China's infrastructure growth and electrification are completely lacking in the case of EVs. Meanwhile, the efforts of activists are conflicting and self-defeating, which makes them unlikely to be able to focus the resources of the NDRC. Finally, while BYD presents a viable XBD candidate, the company still lacks the cost-effective battery technology to disrupt the automotive industry at the present time.

ASSESSING THE FUTURE OF EV ADOPTION – 3 SCENARIOS

Evaluating the future of EV adoption is fraught with uncertainty. In order to mitigate this variance and draw insight, the following discussion pursues a methodological approach. Assessing the future requires three steps.

1) The first step is to define what "future" really means. For the purposes of this analysis – "the future" refers to 2020, or ten years from now.

2) The second step is to identify the key factors that affect the scaling of EV technology. There are four factors that affect EV adoption:
   - **Oil price:** The oil price affects the relative cost of ownership of EV and ICE vehicles and therefore the demand and scaling of EV adoption.
   - **International commitment to addressing climate change:** The international commitment to addressing climate change could create demand for EVs outside of China and thereby create large scale production benefits in the Chinese auto and battery manufacturing industry.
   - **Pace of battery technology advancement:** The cost of a battery with a given power density also affects the relative cost of ownership of EV and ICE vehicles.
   - **Chinese political commitment to addressing environmental issues:** China's level of political commitment to address local and global environmental issues will affect both the relative cost of ownership of EV and ICE vehicles through subsidies as well as the restructuring of the power dynamic between the oil, energy and automotive industries.

3) The third step is to create future scenarios that vary the key factors and draw insights from the implications of each scenario. In order to construct and analyze these scenarios, we built ground-up projections, drew on third-party data sources, relied on expert interviews and used a regression analysis of a data set of Chinese consumer surveys to estimate demand for vehicles at various price points.

Finally, before beginning the scenario analysis, it is worthy of note that we maintained certain "states of the world" constant throughout each of the following analyses. These are:

1) National security and energy security are always a top priority for the Chinese government
2) Social stability and employment are also a top priority for the Chinese government
3) $3,000 vehicles are commercialized for the developing world starting in 2010

Scenario #1: "Coal's (Middle) Kingdom"

Key Variables:

- Oil price: **$75/barrel**
- International commitment to addressing climate change**: Low**
- Pace of battery technology advancement: **Low**
- Level of national Chinese political commitment to addressing environmental issues: **Low**

Narrative

In Scenario #1, global geopolitical relationships sour – the downturn of 2008 and a failure to reach a global post-Kyoto agreement on climate change breed disillusionment and mistrust. To meet growing energy needs, the U.S., China, and other oil importers scramble to strengthen relationships with country's holding the world's remaining oil reserves while aggressively developing coal-to-liquid technology and exploiting tar sands and oil shale. Through the development of intensive 'dirty' liquid fuels, oil prices remain near $75/barrel through 2020. Short-sightedness and volatility in oil prices leads to limited investment in "clean" technologies, including EVs. The $3,000 automobile takes off in China, largely fueled by advanced coal-to-liquid fuels by Shenhua Coal and other state-owned enterprises (SOEs). The flooding of these new vehicles onto the road—along with the coal refineries to create more fuel—intensify environmental degradation while clogging cities with traffic. From the government's perspective, however, the new employment created by China's auto industry and the convenience to drivers ultimately outweighs the air quality concerns. There is no meaningful induced strategy from the Chinese government, while BYD and other battery manufacturers find incremental improvements to existing battery technologies at the historical 8 percent rate, but generate no significant break-throughs.

Implications for EV Costs

With neither induced nor autonomous change taking place in Chinese markets or abroad, the EV manufacturing supply chain does not scale up. We arrive at this conclusion by building a model comparing the relative ownership costs of HEV, PHEV, EV and ICE vehicles. The model is constructed under certain key assumptions – they are described below:

- Within China, existing displacement-based taxes on ICE vehicles provide a modest savings for vehicles using electric technology - $600 for EVs and $300 for HEV and PHEV

- 7,500 miles annual driving range for Chinese consumers (half of the US average due to prevalence of urban driving[99]

- 15,000 miles annual driving range for US consumers

- 33MPG for ICE, 49 MPG for HEV

- $.1/kWh and 4 miles/kWh for EV

- PHEV drives 1/3 in gasoline mode and 2/3 in electric mode

- HEV, PHEV, EVs are assumed to use different electric drive trains, which require batteries with different costs[100]

- Existing battery technology improves at a rate of 8% per year (i.e. equal power density for lower cost)[101]

- Consumers begin to adopt alternatives to ICE vehicles if the payback period (incremental cost above ICE/annual gas savings) is less than 3 years

- An example of the detailed cost calculations can be seen in **Exhibit 3**

The followingchart represents the payback period of a vehicle purchased in a given year for each type of electric vehicle technology. If a particular type of vehicle gains a payback period of less than 3 years, then consumers will view it as practically "cheaper" than an ICE vehicle and will adopt it en masse. This 3 year adoption threshold is labeled on the chart with a red line titled – "Adoption Line." As a reminder, the lines are downward sloping because battery technology improves incrementally every year at the historical rate of 8 percent. The assumed battery prices per kWh are listed across the top of the chart. Please note that these prices should be useful to a reader who may not believe our battery price assumptions. Such a reader can identify the price they find realistic and look to see whether adoption occurs at this price level.

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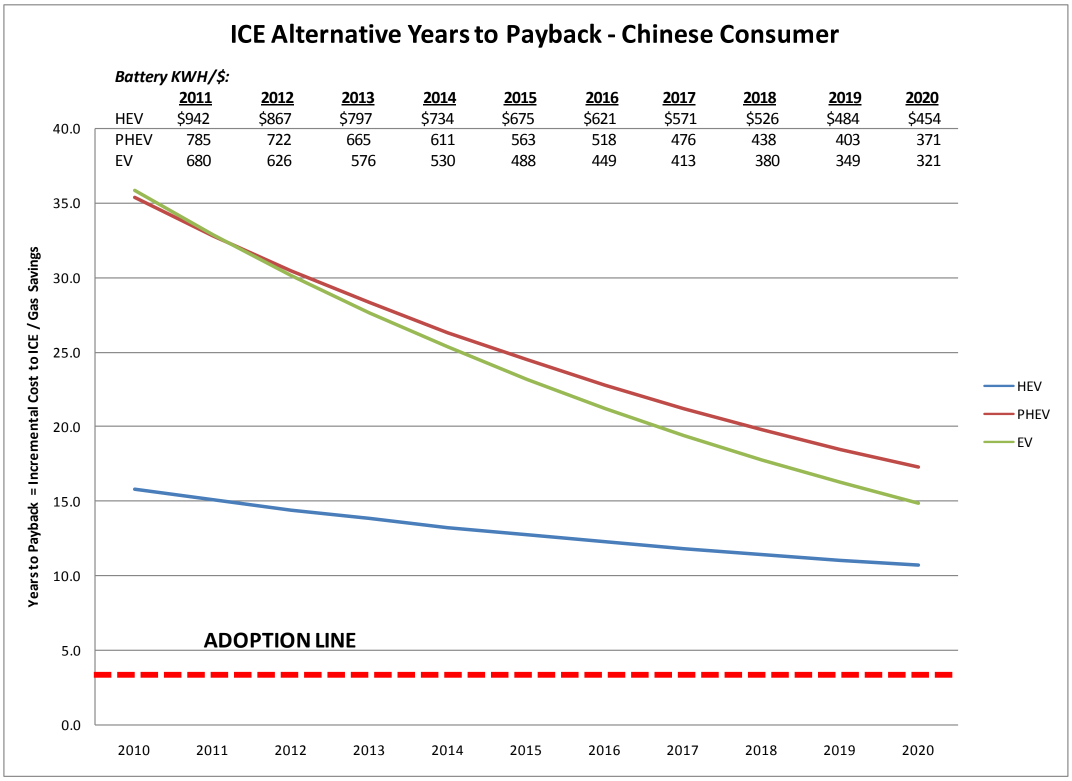
[99] "British drivers on brink of breakdown," Direct Line press release. http://www.directline.com/about_us/news_300605.htm

[100] "Great Leap Forward or Déjà vu? The alternative energy car landscape for China in 2020,"AT Kearney, 2009.

[101] Based on a visit to Tesla Motors.

Implications for EV adoption in China



Source: Created by research paper authors.

Given the high costs and modest government incentives, the model suggests that the EV adoption rate will be stagnant in Scenario #1. As a result, it is assumed that EV sales remain at the current level of 0.1% of total sales.[102] Using a Deutsche Bank projection on total Chinese car sales, we estimated the EV adoption under this scenario as follows:

China EV Adoption in Scenario #1 (000 units)

	2009E	2015E[103]	2020E
EV	10.0	15.8	19.0

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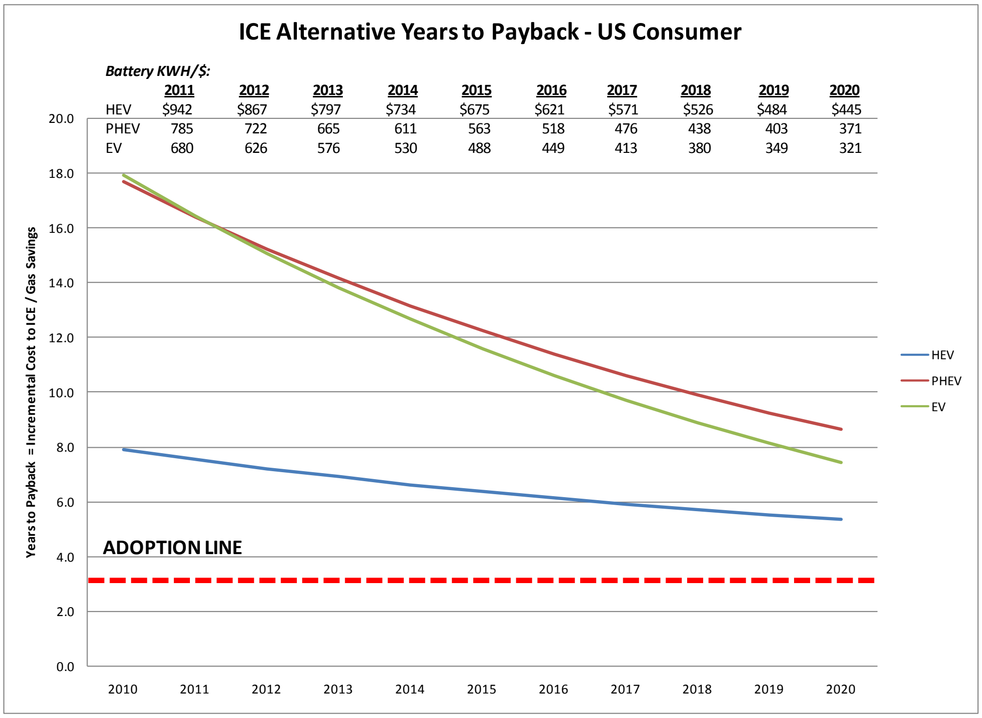
[102] "Electric Cars Plugged-in 2," Deutsche Bank, page 32, 2009.
[103] We took 5 year incremental because the design cycle of cars is 5 years.

Total Auto Sales	9,651	15,828	19,000

Implications for EV Exports to the US:



Source: Created by research paper authors.

Given lower oil prices and a waning global commitment to climate change, we expect global EV sales to be very low overall, since adoption does not make economic sense for consumers. High EV penetration would be limited to smaller markets, with strong government interests in stimulating adoption, such as in Israel and Denmark. In conclusion, in the absence of induced and autonomous forces pushing for EV adoption, the EV production supply chain in China does not scale up.

Scenario #2: “EVs for the World (Not for China)”

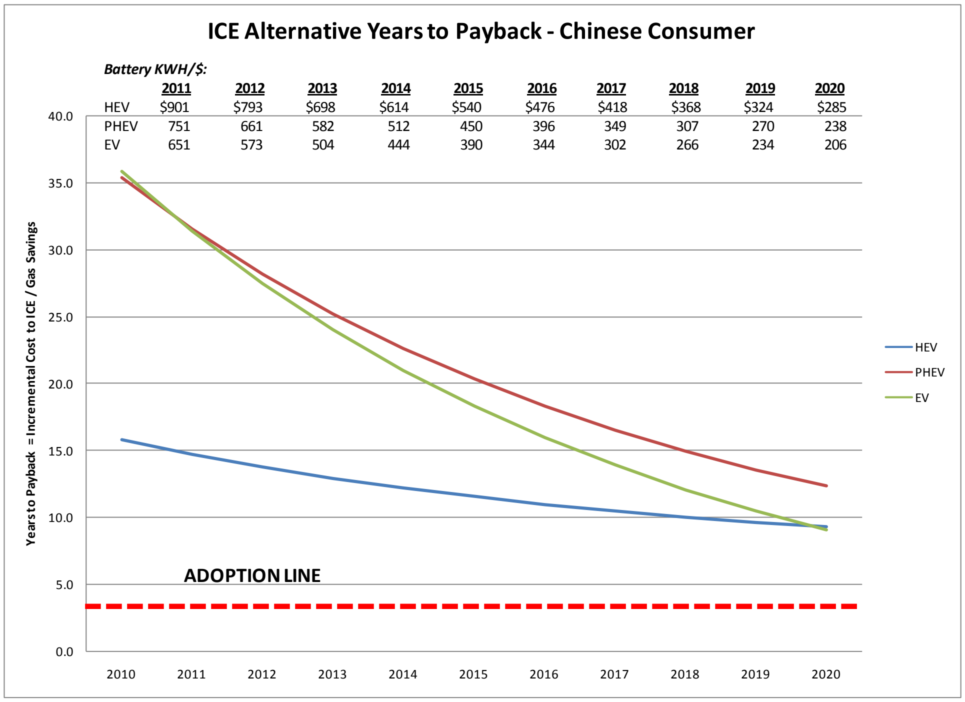
Key Variables:

- Oil price: **$75/barrel**
- International commitment to addressing climate change**: High**

- Pace of battery technology advancement: **Moderate**
- Level of national Chinese political commitment to addressing environmental issues: **Low**

Narrative:
A global agreement on climate change is reached, which includes strong incentives for technology transfer and trade penalties for violation. While the treaty spurs adoption of clean energy technologies in the developed world, China was able to negotiate weak targets as a developing nation; moreover, given cars make up less than 5 percent of China's greenhouse gas emissions, China's post-Kyoto strategy relies heavily on hydroelectric and nuclear power—an extension of its early green stimulus investments. Though the Chinese government maintains its focus on growth over green, Chinese entrepreneurs such as BYD see an opportunity in battery and EV component manufacturing, pursuing export-led manufacturing of electric vehicles batteries; the $3,000 car gives China an 'in' into foreign markets, which OEMs eventually leverage to export their own fully-integrated EVs. As the US shifts to EVs, EV production for export in China scales up and costs to consumers fall.

Implications for EV Costs:
The same cost assumptions used in Scenario #1 are applied to Scenario #2. However, due to incentives to adopt low-carbon vehicles in the US, battery costs are driven down by economies of scale and the learning curve. Specifically, battery prices decline at a rate of 12 percent annually, or 50 percent faster than the historical average. The low level of national Chinese political commitment is reflected in the continued absence of consumer subsidies for purchases of cars with electric technologies. The results of this scenario in China are in the following figure:



Source: Created by research paper authors.

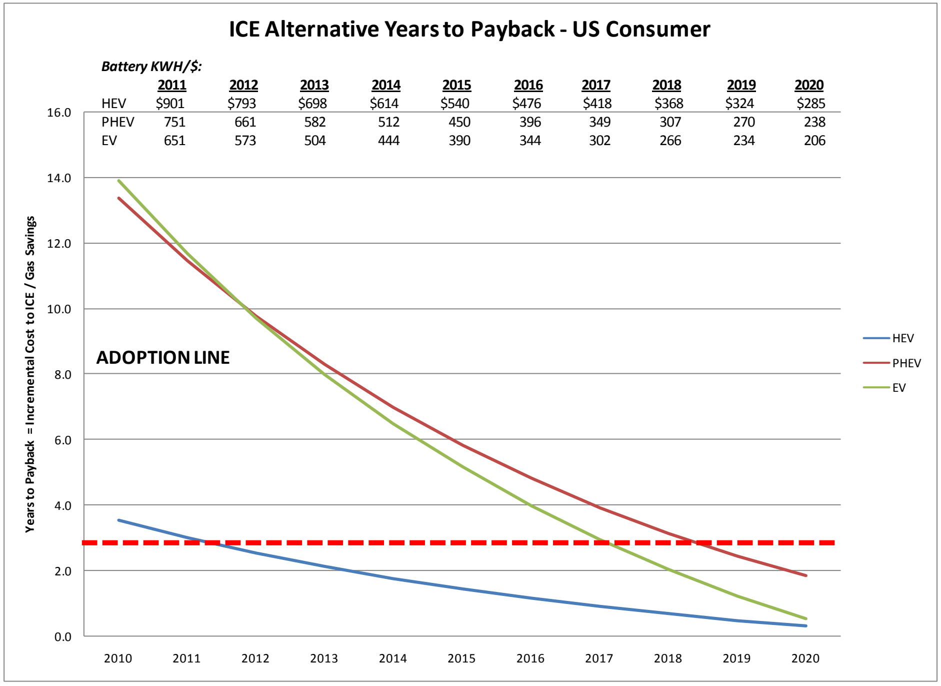
Implications for EV Adoption in China

As in Scenario #1, we see in Scenario #2 that the relative payback period to Chinese consumers is too high to make mass adoption of EVs a reality. Even if rapid efficiency gains are made, the electric technology vehicles do not make economic sense. A key driver of this conclusion is that Chinese people make lower utilization of their cars than in the US (or rather, utilize their cars more closely to urban societies such as those found in Europe) that may allow the Chinese EV production industry to scale. As a result, the ability to generate gas mileage savings is more limited. The only policy solutions to this challenge are to further reduce the relative upfront cost of EVs through subsidies or to fund R&D to improve battery technology at an even faster rate.

As in Scenario #1, Scenario #2 results in an insignificant market share for electric technology vehicles in China through 2020.

Implications for EV Exports to the US:

In this scenario, the US steps up subsidies for electric vehicles as it becomes more concerned with climate change and environmental issues. The cost model assumes a $2,000 subsidy for HEV, $3,000 subsidy for PHEV and a $4,000 subsidy for EVs. The results of these adjustments are in the following figure.



Source: Created by research paper authors.

As one might expect, the addition of subsidies and the increased vehicle utilization bring the payback periods into attractive territory for US consumers. So while, adoption in the Chinese market may be low, the conditions in Scenario #2 – moderate battery innovation and favorable policy abroad – are sufficient to create a meaningful export market for EV batteries (and perhaps its cars). As a final observation, according to our model, the large scale adoption of EVs in Chinese export markets would only occur right before 2020 and not in the immediate future.

Scenario 3: "China – The EV Nation"

Key Variables:

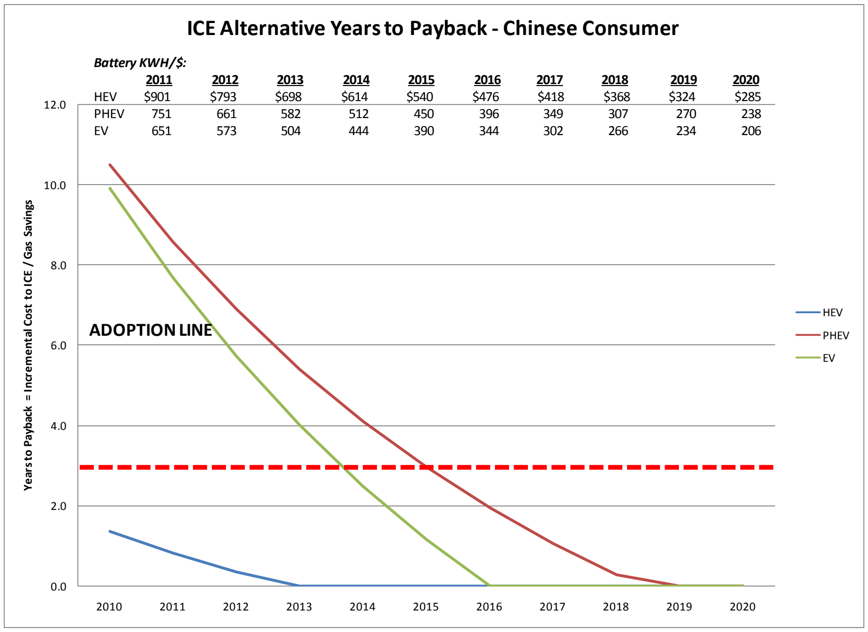
- Oil price: **$150/barrel**
- International commitment to addressing climate change**: High**
- Pace of battery technology advancement: **Moderate**
- Level of national Chinese political commitment to addressing environmental issues: **High**

Narrative

A confluence of high oil prices, energy security concerns, local air pollution concerns, and economic opportunity in the auto sector drive Chinese government to aggressively induce EV development. Early local adoption of EVs is encouraged through subsidies to 'leap frog' the oil-dependent transportation sector. The US government props up and steers incumbent auto players and entrepreneurs to build high-quality EVs With a strong manufacturing base and heavy R&D in Li-ion technology, China becomes a leader in EV manufacturing and in surmounting the challenges of deploying them locally. This positions China as a significant exporter of EVs, first through JVs with companies like Nissan, but eventually of domestic brands, as well. In many ways, China's EV sector shows parallels to the Danish wind sector—by growing strong at home, it was well positioned to enter the global market.

Implications for EV Costs

Scenario #3 uses the same base cost assumptions and 12 percent battery innovation assumption as Scenario #2. In addition, the energy crisis has doubled the price of oil for Chinese consumers. Finally, both the US and Chinese governments extend subsidies to consumers of $3,000 for HEV, $5,000 for PHEVs and $8,000 for EVs. The resulting payback decision curves for Chinese consumers are in the following figure.



Source: Created by research paper authors.

Implications for Chinese EV Adoption

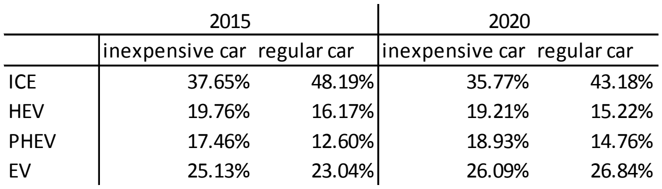
The EV Nation scenario effectively removes the barriers to EV adoption that existed in Scenario #2. Higher gas prices and consumer subsidies resolve the issue of lower vehicle utilization in the Chinese context. It is worthy of note that HEV adoption occurs in the immediate future and EV adoption would not occur at a large scale in China until 2015.

The payback cost curves have helped determine whether EVs would be adopted or not. Now, in order to make a further assessment of the level of EV adoption in China, we used a series of market surveys by AT KEARNY to calculate consumer preferences for vehicles in China. We used the data from the customer surveys to create a regression model that predicts customer adoption at various price points. The model is described by the equation below:

Adoption Index = 71.0 – 2.0 * (Upfront Cost) - .45 * (Operating Cost) + 31.32 * ICE – 2.33 * EV – 17.1 * PHEV – 13.9 * HEV

The detailed statistical tables of this model can be found in **Exhibit 4**. For the purposes of this model, the variables ICE, EV, PHEV and HEV are categorical variables. We also incorporated the inexpensive ICE ($3,000) vehicles into the model. In order to integrate inexpensive ICE vehicles into our model, we considered two different markets - the inexpensive car market and the "regular" car market. In the inexpensive car market, we assumed that the upfront cost of an ICE vehicle would be $3,000. We also assumed that EV manufacturers would respond with an inexpensive EV with a reduced battery size. The cost of the inexpensive EV's is assumed to be $3,000 + the incremental cost of a regular EV over a regular ICE. In the regular car market, we assumed the ICE upfront cost was $15,000.

Entering the results of our cost analyses into the adoption model produced the following output.



	2015		2020	
	inexpensive car	regular car	inexpensive car	regular car
ICE	37.65%	48.19%	35.77%	43.18%
HEV	19.76%	16.17%	19.21%	15.22%
PHEV	17.46%	12.60%	18.93%	14.76%
EV	25.13%	23.04%	26.09%	26.84%

The output strongly suggests that there is a meaningful place for EVs and other electric technology vehicles in Scenario #3 despite the presence of low-cost ICEs. With the relative market shares of each type of vehicle in hand and using the assumption that two-thirds of Chinese vehicle sales will be inexpensive, we can map these figures against an estimate of the overall automobile market in China. The following table applies this methodology to a set of projections prepared by Deutsche Bank on the Chinese auto market.[104]

	2009E	**2015E**	**2020E**
EV (%)	0.1%	24.4%	26.3%
EV (000 Units)	10	3,867	5,004
Total Auto Sales	9,651	15,828	19,000

This methodology results in the expansion of annual Chinese EV sales into the millions of units. At an annual market size of 5 million vehicles per year (greater than Toyota's sales in the US market), there is potential for high scale manufacturing for a number of competitors in the Chinese EV arena. In short, there is a successful mass production and adoption of EVs in China.

Implications for EV Exports to the US

By developing a strong EV product domestically, China's should be able to develop and deploy a leading-edge vehicle and perfect the model domestically. Meanwhile, strong consumer incentives in the US coupled with high oil prices and vehicle utilization would result in widespread adoption of EVs and the potential for exports markets for China as is seen in the following payback analysis.

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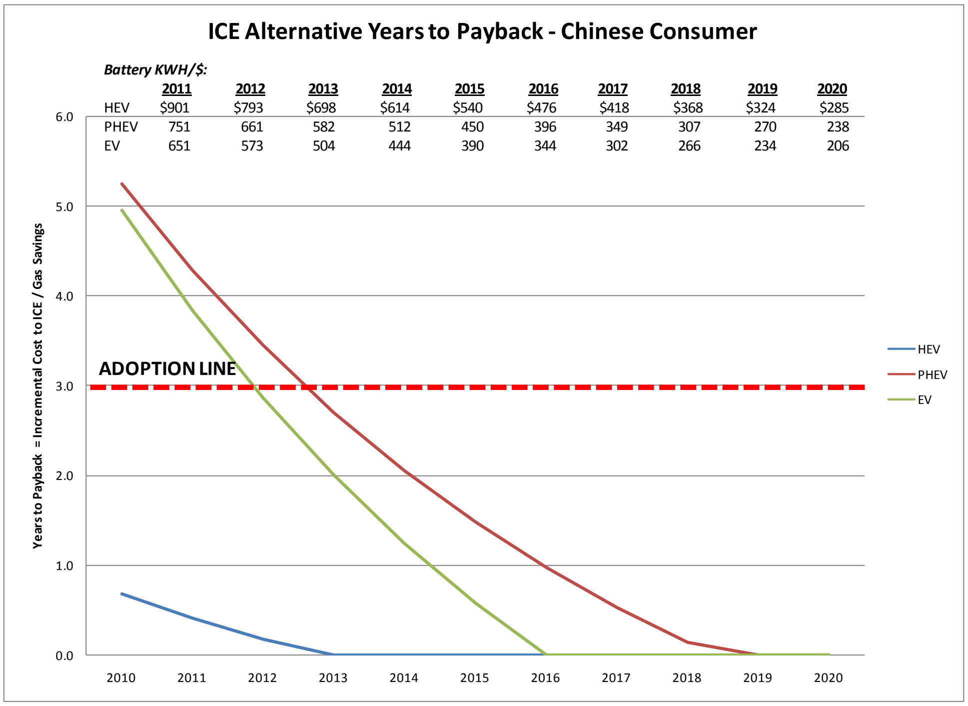
[104] "Electric Cars Plugged-in 2," Deutsche Bank, page 32, 2009.



Source: Created by research paper authors.

CONCLUSION

In aggregate, the 3 scenarios yield a crucial insight: the necessary conditions for adoption are high vehicle utilization or $150 per barrel oil prices AND battery technological innovation at a 50 percent higher rate than the current one AND subsidies to consumers. This result suggests that the US and/or Chinese government must pursue an induced strategy in order to generate the scale of EV adoption necessary to make EVs a viable in product. It is beyond the scope of this paper to weigh-in on the probability that the US pursues a significant strategy to induce EV adoption by U.S. consumers. From the analysis of the Chinese market, however, it is clear that the government is interested in potentially participating in the battery export market, but is not motivated to expend resources to create a meaningful EV market internally. As the assessment of the transportation industry showed, this “wait-and-see” stance is justified, since emissions from automobiles are a tertiary concern for the Chinese government in the intermediate future. Hence, the scaling of the EV supply chain will depend on autonomous actors, such as BYD, finding a massive step-function innovation in battery power density or the US government providing its unbridled support for the industry.

Admittedly, our conclusion relies on China adopting a “wait-and-see” approach that delays EV adoption in the coming ten years, the potential exists for the Chinese government to shift policies during that the next 10 years – thereby rendering our conclusions incorrect. As a result, we thought it is useful to concluding our analysis with a series of “sign-posts” that serve as indicators that Chinese government policy is shifting and rapid EV adoption is imminent.

- The necessary task for EV adoption that requires the longest lead-time is reconciling the interests of the utility companies, oil companies and auto manufacturers. Government efforts to push these industries towards an agreement would indicate that a tectonic shift is in the making.

- A second task that is equally important, but requires less lead time is the implementation of meaningful subsidies for EV adoption. With the cost advantages of HEVs, these subsidies would need to be directed specifically at EVs in order to encourage scaled adoption.
- Finally, a third potential indicator would be for municipal governments to pass laws favoring EVs – these could take the form of bans on ICEs or increased licensing costs on ICEs.

These three sign posts are the key observed actions that would indicate a government policy shift toward supporting EV adoption. Without these actions, the efforts by foreign governments to push EV adoption and the ability of battery manufacturers to generate a technological paradigm shift will be central to forming a large scale EV production supply chain in China and creating widespread EV adoption in China.

Exhibit 1

BYD Company Limited. Key Statistics and Ratios

MARKET CAPITALIZATION

Market Capitalization	$154.14B
Share Price	$67.75
Shares	2.28B

Source: Google Finance. http://finance.google.com

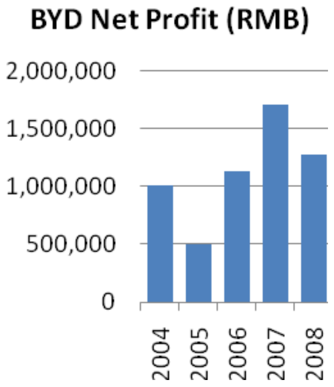
CONDENSED CONSOLIDATED FINANCIAL STATISTICS

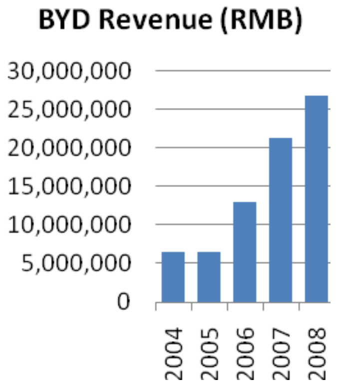
	FOR THE PERIOD ENDING		
	30 September ‘09 RMB ‘000	**30 September ‘08** RMB ‘000	**% Change**
Revenue	26,360,580	18,919,761	39%
Gross profit (for the period)	5,523,357	3,763,655	47%
Net profit (for the period)	2,554,033	991,818	158%
R&D Expenditure	783,139	849,147	-8%
Earnings per share	RMB 1.11	RMB 0.38	192%
Cash and cash equivalents (at end of period)	3,514, 996	1,800,777	95%

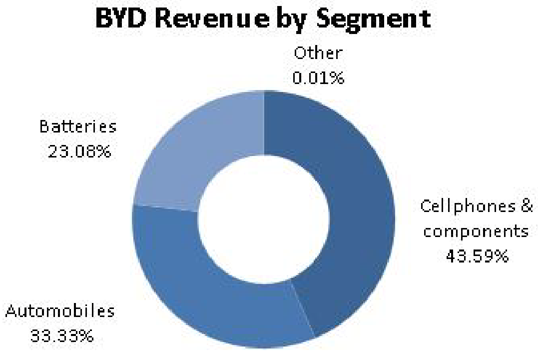
Source: BYD Unaudited Results for the Nine Months Ended 30 September 2006. Approved and posted on 26 November 2009. http://www.hkexnews.hk/listedco/listconews/sehk/20091126/LTN20091126519.pdf

Exhibit 1 (Continued)

BYD Company Limited. Key Statistics and Ratios

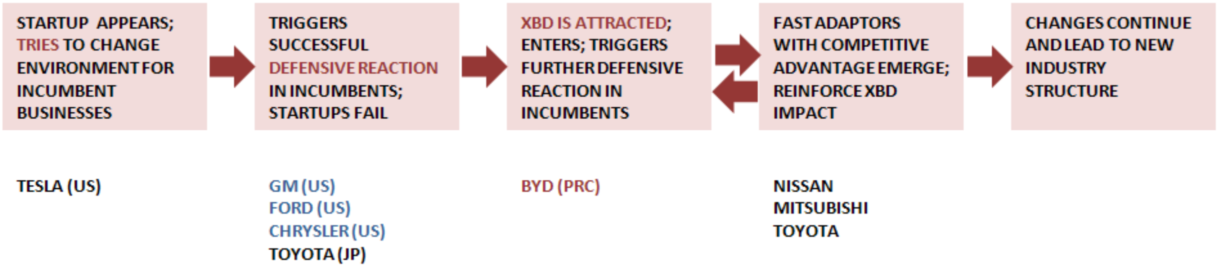






Source: BYD 2008 annual report.
http://www.byd-electronic.com/abu/files/20090421/20090421021430_1156.pdf

Exhibit 2
Cross Boundary Industry Change Propagation for the Global Electric Vehicle Industry



Source: Robert A. Burgelman and Andrew S. Grove, “Cross-Boundary Disruptors: Powerful Inter-Industry Entrepreneurial Change Agents,” *Strategic Entrepreneurship Journal*, December 2007.

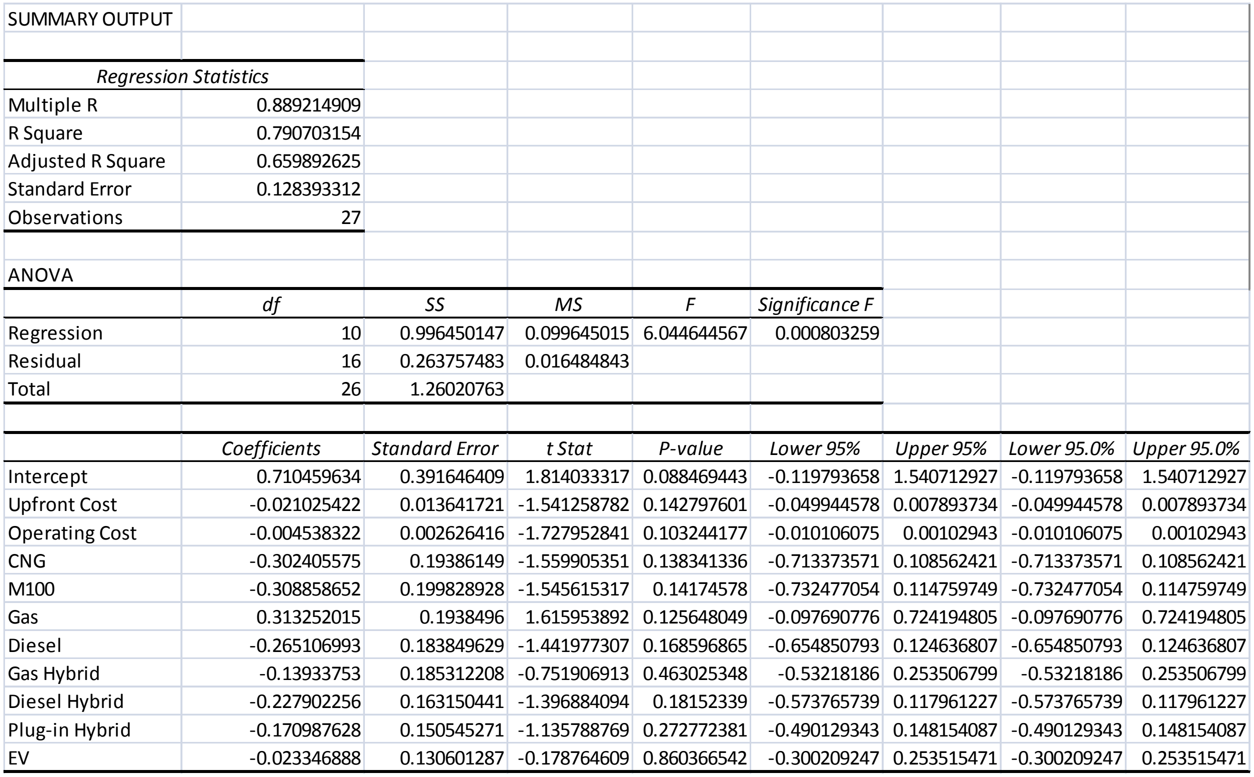
Exhibit 3
Cost Model Detail

Scenario #1

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
HEV											
Battery $/KWH	1024	942	867	797	734	675	621	571	526	484	445
kWH	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Battery Cost	2048	1884	1734	1595	1467	1350	1242	1143	1051	967	890
Incremental Costs	1875	1875	1875	1875	1875	1875	1875	1875	1875	1875	1875
Tax on ICE Displacement	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
Subsidy to Consumer	0	0	0	0	0	0	0	0	0	0	0
Total Incremental Costs	3623	3459	3309	3170	3042	2925	2817	2718	2626	2542	2465
Annual Fuel Savings	229	229	229	229	229	229	229	229	229	229	229
Total Payback Period (Years)	15.8	15.1	14.4	13.8	13.3	12.8	12.3	11.9	11.5	11.1	10.8
PHEV											
Battery $/KWH	853	785	722	665	611	563	518	476	438	403	371
kWH	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Battery Cost	11095	10207	9391	8640	7948	7313	6728	6189	5694	5239	4820
Incremental Costs	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Tax to ICE Displacement	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
Subsidy to Consumer	0	0	0	0	0	0	0	0	0	0	0
Total Incremental Costs	12295	11407	10591	9840	9148	8513	7928	7389	6894	6439	6020
Annual Fuel Savings	347	347	347	347	347	347	347	347	347	347	347
Total Payback Period (Years)	35.4	32.9	30.5	28.4	26.4	24.5	22.8	21.3	19.9	18.6	17.3
EV											
Battery $/KWH	740	680	626	576	530	488	449	413	380	349	321
kWH	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Battery Cost	18492	17012	15651	14399	13247	12188	11213	10316	9490	8731	8033
Incremental Costs	0	0	0	0	0	0	0	0	0	0	0
Tax to ICE Displacement	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600
Subsidy to Consumer	0	0	0	0	0	0	0	0	0	0	0
Total Incremental Costs	17892	16412	15051	13799	12647	11588	10613	9716	8890	8131	7433
Annual Fuel Savings	499	499	499	499	499	499	499	499	499	499	499
Total Payback Period (Years)	35.9	32.9	30.2	27.7	25.3	23.2	21.3	19.5	17.8	16.3	14.9

Source: Created by research paper authors.

Exhibit 4
Statistical Output of Regression Model



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.889214909
R Square	0.790703154
Adjusted R Square	0.659892625
Standard Error	0.128393312
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	0.996450147	0.099645015	6.044644567	0.000803259
Residual	16	0.263757483	0.016484843		
Total	26	1.26020763			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.710459634	0.391646409	1.814033317	0.088469443	-0.119793658	1.540712927	-0.119793658	1.540712927
Upfront Cost	-0.021025422	0.013641721	-1.541258782	0.142797601	-0.049944578	0.007893734	-0.049944578	0.007893734
Operating Cost	-0.004538322	0.002626416	-1.727952841	0.103244177	-0.010106075	0.00102943	-0.010106075	0.00102943
CNG	-0.302405575	0.19386149	-1.559905351	0.138341336	-0.713373571	0.108562421	-0.713373571	0.108562421
M100	-0.308858652	0.199828928	-1.545615317	0.14174578	-0.732477054	0.114759749	-0.732477054	0.114759749
Gas	0.313252015	0.1938496	1.615953892	0.125648049	-0.097690776	0.724194805	-0.097690776	0.724194805
Diesel	-0.265106993	0.183849629	-1.441977307	0.168596865	-0.654850793	0.124636807	-0.654850793	0.124636807
Gas Hybrid	-0.13933753	0.185312208	-0.751906913	0.463025348	-0.53218186	0.253506799	-0.53218186	0.253506799
Diesel Hybrid	-0.227902256	0.163150441	-1.396884094	0.18152339	-0.573765739	0.117961227	-0.573765739	0.117961227
Plug-in Hybrid	-0.170987628	0.150545271	-1.135788769	0.272772381	-0.490129343	0.148154087	-0.490129343	0.148154087
EV	-0.023346888	0.130601287	-0.178764609	0.860366542	-0.300209247	0.253515471	-0.300209247	0.253515471

Source: Created by research paper authors.

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Chapter 6

CARBON CAPTURE AND STORAGE IN THE U.S.: FACT OR FICTION – TWO PATHS TO 2030*

*This chapter was prepared by Jamie Perencevich, Anshuman Sahoo and Kathleen Shattuck.

INTRODUCTION

In the U.S., coal is a critically important resource, providing nearly half of U.S. electricity generation (See **Exhibit 1**). Yet the combustion of coal produces more carbon dioxide emissions per unit of energy produced than any other fuel, resulting in adverse climate change impacts. In the U.S. alone, combustion of coal for electricity produced 1,980 million tons of CO_2 in 2007, roughly equivalent to all emissions from the transportation sector (See **Exhibit 1**). Coal produces over 80% of electricity sector emissions: thus, any strategy to reduce emissions from this sector must directly address coal.

To further complicate matters politically, coal is a key source of energy security in the U.S.: it exists in abundance, and reserves are broadly distributed through Appalachia, the Midwest and the Mountain West, creating a powerful coal state lobby. Current U.S. reserves are expected to last for approximately 230 years, given current levels of production.[105] As a result, coal is likely to remain a key part of the U.S. energy mix for years to come.

Herein lies the attraction of carbon capture and storage (CCS) technology. Yet, while politicians, the media, industry and environmental groups have made much of the promise of CCS technology, little demonstrable progress has occurred to date. The remainder of this paper will explore the disconnect between rhetoric and action, evaluate likely CCS deployment scenarios under the status quo and an accelerated “stress” case, and assess the implications of these analyses for policymakers, businesses, and other stakeholders.

OVERVIEW OF CARBON CAPTURE AND STORAGE IN THE U.S.

Although CCS is frequently spoken of as a single technology in the media, it actually comprises a system of technologies, many of which have been in commercial use for many years in other applications. A CCS system is comprised of three components: capture/compression, transportation, and storage.

Capture and Compression Technologies

Capture and compression technologies separate a relatively pure CO_2 stream from an emissions source and pressurize it for transport. Capture and compression comprise the most expensive part of a CCS system, accounting for 60-80% of total costs.[106] Three principal technologies exist today to capture CO_2 at a point source: post-combustion capture (PCC), pre-combustion capture (IGCC) and oxyfuel combustion technologies. As PCC and IGCC technologies are presently the most advanced in the U.S., our focus is on these alternatives.

- **Post-combustion capture:** Post-combustion capture technology separates CO_2 from flue gas using a sorbent or solvent after the fuel has been combusted. As a result, it can be retrofitted to an existing coal plant.

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[105] U.S. Department of Energy, BP Statistical Review of Energy.

[106] “*Carbon Capture & Storage: Assessing the Economics*,” 2008. p. 17, McKinsey & Company.

- **Pre-combustion capture:** Pre-combustion capture technology (principally, integrated gasification combined cycle, or IGCC, technology) converts coal into a syngas prior to combustion. The syngas is run through a shift reactor to separate CO_2 from H_2, and the hydrogen is used to power a combined cycle gas turbine, improving the plant's efficiency.

The most important difference between PCC and IGCC is the energy penalty, or "parasitic load" associated with the technology, which presently makes CCS prohibitively expensive. In PCC, the flue gas stream contains very low concentrations of CO_2 (12 to14 percent), which makes it more difficult to separate: additional energy must be put into the system to regenerate the sorbent, reducing the plant's overall efficiency by 30 to 40 percent.[107] In the case of IGCC, the gas stream contains a higher concentration of CO_2 (40 to 60 percent), so physical rather than chemical separation methods can be used, making separation less energy intensive. Efficiency is also gained through the combined cycle gas turbine. As a result, the parasitic load for an IGCC plant is lower, on the order of 15 to 20 percent.[108] (See **Exhibit 2** for an example comparison of the parasitic load losses between these two technologies.)

However, parasitic load is not the only cost to CO_2 capture: the energy penalty must be traded off against the capital cost of construction for each type of plant. IGCC plants have a lower energy penalty, but higher capital costs versus pulverized coal plants. For example, Duke Energy's 630 MW Edwardsport IGCC plant currently under construction is estimated to cost $2.5 billion (excluding CCS modifications), equivalent to a cost of $3,968/kW.[109] By comparison, Duke is also building an 825 MW supercritical pulverized coal plant, Cliffside, which is projected to cost $2.4 billion, equivalent to $2,910/kW.[110] While capital costs will vary significantly by site and project, the relative difference illustrated here is representative of a typical spread between these two power plant technologies.

Transportation Technologies

Transportation technologies transfer CO_2 from a point source to a storage site via pipelines, trucks, or ships. These technologies are generally considered to be very mature, due to lengthy experience around the world transporting commodities such as oil and gas via existing pipeline and shipping networks. In the U.S., approximately 3,900 miles of CO_2 transportation pipelines currently exist for use in enhanced oil recovery (EOR), primarily in West Texas and the Rockies.[111] These pipelines transport approximately 49.9 $MtCO_2$ annually.

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[107] J. Wilcox, ENERGY 273: Carbon Capture and Storage. Lecture, Stanford University (October 2009)
H. Herzog, "Capture Technologies and Costs," presented at Workshop on Capacity Building for Carbon Capture and Storage, Pittsburgh (May 2007).

[108] Ibid.

[109] "Duke Energy Indiana Files Cost Update for Clean Coal Power Gasification Power Plant," Company press release, November 24, 2009.

[110] J. Downey, "Duke Energy's Cliffside Project Remains on Schedule," *Charlotte Business Journal,* October 2, 2009.

[111] J.J. Dooley, R.T Dahowski and C.L. Davidson. "Comparing Existing Pipeline Networks with the Potential Scale of Future U.S. CO_2 Pipeline Networks," Energy Procedia 1, February 2009, p. 1595-1602.

Storage Technologies

Storage technologies permanently sequester CO_2, primarily via injection into geological reservoirs (e.g. depleted oil and gas fields, saline formations or for EOR). Research is also underway to examine the feasibility of injection into the ocean, as well as technologies that would transform CO_2 gas into solid carbonate forms. Geological storage has significant precedent, most notably EnCana's Weyburn project in Saskatchewan (an EOR field), Statoil's Sleipner project in Norway (operational since 1996) and BP/Statoil's In Salah project in Algeria.

Thus, while no aspect of CCS presents an insurmountable technical obstacle in and of itself, much of the challenge lies in reducing the energy penalty of the capture technology and integrating a system of components at reasonable cost. The opportunity for CCS in the U.S. lies not only in retrofitting the U.S.' large installed CCS base, but also in building new IGCC plants with capture systems. The majority of U.S. coal plants will need to be replaced within the next 20 to 25 years, presenting opportunity to deploy new technologies.

OBSERVED AND STATED U.S. ACTIONS

Recently, the U.S. government has both stated and demonstrated increased commitment to reducing greenhouse gas emissions. In July, the House of Representatives passed the Waxman-Markey American Clean Energy and Security Act of 2009, landmark climate change legislation. The Senate is presently drafting and debating its own version of climate legislation. And in the executive branch, the President recently announced, in advance of the international climate talks at Copenhagen, that the U.S. will aim to reduce emissions by 17 percent from 2005 levels by 2017 and by 80 percent from 2005 levels by 2050. Thus, the U.S. has demonstrated a stated interest in reducing emissions. However, the specific path to achieving this is still unclear.

In the past year, the government has committed significant capital to CCS. It remains questionable as to whether this financing is sufficient to achieve stated policy goals. Government actions indicate that the federal government is focused on CCS as one of many emissions reducing technologies. Secretary of Energy Steven Chu stated in a letter to international energy ministers: "I believe we must make it our goal to advance carbon capture and storage technology to the point where widespread, affordable deployment can begin in eight to ten years."[112] Congress has supported the Department of Energy's (DOE's) aims by appropriating \$3.4 billion (9.3 percent) of the \$36.7 billion of Recovery Act funding to CCS; an additional \$8 billion in loan guarantees has been appropriated to support advanced fossil fuel technologies. These programs will support demonstration and commercialization of largely existing technologies. However, limited funds have been designated to date for research and development of novel technologies.

In Congress, Senators Jim Webb (D-VA) and Lamar Alexander (R-TN), introduced the "Clean Energy Act of 2009", augmenting the DOE's total loan guarantee authority to \$100 billion and providing \$750 million per year over the next ten years to fund a variety of clean energy

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[112] US Department of Energy, Letter from Secretary Chu. http://www.netl.doe.gov/publications/press/2009/ccs_letter_s1.pdf

technologies, including CCS.[113] This contrasts with Senator Dorgan's (D-ND) recent proposal, which calls for several times this amount of funding to be devoted exclusively to CCS: up to $450 billion over the next 25 years, which includes $5 to $7 billion for research and development, $5 to $25 billion on demonstration projects, and $100 to $415 billion on early-adopting plants. The executive branch is also showing interest in furthering CCS; President Obama recently discussed developing a technical cooperation program on CCS with China.

Often, CCS projects are initiated by autonomous organizations with the expectation of federal funding to follow (e.g. Duke's Edwardsport project will demonstrate capture for 20 percent of emissions). Early deployment of technology has been driven primarily by government funding. Without incentives such as a carbon price, autonomous organizers have little incentive to independently scale-up costly CCS technology. American Coalition for Clean Coal Electricity (ACCCE) members report that 34 percent of funding for CCS projects through 2008 has come from the DOE, and in many cases this figure is even higher.[114] We have observed that both the government and autonomous organizations are keen to collaborate on CCS projects; however uncertainty persists about the government's commitment to these projects.

Despite this, the FutureGen project has compromised industry's view of federal commitment to advancing CCS technology. The FutureGen Coalition partners DOE with thirteen power producers and utilities, as well as international partners, to develop a commercial IGCC/CCS plant. DOE is providing 74 percent of funding; however, the slow and stunted progress of the FutureGen project since 2005 demonstrates a lack of consistent governmental support (**Exhibit 3**).[115] The project was slow to start, and then the Bush administration halted funding for FutureGen in 2008. The Obama administration has restarted the project, but skepticism persists as to the government's ability to and interest in following through over the long term.

Activists have also played a significant role in stimulating interest in CCS by virtue of their adamant and successful opposition to traditional pulverized coal plants. Notable activist efforts include Environmental Defense Fund's (EDF) influence on the TXU buyout, as well as numerous favorable court rulings for EDF, the Sierra Club and the Natural Resources Defense Council (NRDC) to stop or substantially delay new pulverized coal plant construction. Unfortunately, while these efforts have largely succeeded in halting the construction of "dirty" coal projects, activists have not coalesced around a single viewpoint on CCS. Many environmental groups oppose coal unilaterally, with or without CCS. The divergence in views has reduced the efficacy of this sector to successfully organize and lobby change. Both the U.S. Climate Action Partnership (USCAP) and the American Coalition for Clean Coal Electricity (ACCCE) have the capacity as activist groups to autonomously drive the adoption of these technologies; however, while each has brought together those interested in seeing this happen,

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[113] "Alexander, Webb Introduce Bipartisan Clean Energy Legislation with Emphasis on Nuclear Energy Investment." Jim Webb: U.S. Senator for Virginia press release, November 16, 2009. http://webb.senate.gov/newsroom/pressreleases/2009-11-16-01.cfm

[114] Daniel Weiss, "The Clean Coal Smoke Screen," The Center for American Innovation, December 22, 2008. http://www.americanprogress.org/issues/2008/12/clean_coal.html

[115] Mira Kim, "FutureGen." Presentation at Ken Law School, April 24, 2009. http://www.kentlaw.edu/faculty/fbosselman/classes/energysp09/Coursedocs/FutureGen.pdf

they have not yet inspired sufficient cause for action through their efforts.[116] Across all activists concerned with climate change and energy solutions, there is a lack of a unified voice on account of disagreements on how to go about solving the very large, complex problem of reducing emissions. This has diluted the influence of activist groups on driving CCS adoption, though it has helped these groups to oppose traditional coal and draw attention to the problem.

Thus, while both stated and observed actions to date indicate a growing interest in CCS on the part of both government and industry in the U.S., we must examine whether enough capital will be allocated to achieve the necessary funding and technology improvements to realize CCS deployment at scale. An analysis of status quo versus accelerated CCS deployment seeks to answer this question.

SCENARIO OVERVIEW

We distill implications for CCS development and deployment in the U.S. within the context of two scenarios. The first, the "status quo" case, assumes that the observed actions to date accurately reflect current interest in and support for CCS. This case projects that CCS is introduced at a rate justified by and consistent with these actions. The second, the "stress scenario" case, considers an aggressive U.S. goal to reduce CO_2 emissions by 50 percent relative to business as usual by 2030, with the deployment of CCS technology a national priority. A comparative evaluation of these cases allows us to explore both *what will happen*, assuming business as usual, and *what needs to happen* for rapid CCS deployment. In both cases, we identify the extent of CCS deployment by 2030 as well as the required investment levels and resource and regulation developments.

Status Quo Scenario

The actions to date considered in the first case are as summarized in the previous section, which suggest that although the U.S. has stated a strategic commitment to CCS technology, the observed demonstrated financial commitment has not been similarly convincing. The total capacity of CCS projects with financing secured is limited; approximately twelve CCS projects are in progress, but only one, the FutureGen project, is at commercial scale.[117] The status quo case assumes a growth rate for CCS without extraordinary public sector support. We approximate this growth rate by the growth of nuclear energy capacity between 1969 and 1986 to project the build-out of CCS capacity in the U.S. The implied build out is input into a cost model to determine the total investment costs in CCS, the achievable CO_2 reductions from coal-fired power generation, and the resources that would need to be developed in tandem.

Stress Case Scenario

Akin to the process of shipbuilding and airplane manufacturing acceleration during World War II, we assume in the second case that a number of enablers for rapid deployment of CCS are

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[116] H. Rao, "Market Rebels: How Activists Make or Break Radical Innovations," Princeton: Princeton University Press, 2009, p. 174.

[117] FutureGen Industrial Alliance, Inc., December 2, 2009.
http://www.futuregenalliance.org/about/timeline.stm

simultaneously present. The case postulates, for example, that industrial capacity is re-directed towards the manufacture of CCS technology components, engineers are re-trained to design and build CCS projects, the licensing and permitting process is accelerated, and the private sector either faces or is convinced of an imminent high price on CO_2 emissions. In this case, we assume that the U.S. can build CCS plants at a rate equal to that with which the Chinese are currently building conventional coal plants. Here, the implied build out is input into a cost model to determine the total investment needed to achieve the hypothetical U.S. CO_2 emissions goal. Finally, the required resource build out is considered.

In the two sections that follow, we present our case analyses in three parts:

- *Technology and Timing*: which outlines our assumptions about how the construction of coal-fired power plants with different technologies will be timed through 2030;
- *Financing*: which describes our assumptions about investment requirements, adjusted for learning effects; and
- *Resource Constraints*: which analyzes the transport, storage, and workforce requirements for CCS deployment.

STATUS QUO SCENARIO

Technology and Timing

The pace of coal fired power plant deployment has historically been a byproduct of the baseload generation needs of regional utilizes and power companies. Projected demand increases, combined with and on-time or early plant retirements have led to a gradual build out of over 300 GW of coal-fired electricity nameplate capacity to date in the United States. Most U.S. coal plants utilize traditional pulverized coal technology that has been in existence for decades. Many of these older plants have been retrofitted with SOx, NOx capturing technologies. Pulverized coal plants built today, as is the case with a 200 MW plant recently constructed in Springfield, Illinois, take approximately six to eight years to complete from start to finish.[118]

Improvements in coal power plant technology are ongoing, with IGCC technology at the forefront of implementable innovation. Presently, these plants are expected to take longer to build than pulverized coal. By way of comparison, Duke's Edwardsport IGCC plant is scheduled for completion in 2012 after approximately eight to ten years of development and construction.[119,120] Similarly, the FutureGen Coalition has been making its way forward in an on-again, off-again, on-again highly-anticipated effort to complete a full scale demonstration IGCC with CCS facility in Mattoon, Illinois. The plant is to be 275 MW and will take approximately 12 to 14 years to be build, with completion in 2016 or 2017.[121]

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[118] "Building a New Power Plant," City Water, Light & Power website, November 5, 2009. http://www.cwlp.com

[119] "Edwardsport Integrated Gasification Combined Cycle (IGCC) Station," Duke Energy website. http://www.duke-energy.com

[120] Gasification Technologies Council, Duke Energy Indiana Edwardsport IGCC Project Update, October 5-8, 2008. http://www.gasification.org/Docs/Conferences/2008/16SEARS.pdf

[121] FutureGen Industrial Alliance, Inc. Timeline. http://www.futuregenalliance.org/about/timeline.stm

Based on projections from the U.S. Energy Information Administration, nearly 380 GW of nameplate capacity will need to come online by 2030 to meet coal's projected portion of U.S. electricity generation needs (see **Exhibit 4**). In addition to the build out of new facilities, the replacement of retiring plants, whose lifetimes are assumed to be 60 years in maximum duration, will play a significant part in meeting this demand. **Exhibit 5** shows Cumulative Generation Nameplate Capacity of the present fleet of built and planned coal-fired generating facilities, assuming plants were allowed to go off-line without replacement by new facilities. Visualized in terms of retiring plants, **Exhibit 6** shows the MW of Nameplate Capacity retiring in each year up until 2030. With an average plant age of 42 years and an assumed lifetime of 60 years, it is notable that a significant number of plants will need to come on line in 2030 in order to offset the capacity that will reach retirement age in approximately 20 to 25 years.[122]

Looking forward into the future and making an educated estimation about the rate of build out of new coal-fired power plants utilizing IGCC and CCS technology requires the consideration of anticipated technology improvements, financing ability, and political capabilities. As each of these aspects is difficult to project out for five years, let alone 10 or 20 years, comparable examples of the build out of large-scale, new-technology power generating facilities prove useful in estimating the rate at which new facilities are technologically ready to scale, paid for, and politically adopted. We have identified the nuclear power generation build out in the U.S. from 1969 to 1986 an adequate proxy for future build out of IGCC/CCS technology in the U.S. To be certain, this is a rough approximation, but this comparable captures the important aspects of U.S. market presence, large-scale, high-cost, new-technology adoption, construction/engineering services constraints, and new-infrastructure build out (spent waste disposal system). **Exhibit 7** contains the installed MW of nameplate capacity and the associated annual growth rate of nuclear power over the seventeen year period identified.

For the status quo scenario, we have applied the growth rate of new nuclear installation to the U.S.' initial IGCC/CCS plant (275 MW FutureGen) to form a prediction of installed MW of IGCC/CCS capacity in the U.S. from 2008 to 2030 (see **Exhibit 8**). Under this scenario IGCC/CCS capacity grows to 9.1 GW by 2030, with traditional pulverized coal comprising 370.8 GW, which translates into a 16.5 percent increase in traditional nameplate capacity of coal-fired power plants by 2030. Taken as a proxy for emissions (which is rough, considering efficiency gains in plant operation over time), this scenario clearly does not contribute significantly to meet the President's stated target of a 17 percent emissions reduction from 2005 levels by 2030, much less 2017, requiring substantial emissions reduction efforts from other sectors of the economy.

Financing: Investment Requirements

As discussed previously, a chief hurdle to CCS deployment to date has been its high cost; McKinsey, for example, assumes a present CCS cost of \$80 to \$120/tCO_2 abated, which implies first that a suite of other abatement technologies could more economically be pursued to abate CO_2 emissions and second that a commensurate price of CO_2 emissions could trigger CCS

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[122] Energy Information Administration, Electricity: U.S. Data: Electric Power Plants. http://www.eia.doe.gov/fuelelectric.html

development. Note that the low cost estimate assumes the presence of some economically favorable (e.g., enhanced oil recovery (EOR)) opportunities (see **Exhibit 9** for CCS cost estimates). **Exhibit 10**, McKinsey's Global GHG abatement cost curve – 2015, does not even list CCS as a near-term abatement option; the abatement curve shows abatement options in order of increasing abatement costs, with the width of each option's bar representing the total yearly abatement potential. Such estimates have empowered CCS detractors.[123]

We examined the implied investment costs for CCS under the two scenarios, but assumed that the cost of CCS would fall as a function of cumulative installed CCS capacity, according to the experience – or learning – curve effect, which asserts that unit costs fall by some percent with each doubling of cumulative installed capacity.[124] Without empirical data on CCS unit costs, we use industry comparables to estimate the percent by which unit costs fall. We estimated that unit costs would fall by 12 percent, for a learning percent of 88 percent, with each doubling of capacity. This was based on our expectation that the price trajectory would be something between that of the aerospace industry, with a learning percent of 85 percent, and of repetitive welding operations, with a learning percent of 90 percent.[125] Once the installed capacity is above 40 GW, we switch to a low learning scenario, in which the learning percent is modified to 96 percent. This matches the learning percent observed in raw materials manufacturing.[126]

To calculate the required investment in CCS through 2030, we split the 2009 – 2030 timeframe into four time periods: 2009 – 2015, 2015 – 2020, 2020 – 2025, and 2025 – 2030. CCS costs in each period were decreased based on the installed capacity of CCS at the end of the previous period. The timing assumptions shared in the above subsection implied installed capacities of 745 MW, 4 GW, 5.7 GW, and 9.1 GW by 2015, 2020, 2025, and 2030, respectively (see **Exhibit 8**). Based on these capacities, and the McKinsey estimate of \$80 to \$120/tCO_2 abated for 2009 - 2015, we estimated the following CCS costs per ton of CO_2 abated: \$56 to \$84 in 2015 - 20, \$48 to \$72 in 2020 – 2025, and \$35 to \$53 in 2025 – 2030 (see **Exhibit 11** for status quo cost evolution). These costs imply a total required investment of \$70 to \$105 billion between 2009 and 2030 to achieve the status quo scenario 9.1GW CCS capacity installation.[127]

Moreover, we approximated the magnitude of CO_2 abated in the coal-fired power sector from the new CCS capacity. Based on a CO_2 intensity of 6,396 tons CO_2 emitted/ MW of coal-fired electricity, we estimate that the status quo investment would yield 41 MtCO_2 abated in 2030. Further assuming that abatements in the coal-fired electricity sector would represent 10 percent of economy-wide abatement, in-line with IEA estimates, we calculate that the total magnitude of

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[123] Lorne Gunter, "Carbon capture costs show folly of idea," *Edmonton Journal*, November 29, 2009. http://www.edmontonjournal.com/health/Carbon+capture+costs+show+folly+idea/2282130/story.html

[124] Based on Henderson's Law, a power law function developed by the Boston Consulting Group that describes the experience curve. For more information see:
http://209.83.147.85/impact_expertise/publications/files/Experience_Curve_V_Price_Stability_1973.pdf

[125] "NASA Cost Estimating Web Site Learning Curve Calculator," NASA website.
http://cost.jsc.nasa.gov/learn.html

[126] Ibid.

[127] Assumes 6,396 tons CO_2/MW of coal-fired electricity. (Based on data available at http://www.eia.doe.gov/oiaf/1605/coefficients.html and http://www.ucsusa.org/clean_energy/coalvswind/brief_coal.html), a 70 percent capacity factor, a 35 year amortization of investment costs, and a 100 percent capture of CO_2.

abatement was 410 $MtCO_2$, or 4.2 percent of estimated business-as-usual (BAU) emissions in 2030 (see **Exhibit 12** for estimates of relative abatement shares by sector).

Resource Constraints

We further identified resource constraints as a potential key limit to large-scale CCS deployment in the U.S. In particular, three constraints are of potential concern. First, CCS scale-up will require the development of CO_2 storage hubs and pipeline networks beyond current CO_2 transportation capacity. Second, CO_2 storage sites will need to be identified and connected to the network of pipelines. The government will congruently need to develop standards on CCS risk site assessment as well as on the mineral rights and liability issues associated with storage. Further research on the efficacy of specific storage sites will need to be undertaken. Lastly, human capital poses a final constraint: are there enough specialized engineers in the U.S. to achieve full-scale CCS deployment? While many of these potential bottlenecks exist in both the status quo and the stress case, we will examine each of these three constraints in each scenario.

CO_2 Pipelines

CO_2 transport through pipelines is a proven technology, with 6,275 km (~3900 miles)[128] of pipelines currently installed with a transport capacity of 49.9 $MtCO_2$/yr.[129] Most of these pipelines are in West Texas and the Rocky Mountain region (**Exhibit 13**). By overlaying a map of current U.S. emissions sources with geologic storage capacity in the U.S., we see that most of significant sources of emissions are co-located with storage sites (**Exhibit 14**). Therefore, in the status quo scenario, limited pipeline build out is required to achieve the needed CCS deployment. NETL confirms this with an assumption that the average distance CO_2 needs to be transported in the U.S. is 40 km.[130] For purposes of analysis, we will use this figure as an average transport distance from capture to storage site. The rate of the build out of existing CO_2 pipelines was 15 percent annually over the last 28 years, from 1972 to 2000. We assume that this represents the status quo build out rate going forward.

At this same rate of status quo pipeline deployment, we would build pipelines sufficient to transport emissions generated by 14.1 GW of coal-fired power, at a cost of $0.80 billion by 2030. This easily surpasses the necessary capacity requirement of 9.1 MW as calculated above. In fact, the status quo growth of pipelines could slow to 12.5 percent annually to meet the 9.1 MW capacity requirement, at a cost of $0.5 billion. As pipeline construction is a well-established and large industry in the U.S. with significant operating history and experience in the oil and gas industry, among others, we believe that there are easily adequate resources to build at this rate. Therefore, this is not expected to be a significant constraint to CCS deployment.

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[128] JJ Dooley, “Comparing Existing Pipeline Networks with the Potential Scale of Future U.S. CO2 Pipeline Networks.” *Science Direct,* 2009.

[129] Paul Fruend, “IPCC Special Report on Carbon Dioxide Capture and Storage.” Intergovernmental Panel on Climate Change (IPCC) website.

[130] “Carbon Sequestration Atlas of the U.S. and Canada,” Department of Energy - National Energy Technology Laboratory (NETL).

CO_2 Storage Sites

In the U.S., substantial CO_2 sequestration resources exist. Geologic storage capacity in the U.S. is estimated to be 4 to 14 trillion tCO_2.[131] By comparison, in 2007 stationary sources emitted 3.2 $GtCO_2$.[132] This indicates that the U.S. has sufficient resources to sequester its stationary source emissions for hundreds of years. Therefore, the largest constraint for storage becomes the cost of developing the sites. While further mapping of storage sites is required, this is feasible, particularly with involvement from the national labs and government resources. $50 million in Recovery Act funding has been allocated to this purpose.[133] Further costs of the storage sites include material, equipment, installation, monitoring, maintenance, design, project management and insurance.

Under the status quo scenario, an estimated 41 $MtCO_2$ will need to be stored, as previously shown. McKinsey estimates that the average cost to store a metric ton of CO_2 is $6.71.[134] This yields a total cost of $275 million for CO_2 storage sites. As with transportation, we do not believe this cost represents a bottleneck in CCS deployment.

Human Capital

Potential work force constraints arise from a dearth of engineers who are capable of deploying CCS. The number of engineering degrees conferred each year in the U.S. has been constant since the early 1980s (see **Exhibit 15**), however an increasing number of those are computer science focused.[135] Will there be enough qualified energy engineers going forward to sustain the growth of CCS? This remains an outstanding question, but if enough capital is devoted to CCS innovation, we believe that there will be sufficient increased interest from engineering students to keep pace with growth. The government has already recognized this potential constraint and has allocated $20 million to date in Recovery Act funding to educate and train future geologists, scientists and engineers with skills and competencies in geology, geophysics, geomechanics, geochemistry, and reservoir engineering disciplines needed to staff a broad national CCS program.[136]

STRESS CASE SCENARIO

Technology and Timing

Under the stress case scenario, the pace of CCS deployment must increase. This requires not only that more capacity come on line, but that the timeline from plant proposal to siting, construction and completion must also be accelerated. As discussed previously, early

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[131] Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Capture and Storage, 2005.

[132] U.S. Energy Information Administration.

[133] "Secretary Chu Announces $2.4 billion of ARRA Funds for Carbon Capture and Storage," U.S. Department of Energy, May 21, 2009.
www.energy.gov/news2009/7405.htm.

134 "CCS Assessing the Economics," *McKinsey*.

[135] National Center for Education Statistics, November 17, 2009.

[136] "Secretary Chu Announces $2.4 billion of ARRA Funds for Carbon Capture and Storage," U.S. Department of Energy, May 21, 2009.
www.energy.gov/news2009/7405.htm.

IGCC/CCS plants are projected to take approximately double the development time to of traditional plants (12 to 14 years vs. 6 to 8 years for traditional pulverized coal).[137] Presently, power plants are built in a highly regulated fashion to ensure maximum stakeholder engagement and to reduce dangers associated with the process. This can add significant time to deployment if challenges arise in the permitting process. Assuming that this process is accelerated by the pressing need to meet goals under the stress scenario, the following steps would need to be completed at a higher cost or in a less restrictive environment (e.g. working around the clock instead of 9 to 5): siting, environmental review, permitting in parallel with project structuring and conceptual design, design phases, project initiation, construction, start up and testing, operation and continuous testing.[138]

Even with increases in cost and work rate, it is unlikely that significant goals can be met in a timeline shorter than twenty years because of the time-intensive nature of coal-fired electricity generation construction, which averages ten years. With the twenty-year timeline in mind, and assuming that political will exists to expedite technology and financing, the pace of IGCC/CCS deployment under the stress scenario can be approximated based on China's present build out rate for coal-fired power plants (approximately one per week). This growth rate is useful because China is by all accounts building out its coal-fired electricity generating capacity under a stress-case scenario of its own – maintaining growth and stability in their rapidly developing country. That said, as with the status quo rate calculated based on U.S. nuclear build out, this comparable is inherently flawed for reasons of differing building, permitting, and labor practices between the two countries. However, it will serve as a relative approximation for purposes of comparison.

With deference to the fact that China is building traditional plants, which differ from IGCC/CCS in their present development time lines (approximately twice as long for IGCC/CCS, as noted above), the analysis assumes that the U.S. can complete one new plant every two weeks. With a new plant averaging 250 MW in size (similar to FutureGen at 275MW, and the average plant size in the U.S., 230 MW[139]) being built every two weeks following the scheduled completion of FutureGen in 2013, the U.S. is able to reach its stress case goal, resulting in 108.3 GW of IGCC/CCS and 271.5 GW of traditional coal-fired electricity coming online in 2030 with no retro-fits required (see **Exhibit 16**). This scenario results in a 17 percent (as presently targeted) decrease in nameplate traditional pulverized coal capacity from 2005 levels by approximately 2027. Assuming that traditional capacity is replaced by IGCC/CCS, the U.S. can meet the 2017 target stated recently by President Obama approximately ten years later than expected. The apparent delay in meeting this broad target through CCS is likely mitigated by other sources of emission reduction that result in greater reductions at a faster rate than IGCC/CCS adoption.

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[137] Although the timeline for IGCC/CCS plant production is likely to drop some after learning occurs following the completing of the initial demonstration plants.

[138] FutureGen Industrial Alliance, Inc.). Timeline.
http://www.futuregenalliance.org/about/timeline.stm

[139] Electricity: U.S. Data: Electric Power Plants, Energy Information Administration.
http://www.eia.doe.gov/fuelelectric.html

Financing: Investment Requirements

While the CCS capacity requirement in the stress case is about twelve times greater than that for the status-quo case, learning effects limit the investment costs to a five-fold increase. The timing and technology assumptions outlined in the above subsection implied installed capacities of 13 GW, 46 GW, 78 GW, and 108 GW by 2015, 2020, 2025, and 2030, respectively (see **Exhibit 16**). Based on these capacities, and again using the McKinsey estimate of \$80 to \$120/tCO_2 abated for 2009 - 2015, we estimated the following CCS costs per ton of CO_2 abated: \$23 to \$34 in 2015 - 20, \$9 to \$14 in 2020 – 2025, and \$4 to \$6 in 2025 – 2030 (see **Exhibit 17** for stress scenario cost evolution). These costs implied a total investment of \$350 to \$525 billion by 2030 to achieve the 108 GW CCS capacity.[140]

By definition of the stress scenario, this investment yields CO_2 emissions abatement of 50 percent from coal-fired power generation relative to business-as-usual economy-wide emissions in 2030. Applying again our assumption that abatement from coal-fired power generation will account for 10 percent of economy-wide abatement, the stress scenario implies an abatement of 485 MtCO_2 from coal-fired power generation, or 4,850 MtCO_2 over the entire economy.

Before continuing, we find it important to acknowledge that our analysis is highly sensitive to the learning factor used, and to the range of cumulative capacity within which CCS technology remains in the high learning scenario (i.e., has a 88 percent learning factor) vs. the low learning scenario (i.e., 96 percent learning factor). Although recent reports suggest investment in the range implied by our analysis is needed for wide CCS deployment, a less pronounced learning effect, or a more limited high-learning period, would drive our price estimates upwards.[141] Nonetheless, we emphasize that learning effects allow CCS investment requirements to scale far less than linearly. The implication for firms and governments would be to more aggressively deploy CCS to capture learning effects in the near-term.

Resource Constraints

Even if the U.S. is able to implement policy and fully fund CCS deployment in a manner that achieves some scale-up, does the country have the resources necessary to achieve the substantial CCS deployment goals under the stress case scenario? We consider the same three primary constraints as in the status quo case: CO_2 pipelines, CO_2 storage sites and human capital.

CO_2 Pipelines

Starting with the existing pipelines, we consider how many more kilometers of pipeline need to be added in order to achieve the stress case CCS reduction. We use the maximum annual CCS capacity that was determined above (108.3 GW) to determine how many additional 500 MW plants will be added. We then look at the incremental pipeline infrastructure required for each of the additional plants and the associated cost, using the same underlying assumptions in the status quo case.

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[140] Assumptions are same as those made under the status quo case.

[141] See, e.g., Clean Coal / CCS Technology Development Pathways.
http://dorgan.senate.gov/issues/energy/cleancoal/cleancoal.pdf

Existing Capacity ($MtCO_2yr$)	49.9
Installed Pipeline (km)	6275
Required Max Annual CCS Capacity (MW)	108,322
Required Number of Plants (500 MW)	217
Average Distance CO_2 Transported (km)	40.2
New Required Pipeline (km)	8,716
Required Annual Pipeline Growth	27%
Cost of pipeline investment ($/km) [142]	$ 700,000
Total Cost ($bn)	$ 6.1

From this, we see that the pipeline infrastructure will be required to grow at an annual rate of 27 percent, which will result in a total cost of $6.1 billion. This is considerably higher than the status quo costs of $0.8 billion. However, this represents a minimal fraction of the overall cost of CCS deployment, and hence does not present a bottleneck for our stress case.

CO_2 Storage Sites

We follow a similar methodology as the status quo case to determine the CO_2 storage site costs. Under the stress case, we estimate that 485 $MtCO_2$ need to be stored. Using McKinsey's costs of $6.71/ton, storage costs will amount to $3.3 billion. Again, compared to the total cost of CCS deployment, this is a minimal and non-concerning cost.

	Status Quo	Stress Case
Required Storage of CO_2 ($MtCO_2$)	58.3	485.0
McKinsey cost estimate (EUR/tonne of storage)	4.5	4.5
Currency Conversion @1.496	6.714	6.714
Total Cost of Storage ($bn)	$ 0.3	$ 3.3

Human Capital

Human capital constraints become more concerning in the stress case scenario. Even more graduates will need to be focused on CCS technologies in order for CCS to reach large-scale deployment than in the status quo scenario. While the existing domestic stock of qualified engineers could potentially be supplemented by H1B visa holders, there may be an increased demand globally for qualified engineers if CCS deployment escalates. Regardless, this is likely to still be of minimal concern relative to the policy, funding and technology requirements to meet the stress case scenario.

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[142] Note: assumes the average distance CO2 piped is 40 km (NETL) at a cost of $700,000/km (*IPCC Special Report on Carbon Dioxide Capture and Storage, 2005).*

KEY FINDINGS

In summary, our analysis yields the following results:

(all figures through 2030)	**Status Quo**	**Stress Case**
Annual CO_2 abated (economywide)	410 Mt (4.2% below BAU)	4,850 Mt (50% below BAU)
Annual CO_2 stored (CCS)	41 Mt	485 Mt
Total CCS capacity built	9.1 GW	108.3 GW
Capture Investment	$70 – $105 billion	$350 – $525 billion
Transport Investment	$0.8 billion	$6.1 billion
Storage Investment	$0.3 billion	$3.3 billion
Total Investment	$71 – $106 billion	$359 – $534 billion

We conclude that, under the status quo scenario, the U.S. is unlikely to achieve substantial emissions reductions from CCS technology. It is simply too expensive and time-consuming to deploy in order to have a meaningful impact on emissions reduction goals over the relevant time period to 2030. If CCS is to be a significant part of U.S. climate strategy, a scenario much more akin to the stress case scenario is required. To be sure, a very substantial investment is still required, but the impact of learning on CCS unit costs makes a stress scenario much more compelling than the status quo case under which relatively little return (GW CCS deployed) is earned on the smaller number of dollars invested. Realizing the value of learning effects as quickly as possible is essential to making CCS affordable. In the absence of these, other technologies are likely to be preferred methods of abatement as they can achieve similar scales of emissions reductions more quickly and at lower cost.

It is important to note that other technologies are also likely to benefit from the effects of learning as they are deployed with increasing frequency. For this reason, it is challenging to assess where CCS will fall on the abatement cost curve relative to other technologies in 2030. If other technology costs decline with learning faster than CCS, these technologies may become more favored and reduce the overall role of CCS in the U.S. abatement portfolio. Conversely, if CCS declines in cost more quickly than other technologies, it may in fact play a larger role than the 10 percent abatement that we have assumed.

What, then, is needed to move the U.S. to a stress scenario trajectory? We have identified key constraints that may delay CCS deployment:

	Loose Constraint	**Moderate Constraint**	**Binding Constraint**
Capture Technology			✓
Transport Technology	✓		
Storage Technology	✓		
Storage Capacity	✓		
Human Capital	✓		
Availability of Financing			✓
Liability Management		✓	

Three of these are especially important:

- **Cost of Capture Technology**: As discussed previously, the high cost of capture remains a central obstacle to deployment.

- **Availability of Financing:** Most importantly, in the absence of a sufficiently high carbon price, no incentive exists for the private sector to voluntarily pursue CCS technology. Accordingly, significant amounts of government funding – largely in parallel with private sector financing – will be required to push the technology's development. Secondly, public markets financing is not presently available for CCS projects due to the high degree of associated technology risk. Accordingly, early projects will require federal loan guarantees or equity commitments to enable financing. Once a number of demonstration plants have been established, we expect that capital markets financing will be available to CCS projects.

- **Liability Management:** Liability management and long-term stewardship is a key institutional obstacle to CCS deployment. Although this is somewhat of a longer-term issue than either financing or technology, the lack of clarity on post-well closure operator liability may limit private sector willingness to deploy CCS technologies. It is likely that a federal or state entity will be required to assume long-term ownership, management and monitoring of the sites to ensure that there is no CO_2 leakage or human/environmental damage that results. One model for this type of legislation may be the Price-Anderson Act providing for long-term indemnity to nuclear power producers.

Constraints around financing and capture technology may present a potential opportunity for an international competitor (e.g. China) to enter the U.S. market. While the U.S. system of innovation has historically largely relied on a market "pull" to drive innovation and technology commercialization, China operates under a "push" model, whereby selected technologies are heavily deployed with government backing. If the PRC were to choose to invest heavily in CCS technology, it may be able to capture the effects of learning and then subsequently export the technology to the U.S. or other markets at a significantly higher price. At present, China likely lacks incentives to do this, but if the U.S. or other countries were to adopt stringent emissions reduction targets yielding a high carbon price, this alternative may become more attractive to the Chinese.

POLICY IMPLICAITONS

What, then, would be required for the U.S. to achieve a stress case trajectory? And, most importantly, is the scale of CCS deployment implied by this scenario even a desirable objective? Clearly, there are strategic imperatives for the U.S. to develop CCS and reduce domestic greenhouse gas emissions. As discussed previously, coal is a significant U.S. resource, and activist environmental groups vehemently oppose the development of pulverized coal plants without CCS technology. Further, and perhaps more importantly, strongly pursuing CCS demonstrates the U.S.' commitment to acting on climate change to the international community, which could provide the U.S. with greater international stature and leverage in other multilateral negotiations. The central question is whether or not these benefits outweigh the significant costs of rapidly accelerating CCS deployment along a stress scenario trajectory, particularly given the substantial uncertainty about the technology's learning effects and ability to progress down the cost curve, as well as CCS' ultimate cost relative to other greenhouse gas abatement technologies, which will also be undergoing learning effects over this period.

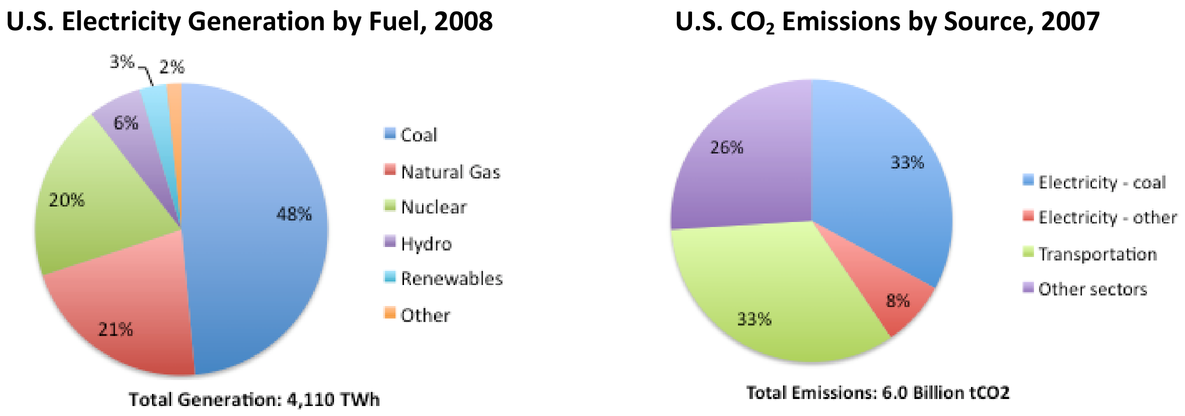
In order to answer this question, the government and private sector need data about the ability for CCS to scale-up and move down the cost curve. This can only be gained through experience, and should be concentrated on CO_2 capture, as this is the most challenging and costly aspect of the process. Therefore, the government must make substantial commitments to a number of utility-scale demonstration projects in order to assess the viability and desirability of further commercialization. Incentives can be created in a number of ways. First and foremost, Congressional passage of legislation establishing strong, mandatory emissions reduction targets would establish a long-term price signal that enables the private sector to account for carbon constraints in their decision-making processes. This would likely accelerate the prospects for rapid completion of demonstration projects and further CCS deployment. Second, the government must provide funding to enable these demonstration projects to be built quickly and data aggregated. Loan guarantees and equity cost-sharing agreements with the private sector (either individual companies or consortia, as with FutureGen) are essential to this approach.

Further funding of large-scale CCS deployment on the order of what was derived in our stress scenario should be limited until enough information is available from the demonstration projects to accurately assess whether or not adequate learning capabilities exist to pursue CCS deployment whole-heartedly. To this end, prior to the initiation of demonstration projects, clear increments and benchmarks for evaluating learning should be established and consistently revisited. If it becomes clear that a plateau has been reached or is imminent, the government should consider redeploying capital into alternative CO_2 abatement technologies with greater opportunity for low-cost scale up and impact.

The government should also consider making all data on demonstration projects publicly available to the U.S. energy and science communities in order to most quickly and effectively develop and deploy CCS technology. Certainly, this is fraught with IP issues, however if CCS were to be deemed a national priority research collaboration on the technology could be enormously important to accelerating deployment quickly.

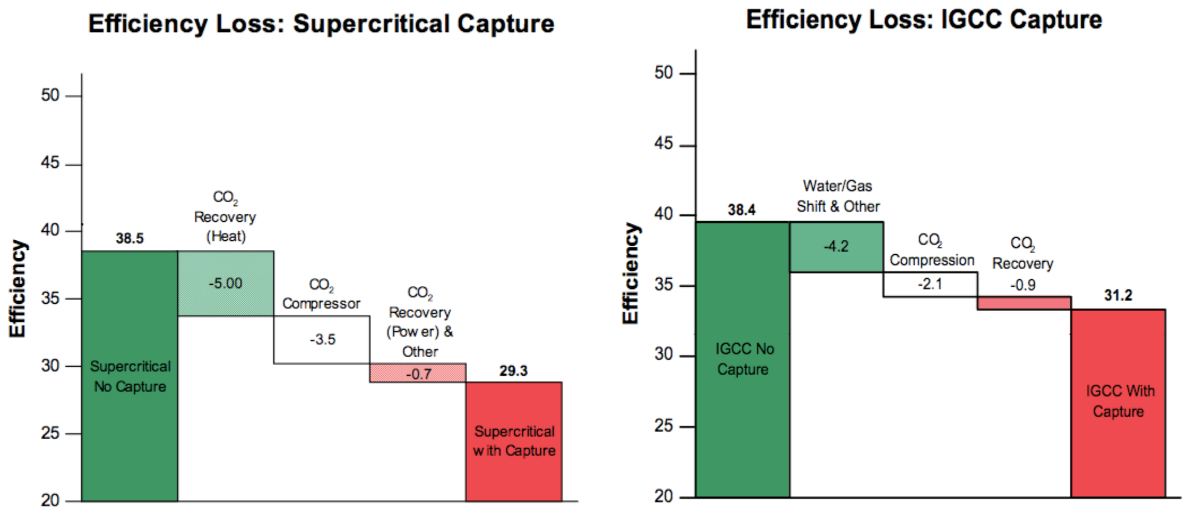
Finally, CCS cannot go anywhere without public support for its implementation. Education is required to both subvert irrational opposition to CCS (so-called NUMBY “not-under-my-backyard” behavior) and also to create a consumer-based market “pull” to encourage utilities and the government to invest in and adopt the technology. But perhaps most importantly, people must believe that climate change is an immediate danger and support climate legislation if CCS is to have any hope of succeeding at scale.

Exhibit 1
U.S. Electricity Generation and CO_2 Emissions



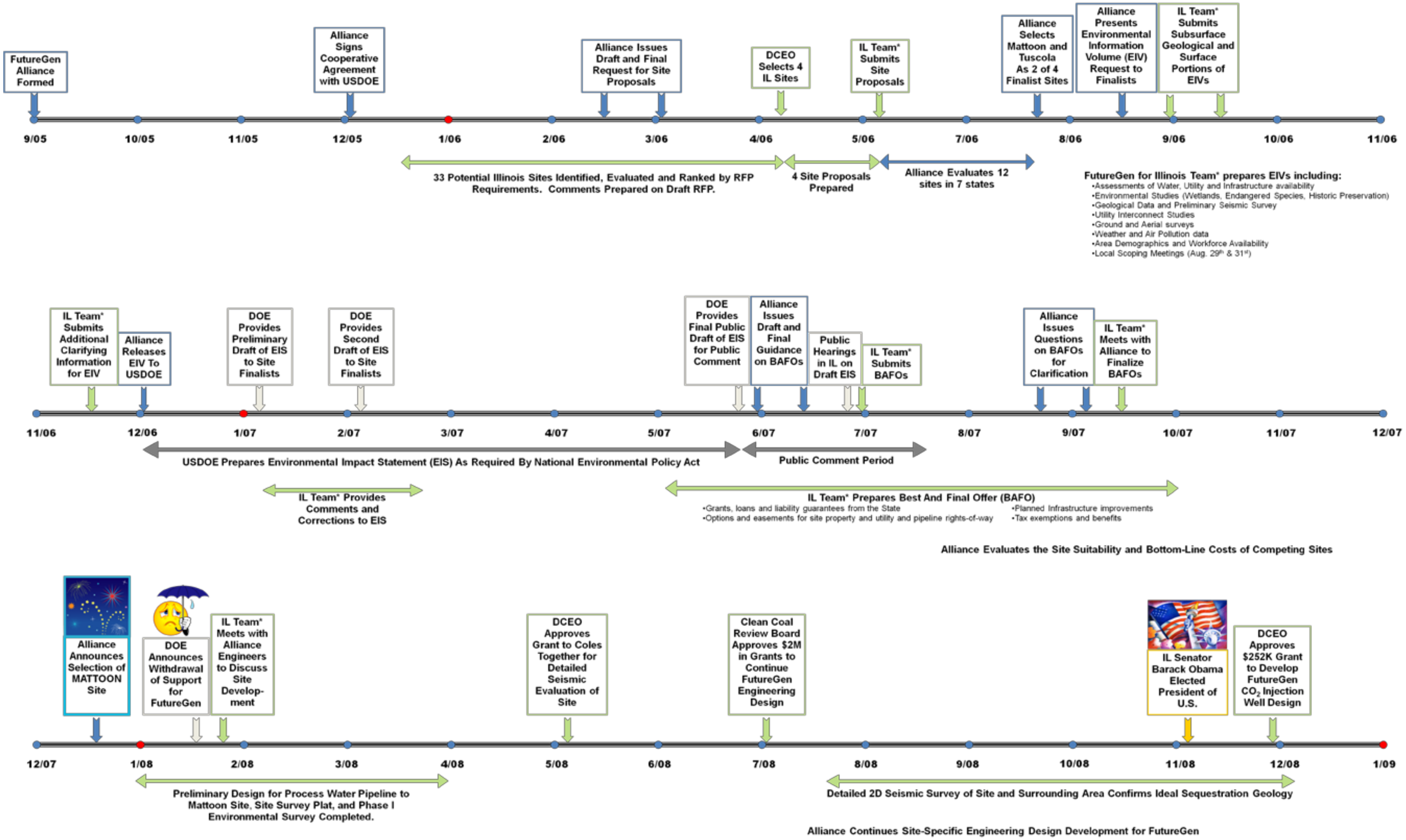
Source: U.S. Energy Information Administration.

Exhibit 2
Comparison of PCC and IGCC Efficiency Losses



Source: Herzog, MIT Laboratory for Energy and the Environment (2007).

Exhibit 3
FutureGen Timeline



FutureGen Alliance Formed

Alliance Signs Cooperative Agreement with USDOE

Alliance Issues Draft and Final Request for Site Proposals

DCEO Selects 4 IL Sites

IL Team* Submits Site Proposals

Alliance Selects Mattoon and Tuscola As 2 of 4 Finalist Sites

Alliance Presents Environmental Information Volume (EIV) Request to Finalists

IL Team* Submits Subsurface Geological and Surface Portions of EIVs

9/05 10/05 11/05 12/05 1/06 2/06 3/06 4/06 5/06 7/06 8/06 9/06 10/06 11/06

33 Potential Illinois Sites Identified, Evaluated and Ranked by RFP Requirements. Comments Prepared on Draft RFP.

4 Site Proposals Prepared

Alliance Evaluates 12 sites in 7 states

FutureGen for Illinois Team* prepares EIVs including:
- Assessments of Water, Utility and Infrastructure availability
- Environmental Studies (Wetlands, Endangered Species, Historic Preservation)
- Geological Data and Preliminary Seismic Survey
- Utility Interconnect Studies
- Ground and Aerial surveys
- Weather and Air Pollution data
- Area Demographics and Workforce Availability
- Local Scoping Meetings (Aug. 29th & 31st)

IL Team* Submits Additional Clarifying Information for EIV

Alliance Releases EIV To USDOE

DOE Provides Preliminary Draft of EIS to Site Finalists

DOE Provides Second Draft of EIS to Site Finalists

DOE Provides Final Public Draft of EIS for Public Comment

Alliance Issues Draft and Final Guidance on BAFOs

Public Hearings in IL on Draft EIS

IL Team* Submits BAFOs

Alliance Issues Questions on BAFOs for Clarification

IL Team* Meets with Alliance to Finalize BAFOs

11/06 12/06 1/07 2/07 3/07 4/07 5/07 6/07 7/07 8/07 9/07 10/07 11/07 12/07

USDOE Prepares Environmental Impact Statement (EIS) As Required By National Environmental Policy Act

Public Comment Period

IL Team* Provides Comments and Corrections to EIS

IL Team* Prepares Best And Final Offer (BAFO)
- Grants, loans and liability guarantees from the State
- Options and easements for site property and utility and pipeline rights-of-way
- Planned Infrastructure improvements
- Tax exemptions and benefits

Alliance Evaluates the Site Suitability and Bottom-Line Costs of Competing Sites

Alliance Announces Selection of MATTOON Site

DOE Announces Withdrawal of Support for FutureGen

IL Team* Meets with Alliance Engineers to Discuss Site Development

DCEO Approves Grant to Coles Together for Detailed Seismic Evaluation of Site

Clean Coal Review Board Approves $2M in Grants to Continue FutureGen Engineering Design

IL Senator Barack Obama Elected President of U.S.

DCEO Approves $252K Grant to Develop FutureGen CO_2 Injection Well Design

12/07 1/08 2/08 3/08 4/08 5/08 6/08 7/08 8/08 9/08 10/08 11/08 12/08 1/09

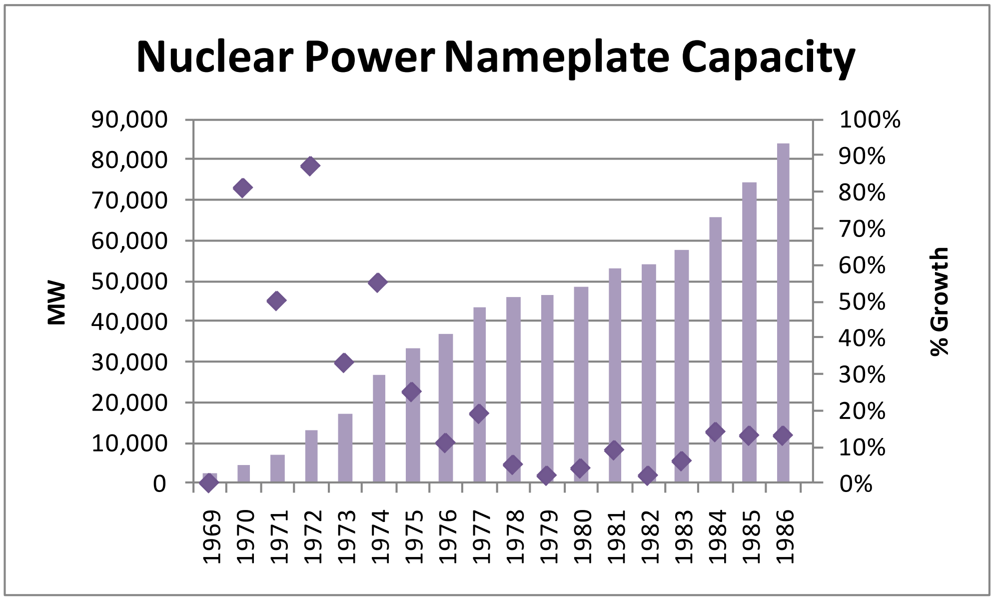
Preliminary Design for Process Water Pipeline to Mattoon Site, Site Survey Plat, and Phase I Environmental Survey Completed.

Detailed 2D Seismic Survey of Site and Surrounding Area Confirms Ideal Sequestration Geology

Alliance Continues Site-Specific Engineering Design Development for FutureGen

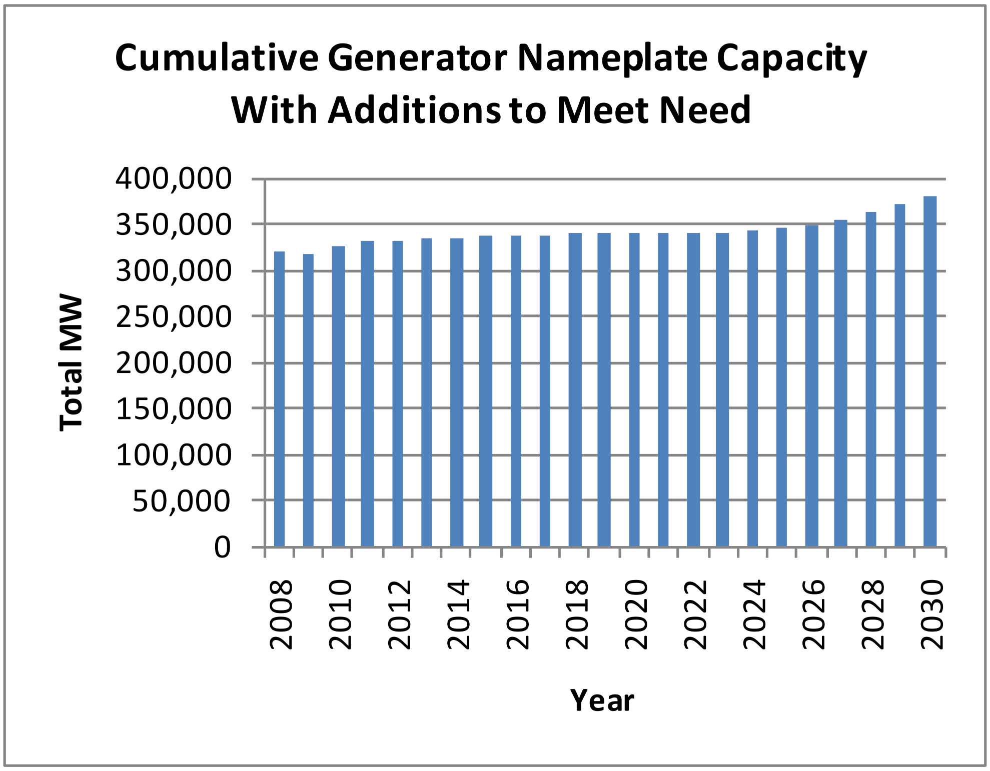
Source: Patrick Engineering Inc. "FutureGen Historical Timeline." www.futuregenforillinois.com/.../FutureGen%20Historical%20Timeline.ppt

Exhibit 4
Historical U.S. Nuclear Power Capacity Growth



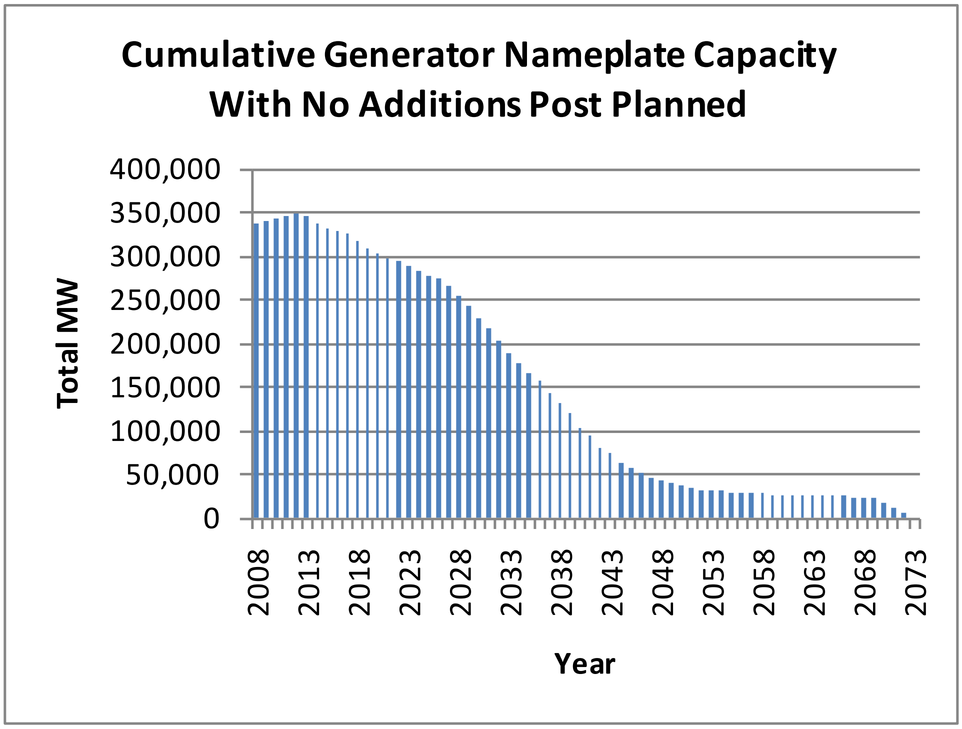
Source: Created by research paper authors with information from EIA and internal analysis.

Exhibit 5
Projected U.S. Coal-Fired Generation Capacity with Additions



Source: Created by research paper authors with information from EIA and internal analysis.

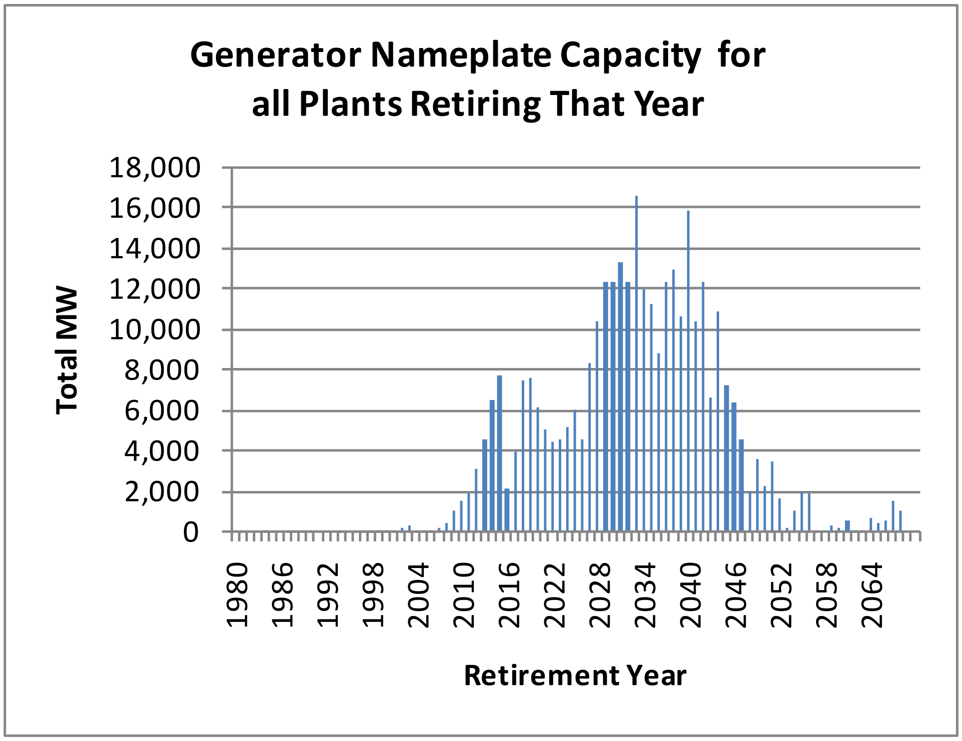
Exhibit 6
Projected U.S. Coal-Fired Generation Capacity with No New Additions



Source: Created by research paper authors with information from EIA and internal analysis.

Exhibit 7

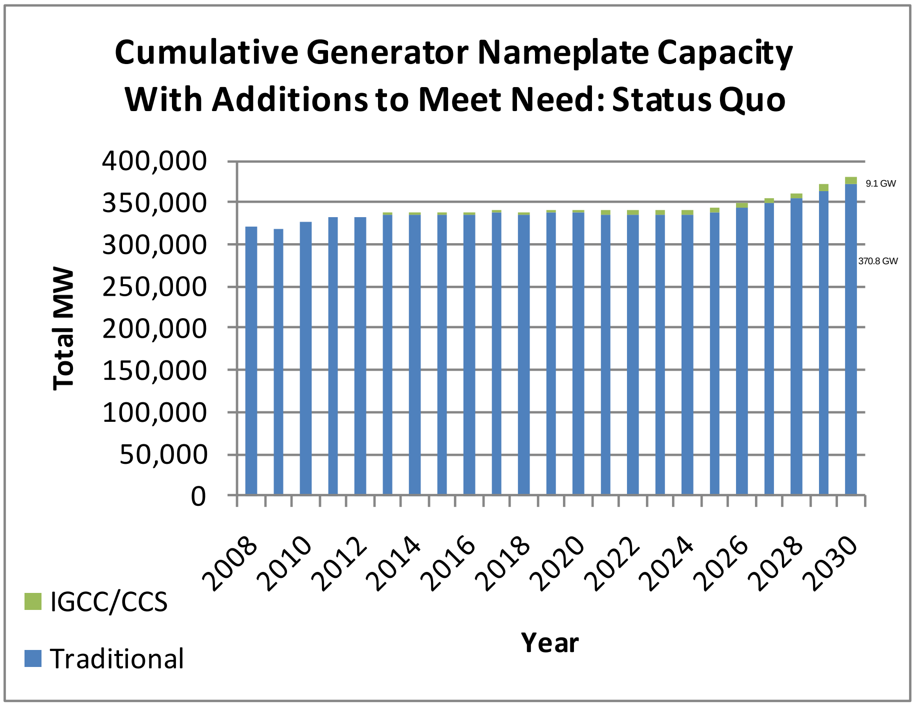
Projected U.S. Coal-Fired Generation Retirements



Source: Created by research paper authors with information from EIA and internal analysis.

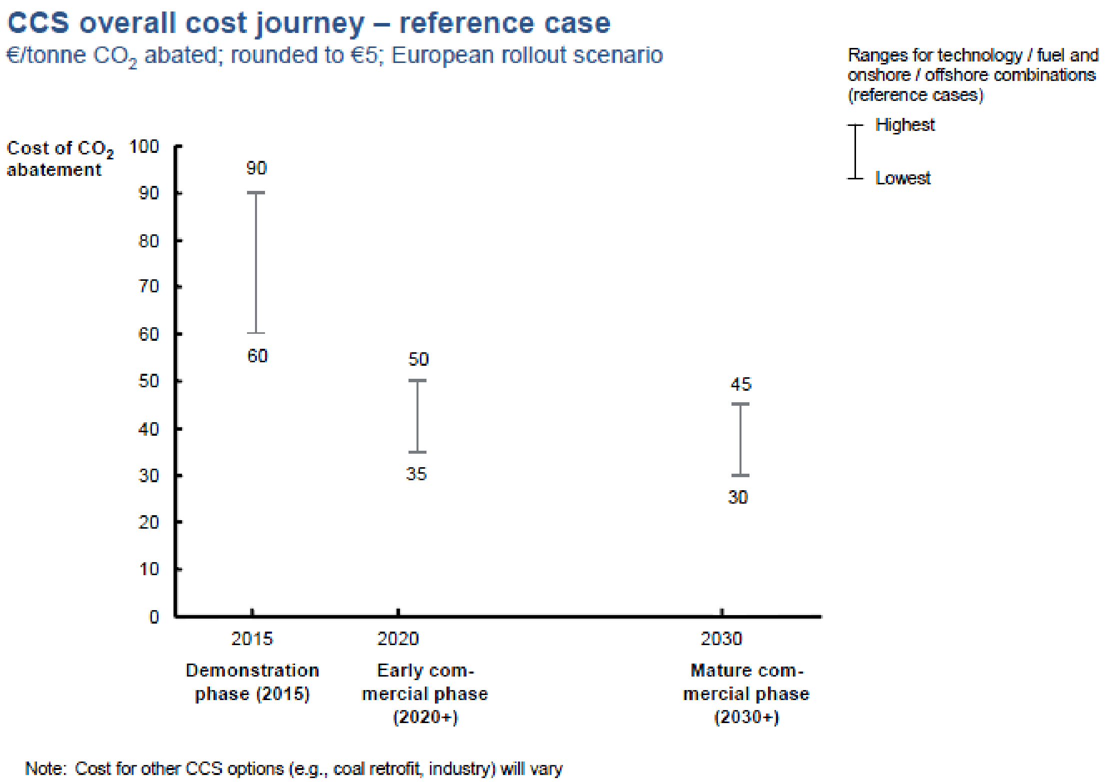
Exhibit 8

Projected U.S. Coal-Fired Generation Capacity with Additions to Meet Need: Status Quo Scenario



Source: Created by research paper authors with information from EIA and internal analysis.

Exhibit 9
McKinsey CCS Cost Projections



CCS overall cost journey – reference case

€/tonne CO_2 abated; rounded to €5; European rollout scenario

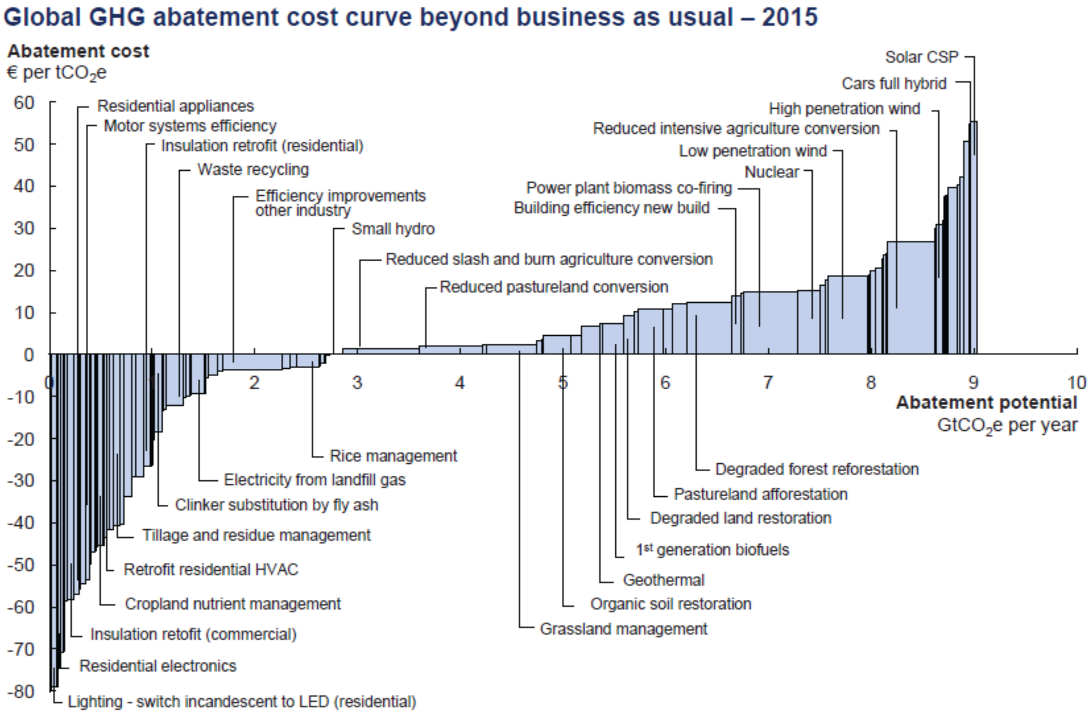
Note: Cost for other CCS options (e.g., coal retrofit, industry) will vary

Note: Used 1.33 USD/EUR exchange rates. Only used demonstration phase cost estimates as standard benchmark for current costs.

Source: McKinsey, Carbon Capture & Storage: Assessing the Economics (2008).
http://www.mckinsey.com/clientservice/ccsi/pdf/ccs_assessing_the_economics.pdf

Exhibit 10

McKinsey 2015 Global GHG Abatement Curve

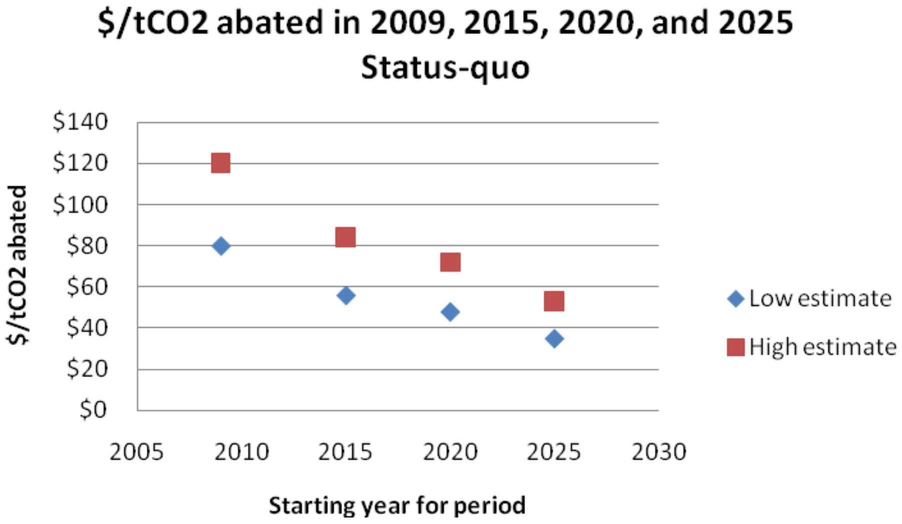


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: McKinsey, Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve (2009).
http://www.mckinsey.com/clientservice/ccsi/pathways_low_carbon_economy.asp

Exhibit 11

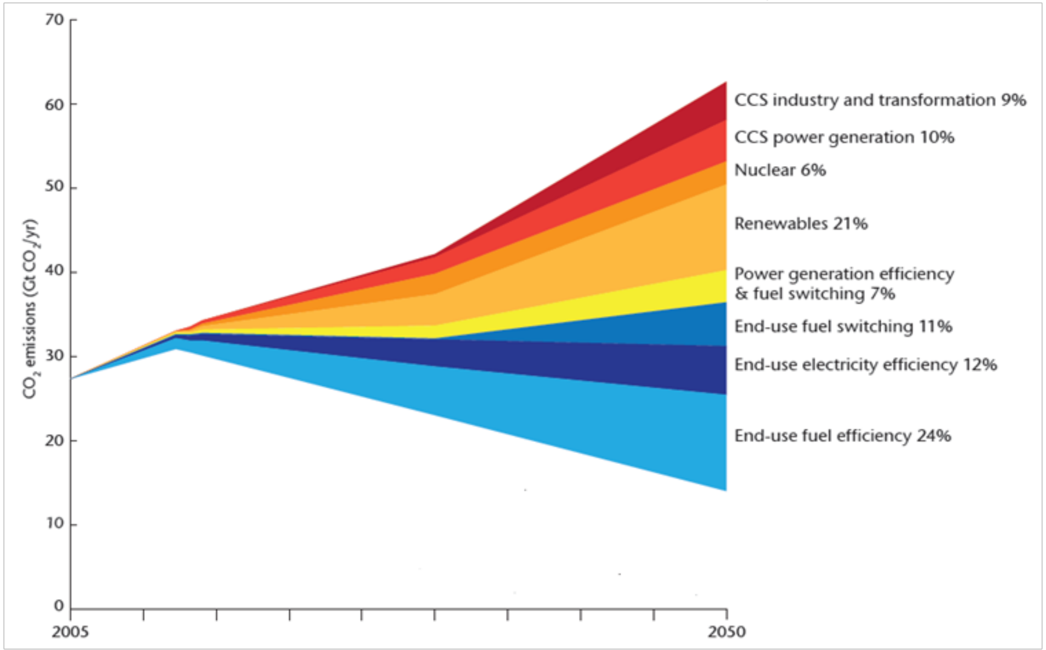
Status Quo Scenario CO_2 Abatement Cost



Source: Created by research paper authors.

Exhibit 12

Contributions to CO_2 Emissions Reduction by Abatement Mechanism



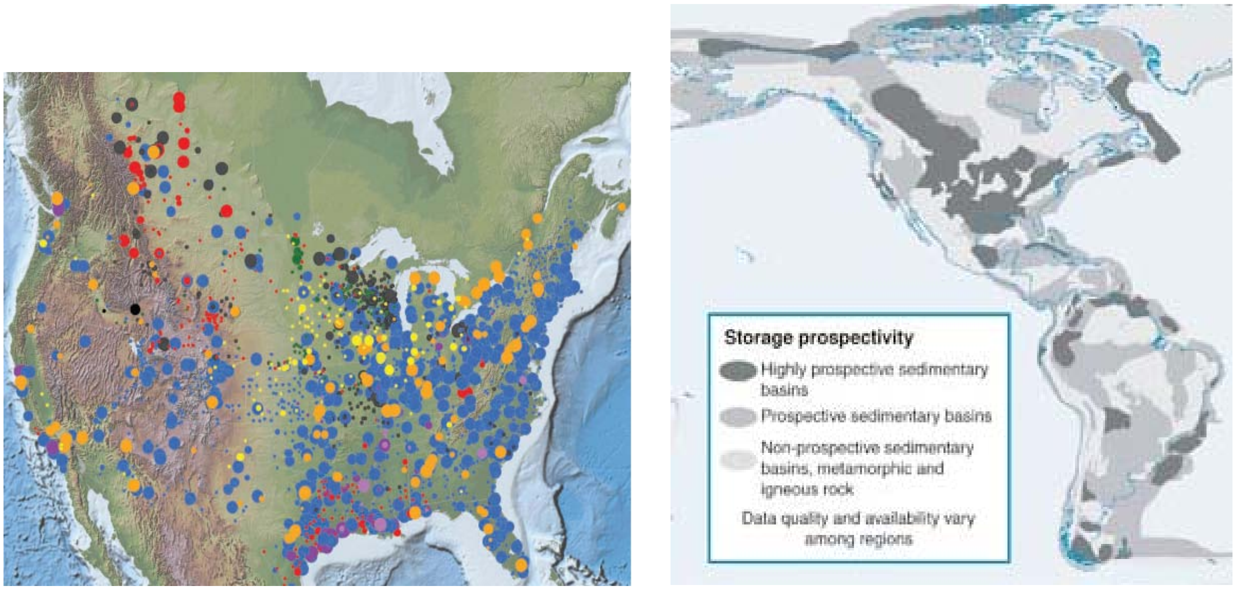
Note: Emissions per year on y-axis are global figures, and are not used in this analysis. We use the IEA roadmap to estimate that CCS in power generation contributes 10% of economy-wide abatement.

Source: International Energy Agency (IEA) CCS Roadmap.

Exhibit 13
Existing CO_2 Transportation Pipelines

Source: IPCC 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Figures…Cambridge University Press.

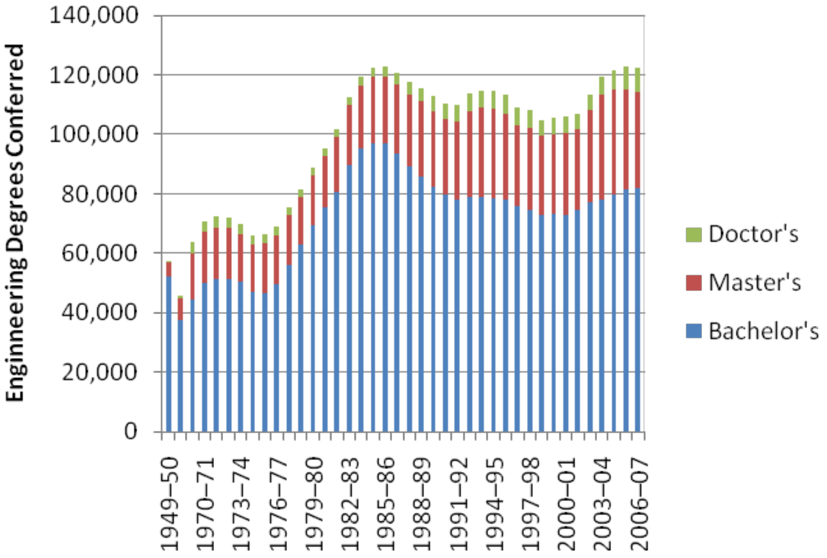
Exhibit 14
U.S. Emissions Sources and Geologic Storage Capacity


Sources of CO_2 Emissions

Geologic Storage Capacity

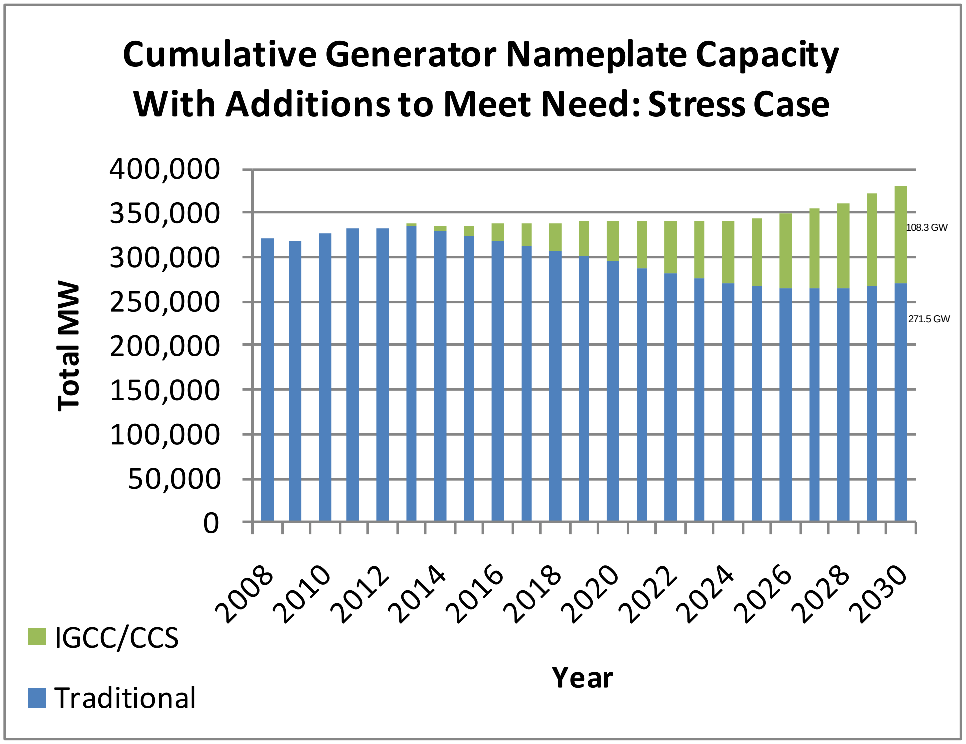
Source: IPCC 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Figures…Cambridge University Press.

Exhibit 15
Historical U.S. Engineering Degrees Conferred



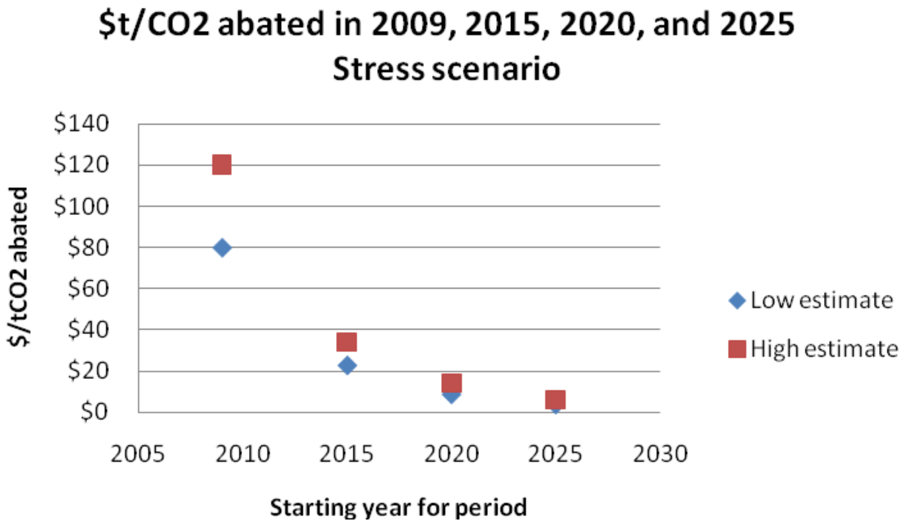
Source: National Center for Education Statistics.

Exhibit 16
Projected U.S. Coal-Fired Generation Capacity with Additions to Meet Need Stress Scenario



Source: Compiled with data from the Energy Information Administration and internal analysis.

Exhibit 17
Stress Scenario CO_2 Abatement Cost



Source: Created by research paper authors.

Chapter 7*

CLEAN COAL IN THE PEOPLE'S REPUBLIC OF CHINA**

* This chapter was prepared by Hollis Kline, Huong Tran and Kevin Yang

** We would like to thank the Program on Energy and Sustainable Development (PESD) at Stanford University, and in particular Richard K. Morse, for sharing their most recent research.

PROBLEM STATEMENT AND OVERVIEW

In 2007, China overtook the US as the largest emitter of greenhouse gases in the world, and continued emissions growth is expected to support the hyper-charged Chinese economy. Whereas coal accounts for 30 percent of global energy use, it generates 70 percent of energy used in China. The heavy reliance on coal in China is expected to continue, with approximately one new coal plant coming on-line each week.[143]

Therefore, a major component of any attempt to combat global climate change will be the reduction of China's coal-related emissions. This can be done either by increasing the usage of renewable generation, or reducing the emissions from coal through a suite of technologies commonly referred to as clean coal.

In the U.S. and EU, clean coal typically refers to carbon capture and sequestration (CCS), in which carbon dioxide is captured before or after generation and then sequestered underground. Although CCS has been used for decades at a small scale to enhance oil recovery, it has not been implemented anywhere in the world at commercial scale. In China, however, clean coal is conceptualized as any improvement along the value chain that reduces environmental impact, from mining to transport to generation to CCS. Up to this point, China has chosen to focus its attention on improving generation efficiency due to its economic benefits, and has become the world leader in building supercritical and ultra-supercritical plants. The Chinese government considers CCS as an economically-unattractive emerging technology that is not a significant priority. Therefore, our paper will analyze what would need to happen for CCS to be implemented in China.

It is important to note that in China's power sector, there is little distinction between induced and autonomous actions because all the major utilities are large state-owned enterprises with deep connections with the government. Therefore, it is reasonable to expect that the utilities will act in accordance to the government's strategy.

An illustration of how Chinese utilities are an extension of the government is that power markets in China are heavily regulated to keep consumer electricity prices low and stable. Morse and his colleagues point out that the utilities face a situation in which the price that they can charge customers is fixed by the government, whereas their costs fluctuate with the market price of coal. In the past when coal prices have spiked, the utilities have suffered severe losses. The consequence of this situation is that unless China deregulates their power markets to allow the cost of CCS to be passed onto consumers, the utilities will be unable to afford the adoption of CCS.[144]

Our analysis of clean coal in China looks at the policy, financing, and technology facets under three conditions. First, we lay out the current status, and discuss some of the relevant events that

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[143] Debra Schifrin, Robert A. Burgelman and Andy Grove, "Clean Coal in the U.S. and China: An Industry Note," *Stanford Graduate School of Business Case SM-183,"* October 6, 2009.

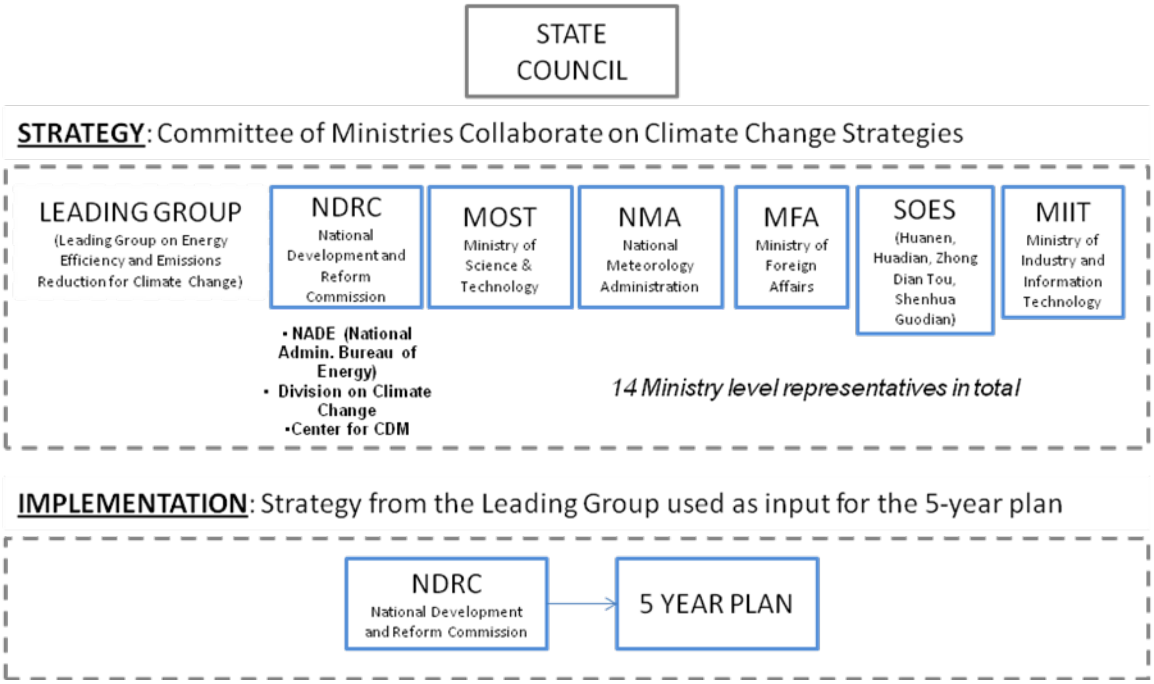
[144] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009, pp.4, 14-15.

have created the present situation. Next, we consider the status quo outlook, as defined by China's recent commitment to 40-45 percent reductions in carbon intensity by 2020, relative to 2005 levels (see Appendix C). Finally, we consider a stress scenario, where China agrees to cut absolute emissions by 50 percent over 20 years.

CURRENT STATUS

Policy

Climate change policy making in China faces structural and strategic roadblocks. Structurally, the decision making process is opaque to most and characterized by a large number of administrative bodies that influence decision making, each with an unknown amount of clout.



As shown above, strategy is determined by 14 ministry level representatives in addition to various state-owned enterprises ("SOE") collectively named the Leading Group. The Group, while not a permanent committee, convenes to drive various administrative arms of the government and industry representatives to consensus. Among the 14 ministries, the NDRC, MOST, NMA, and MFA weigh in most heavily. The key research and implementation arms for energy (NADE), carbon credits (Center for CDM), and climate change (Division on Climate Change) all fall under the NDRC. While collaborative in nature, the relative influence of each body is murky at best. These bodies influence the strategy set by the NDRC in the five-year plans. Such a structure highlights that China's policy making sector is not monolithic as widely believed. In practice, an increasing number of competing interests from the various ministries and state-owned enterprises are weighing in, making consensus difficult.

Strategically, China has made outwardly clear that the country would like to engage in climate change talks, but it is unclear whether significant action will truly materialize. In September 2009, President Hu Jintao made a speech on climate change to the UN General Assembly, stating that the Chinese government is setting forth three mandatory national initiatives to address climate change:

(1) reduce energy intensity (energy used/GDP) and discharge of major pollutants,
(2) increase forest coverage and
(3) increase the share of renewable energy for the period of 2005 through 2010[145]

With the characteristic vagary of most Chinese-issued public statements, the government also states that it will endeavor to cut carbon dioxide emissions as a percent of GDP by a notable margin by 2020 from the 2005 level.[146] The metric of energy intensity and carbon intensity defined by China, energy used or carbon emitted as a percent of GDP, is not an absolute target and still allows China to increase emissions so long as its economy continues to grow.

Although greenhouse gas emissions ("GHG") have received heighted attention in the last six months, China has put little focus on utilizing clean coal as a means to achieving an abatement target. Currently there is no short-term or mid-term planning for CCS development evidenced by the absence of CCS language in the NDRC article "China's National Climate Change Programme" or the 11th Five-year plan. The current emphasis appears to be on conservation and efficient use of resources.[147]

Financing

Practically, large international policy issues would continue to loom large in China even if it did make a strategic decision to implement CCS. Specifically, who would finance development of new technologies, pilot projects of scale, and implementation? China has demanded that developed countries commit from 0.5 percent to 1 percent of their annual gross domestic product to help poorer nations make reductions. The U.S. and Europe have responded that such demands are unacceptable.[148] When it comes to financing such a large undertaking with price tags in the trillions of dollars for China to reduce carbon emission, no developed country is willing to stunt its own growth. Such unilateral financing by developed countries presents varied risks amid the global recession and during a time when China's growth and advancement stand to rival that of developed countries. Additionally, as detailed by Morse et al.,[149] China's power industry is poorly structured to enable sustainable clean coal use even if there are other sources of long-term financing (i.e. carbon credit markets). Currently the system is comprised of centrally determined power prices and market-driven coal prices. This mismatch can result in as much as 85 percent

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[145] "Hu Jintao's Speech on Climate Change," *The New York Times,* September 22, 2009.

[146] Shai Oster, "China Seeks Help From Rich World on Climate," *Wall Street Journal,* November 30, 2009.

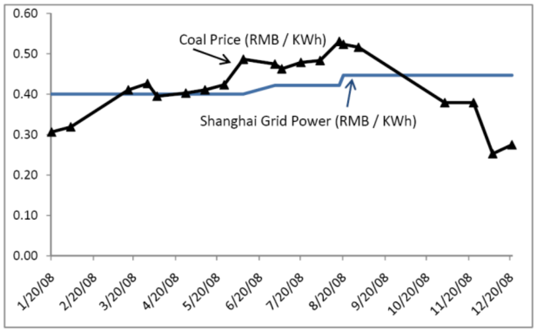
[147] PRC NDRC National Climate Change Programme Report, Beijing, June 2007.
http://en.ndrc.gov.cn/newsrelease/P020070604561191006823.pdf

[148] Shai Oster, op.cit.

[149] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009, p.16.

fluctuation in coal prices with only 10 percent fluctuation in power prices for kwh as illustrated below.[150] Because coal companies cannot pass through the increased cost of coal to consumers, even with a carbon market there is asymmetric risk sharing. In other words, the government's desire for affordable power precludes adopters of CCS from cost recovery.

Figure 1 China's power market cannot bear the cost of coal



Source: Program on Energy and Sustainable Development, Stanford University.[151]

Examining recent climate change events between U.S. and China can shed light on China's current trajectory and what needs to happen to achieve 50 percent emissions in 20 years. In looking at the timeline of events since early 2009 (Appendix [A]), we observe that the U.S. has made many unilateral movements related to CCS investment (i.e. national stimulus package, Waxman Markey Clean Energy Bill, and Steven Chu's letter) in addition to bilateral agreements with China (i.e. joint U.S. China Clean Energy Research Center, MOU on energy and climate change between U.S. and China). However, China has made no unilateral agreements, further suggesting that there needs to be a combination of international impetus and financial incentive for it to become a real priority. China's stage of economic development further makes the case for a compelling financial incentive for CCS to make it a priority on its national agenda.

Technology

Over 2,300 coal plants[152] currently operate in China, and approximately 25 percent of these plants have been constructed within the last seven years. Coal accounts for about 70 percent of total energy consumption in China, followed by oil (20 percent), hydroelectric power (6 percent), natural gas (3 percent), nuclear (1 percent), and other renewables (0.06 percent). China builds an average of one new plant a week to keep pace with coal-generated energy demands. In order to reduce local pollution and meet energy efficiency goals, China has become the world leader in implementation of critical, supercritical (SC), and ultra-supercritical (USC) technologies. Nearly two-thirds of its new plants employ one of the three more-efficient technologies – as opposed to the subcritical pulverized coal process that still dominates the U.S. landscape – with resulting

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[150] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy," Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009.

[151] Ibid., p.16.

[152] State Grid Corp of China website.

efficiencies as high as 44 percent.[153] China is only minimally motivated by climate change concerns, instead focusing on realizing more immediate economic and social benefits.

In addition to widely deploying critical, SC, and USC technologies, China is also exploring alternative technologies, including Integrated Gasification Combined Cycle (IGCC), Coal-to-liquid (CTL), and Carbon Capture and Sequestration (CCS). None of these technologies has been tested at commercial scale, however, and China has different incentives to pursue each one.

As detailed by Morse et al.,[154] China views IGCC favorably because the process reduces coal demand and air pollution by increasing combustion efficiency, thus contributing to the PRC's goal of a 20 percent decrease in energy intensity by 2010. [155] The GreenGen demonstration plant in Tianjin, which is slated for completion in 2016, will be China's first commercial scale IGCC/CCS plant. Once all three phases are complete, this plant will produce 650 MW of power, equivalent to 3,500 tons/day of coal gasification.[156] Through the development of IGCC and CCS technologies, China stands to accrue valuable domestic IP with the potential for global export. If future international accords stipulate drastic emissions reductions, China will be well-positioned to maintain independence from foreign power plant manufacturers and to sell its superior technologies to other countries.[157]

China is also aggressively pursuing CTL technologies in order to provide alternatives to importing oil. Shenhua is currently operating a demonstration-scale CTL plant in Inner Mongolia, with plans to add CCS late this year or early next. CTL is attractive to China because it furthers its fuel security goals on two fronts: by providing transport-ready fuel, and by yielding pure streams of CO2 that can be used in enhanced oil recovery. Carbon emissions released in the complete CTL value chain including CCS are approximately the same as consuming oil, therefore CTL essentially doesn't move the needle much on the climate change front even with CCS. Since CTL deployment is highly correlated with oil prices, and since the technology is relatively low risk/high reward, it is likely that China will begin to roll out an increasing number of CTL plants in the near term. [158]

Morse et al.[159] state that although China is developing the capability to scale CCS at its demonstration facilities, it is unlikely that it will choose to do so at an industrial scale unless external pressure is applied and/or financing provided. Several factors deter global investment in CCS projects: technological uncertainty about the performance of capture technologies at scale; high costs of implementation; regulatory uncertainty, including liability concerns associated with

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[153] Debra Schifrin, Robert A. Burgelman and Andy Grove, "Clean Coal in the U.S. and China: An Industry Note," *Stanford Graduate School of Business Case SM-183,"* October 6, 2009.

[154] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009.

[155] Ibid., p.11.

[156] GreenGen Co., Ltd. Website.
http://www.greengen.com.cn/en/index.asp

[157] Richard K. Morse, Varun Rai and Gang He, op.cit., p 11.

[158] Ibid., pp. 8-9.

[159] Ibid., p. 2.

sequestered CO2; and the lack of a clear carbon policy. In China, additional hurdles exist. According to Morse et al., the PRC’s fundamental interests “in energy security, economic growth and development, and macroeconomic stability directly argue against large-scale implementation of CCS unless such an implementation is almost entirely supported by outside funding.” [160]

STATUS QUO

Policy

In November 2009, China’s public statements endeavored to put more specifics around the targets. Yu Qingtai, special representative on climate-change, specified a 40 percent to 45 percent cut in "carbon intensity," or emissions relative to economic output, below 2005 levels by 2020 without international funding.[161] While the statement quantifies targets for China, such a guarantee does not imply action above and beyond the increases in energy efficiency already being done. We consider such a statement China’s status quo. When carbon intensity is modeled out from 2005 to 2020, using historical GDP growth figures and forecasted figures for future GDP and carbon emissions, we note that without any change in current practices China will reduce its carbon intensity by 50 percent. See Appendix C for details on how China’s recent carbon intensity target compares with status quo projections.

Currently, the biggest gating item for CCS is that there is no bilateral binding agreement with the U.S. or other developed countries. Tactically, there are no initiatives to build industrial-scale CCS demonstration projects in China on existing sources/streams of carbon other than one pilot by Shenhua Group in inner Mongolia, which is only sequestering 100,000 tons of CO2. Without demonstrable, industrial-scale projects, Chinese and global citizens cannot get comfortable enough with these technologies to contemplate scaling them. Additionally, without a reformed power industry, few coal companies will take on all the costs and risk associated with adopting CCS. Status quo action will come in the form of mandated high-efficiency or retrofitted coal plants in addition to energy generation efficiency to achieve carbon intensity targets laid out by China. Without significant change, EIA projects that China’s CO2 emissions will grow at 2.8 percent annually from 2006 to 2030.[162]

Financing

In China, there has been some movement with respect to investment in CCS technology domestically and internationally, albeit very little. Currently, there are three major national science and technology programs in China sponsored by the Ministry of Science and Technology (MOST): the National Key Technology R&D Program, the National Basic Research Program (973 Program), and the National High-tech R&D Program (863 Program). The National Key Technology R&D Program has supported strategic studies on CCS with emphasis placed on the

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[160] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy," Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009, p. 2.

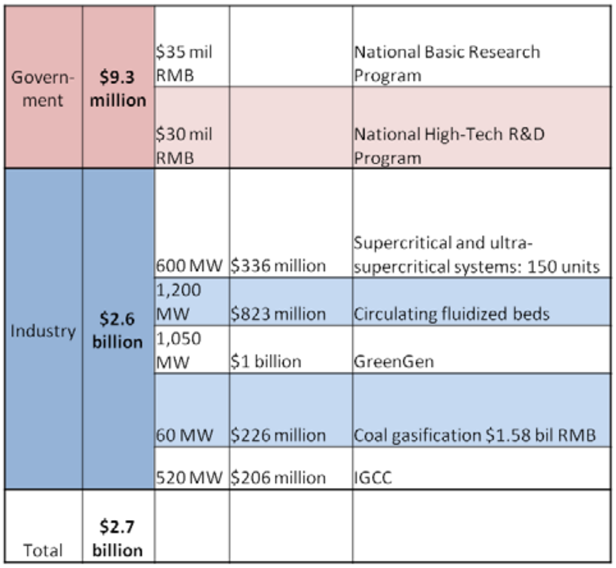
[161] Shai Oster, "China Seeks Help From Rich World on Climate," *The Wall Street Journal*, November 30, 2009.

[162] Energy Information Administration Official Energy Statistics from the U.S. Government: Chapter 8 - Energy-Related Carbon Dioxide Emissions, May 2010. http://www.eia.doe.gov/oiaf/ieo/emissions.html

applicability of CCS in China and its impact on energy systems and GHG emissions. Four key projects are been implemented under the 973 Program, including research on enhanced oil recovery, basic research on polygeneration systems with syngas co-production from coal gas and coke oven gas, basic research on high efficiency catalytic reforming of natural gas and syngas, and research on thermal-to-power conversion processes in gas turbines. Three research areas have been funded by 863 Program, carbon capture absorption, carbon capture adsorption, and carbon storage technologies. All these major MOST initiatives receive government funding of less than $10 million.[163]

While the capital allocated by China specifically to CCS has been small, it has publicly formed regional and international partnerships on several research programs, industrial projects and international projects to develop CCS technology. (See Appendix B.) This engagement with the international community signals a willingness to collaborate on such initiatives in so far as there is an outside partner.

The majority of current clean coal investments come from industrial sector projects involving supercritical and ultra-supercritical power plants, circulating fluidized beds, coal gasification, IGCC and coal-to-liquid. All these projects account for 96 percent of the total $2.7 billion[164] invested into clean coal in China. The investments are summarized in the following figure:



Govern-ment	**$9.3 million**	$35 mil RMB		National Basic Research Program
		$30 mil RMB		National High-Tech R&D Program
Industry	**$2.6 billion**	600 MW	$336 million	Supercritical and ultra-supercritical systems: 150 units
		1,200 MW	$823 million	Circulating fluidized beds
		1,050 MW	$1 billion	GreenGen
		60 MW	$226 million	Coal gasification $1.58 bil RMB
		520 MW	$206 million	IGCC
Total	**$2.7 billion**			

Source: Created by research paper authors.

Project financing for CCS is not readily available in China, given that significant investment is required for high-risk technology projects of scale. Also, IGCC projects and CCS projects of scale both in China and the US have a price tag of billions (Shenhua Coal-to-liquid $1.4 billion, GreenGen $1 billion, Duke Energy plant $2 billion, FutureGen $1.5 billion).[165] Funding sources

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[163] Liu and Gallagher, “Driving CCS Forward in China,” Energy Procedia, 2009.

[164] Chen and Xu, “Clean Coal Technology Development in China,” Energy Policy, 2009.

[165] Debra Schifrin, Robert A. Burgelman and Andy Grove, “Clean Coal in the U.S. and China: An Industry Note,” Stanford Graduate School of Business Case SM-183, October 6, 2009.

are generally scarce, especially in the current economic climate.

The financial risk of a CCS project is not limited to the lack of concrete revenue streams for investment cost recovery. There is also no formalized carbon credit trading market for CCS due to the dearth of large scale implementation projects as well as liability issues. Furthermore, there is no CCS project making up CER (certified emissions reduction) within Kyoto Protocol's Clean Development Mechanism. Current infrastructure of supply chain limits CCS implementation given increased input requirements. Morse et al. found that based on the IEA Blue scenario, significant increases in cost/inputs are needed to sustain CCS; namely, $15 billion is needed to upgrade mining capacity, rail infrastructure, port expansion, shipping capacity etc. to make changes to the baseline.[166]

Technology

Although China is likely to meet its carbon intensity reduction goals simply by undertaking energy efficiency measures while growing GDP, its carbon emissions will still increase. Under the status quo scenario, China is contributing to rather than halting or reversing climate change. In short, the country's status quo objectives are not a meaningful measure of emissions reduction "success."

The biggest gating item on the technology front is China's incentives; they simply are not aligned with the development of commercial-scale CCS technologies, as discussed above. In addition, China's substantial investments in other renewable technologies – particularly solar and wind – serve as a disincentive to invest heavily in CCS. Funding of CCS projects will almost certainly occur at the expense of other renewables initiatives.[167]

STRESS SCENARIO ANALYSIS

We consider a stress scenario in which China agrees to reduce absolute carbon emissions by 50 percent by 2030 relative to 2010 levels. This scenario would likely only come to pass if some catastrophic climate change disaster shocked the world into action. We decided to consider a 20 year period because it more realistically reflects the amount of time needed for large-scale implementation of CCS, given that it takes 5-10 years to build a coal plant.

In Appendix D, we show a high-level calculation of the $2 trillion price tag over 20 years associated using CCS to abate 40 percent of carbon emissions needed to achieve the stress scenario. We used a 2008 McKinsey study of CCS economics as the basis for our learning curve projections.[168]

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[166] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009, p.17.

[167] Ibid., p.18.

[168] "CCS: Assessing the Economics," McKinsey, 2008.

Policy

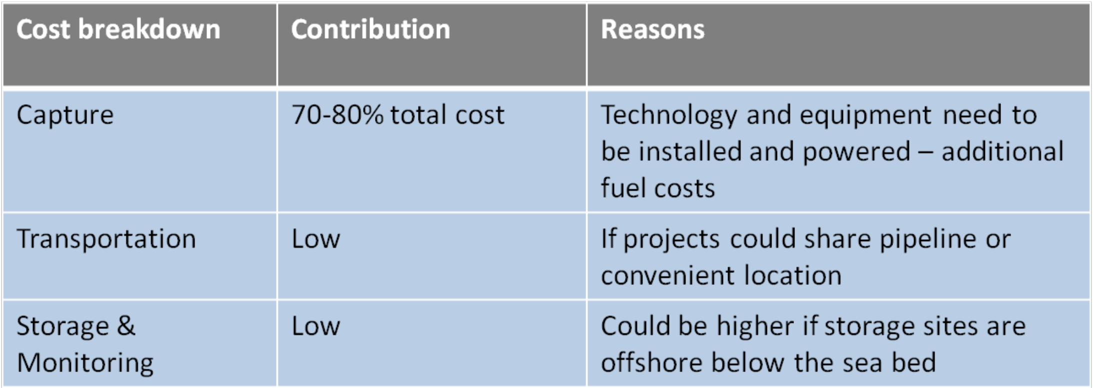
There are many steps that need to be taken to reach 50 percent emissions reduction in 20 years. First, bilateral and international agreements on climate change, and specifically CCS, must be established. Second, the low hanging fruit of energy efficiency improvements and renewable energy capacity building must be picked off, driven by stringent legislation. Third, investment in industrial-scale demonstration projects in China and globally must take place to build confidence in sequestration and to unearth all the risks. After proof of implementation at industrial scale, wider scale implementation needs to quickly follow (i.e. 2-3 years) backed by significant financing. Lastly, reform of the power industry must occur in the form of decoupling coal prices and electricity prices to enable risk sharing.

Financing

We have categorized financing solutions as short-term, mid-term, or long-term according to the expected difficulty of mobilizing resources and stakeholders in China.

Short-term financing solutions

According to a study by the International Energy Agency, carbon capture represents 70-80 percent of the total cost of CCS.[169]



Cost breakdown	Contribution	Reasons
Capture	70-80% total cost	Technology and equipment need to be installed and powered – additional fuel costs
Transportation	Low	If projects could share pipeline or convenient location
Storage & Monitoring	Low	Could be higher if storage sites are offshore below the sea bed

Consequently, if the carbon capture step can be eliminated, CCS projects could be conducted at very low costs, as low as \$6/tCO2.[170] This opportunity exists today in China in the form of coal gasification plants that make ammonia for fertilizer and release pure CO2 into the atmosphere. Pilot projects that sequester these gases underground could be implemented quickly at low cost, and yield valuable lessons that could later be applied to coal plants.

According to the 2008 McKinsey study "CCS: Assessing the economics," the CCS costs will trend lower over time thanks to economies of scale, learning curve savings, shared CO2 pipeline

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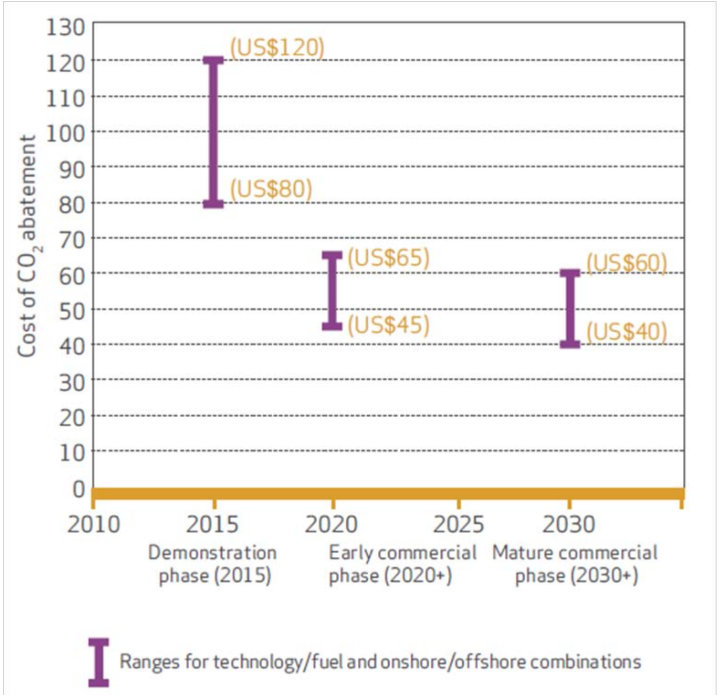
[169] "Energy Technology Perspectives," International Energy Agency, 2008.

[170] United National Framework Convention on Climate Change. http://unfccc.int/files/meetings/sb24/in-session/application/pdf/sbsta_may_20th_in_salah_wright.pdf

networks, and geological storage sites.[171] Technology advances also promise lower cost opportunities, particularly for CO2 capture, which represents the bulk of the cost component.



Source: McKinsey & Company "Carbon Capture and Storage: Assessing the Economics" (2008).

The above premises underline that CCS could be a low-carbon technology opportunity for China. According to the abatement curve created by McKinsey in U.S. cost analysis (which still holds true in China with relatively cheaper costs than in the U.S.), CCS with Enhanced Oil recovery could offer more economic incentives for China, resulting in increased amenability to international cooperation.

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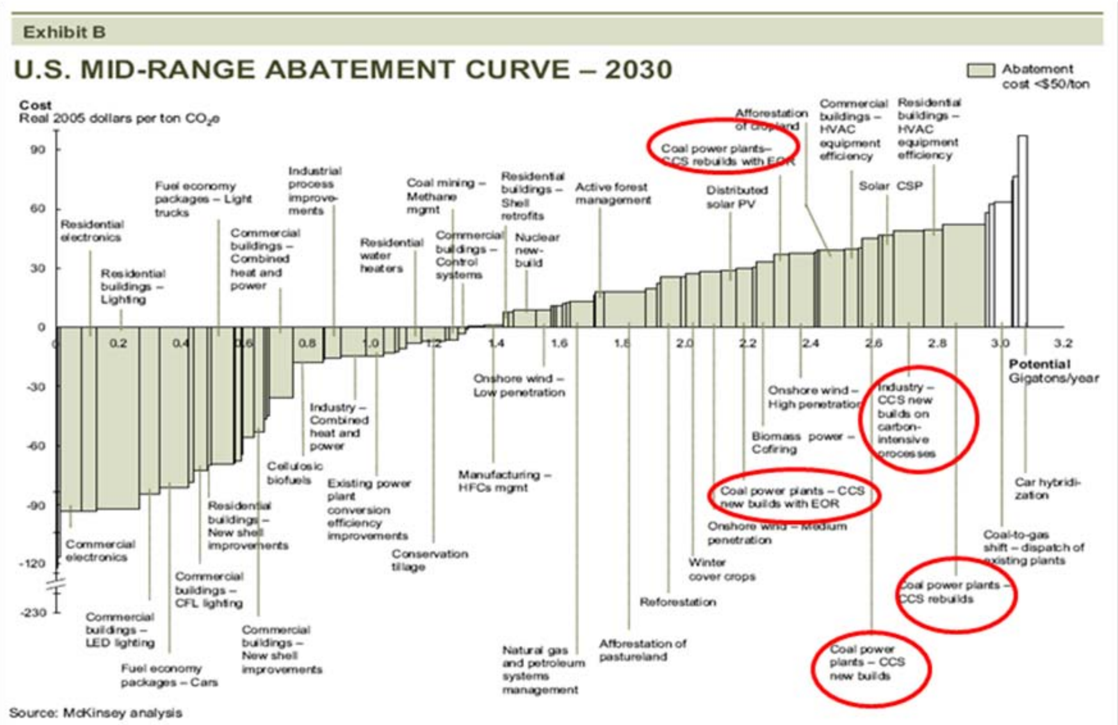
[171] "CCS: Assessing the Economics," McKinsey, 2008.



Source: McKinsey & Company “Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost” (2007).

Based on the above premises, we propose **short-term financing solutions** for China to encourage public private partnership (PPP) and international cooperation / investment around CCS deployment. There are various tactical approaches to incentivize PPP such as guaranteeing payment for an initial fixed volume of CO2 sequestered; encouraging CO2 capture in the industrial sector (outside of the power sector) where CO2 is a by-product of normal operations; opening more cooperative projects in CCS with Enhanced Oil Recovery etc.

Mid-term financing solutions

The development of the Clean Development Mechanism (CDM) in China is worth examining due to its potential applicability to CCS development. Currently, CDM does not include CCS projects, according to the agreement in Kyoto Protocol.[172]

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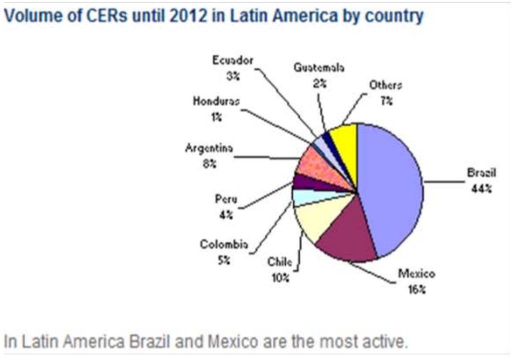
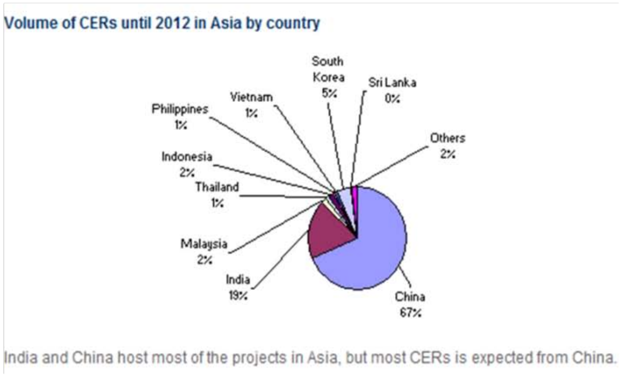
[172] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009, p.19.

Current Clean Development Mechanism without CCS


Volume of CERs until 2012 in Latin America by country

In Latin America Brazil and Mexico are the most active.

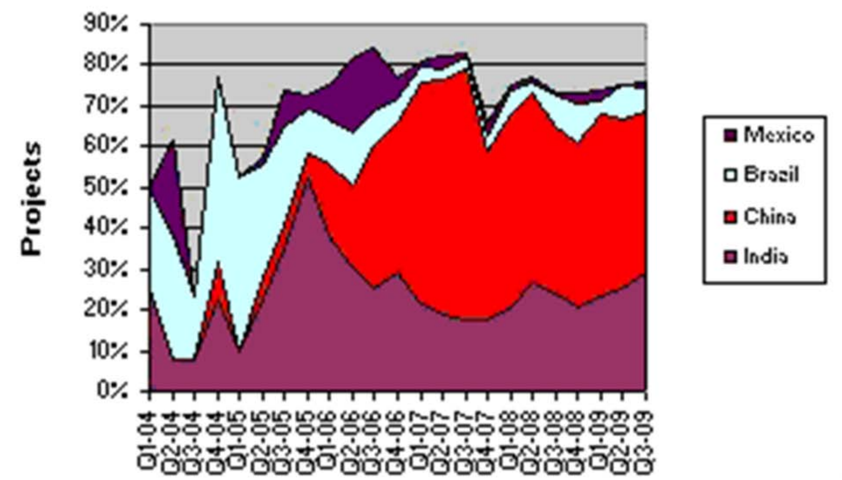

Volume of CERs until 2012 in Asia by country

India and China host most of the projects in Asia, but most CERs is expected from China.

Source: UNEP Risoe Centre.
http://www.cdmpipeline.org/cdm-projects-region.htm

Asia Pacific accounts for 78.3 percent of all projects, equivalent to 80.7 percent total CERs generation.[173] Within that, China accounts for 67 percent CERs generated, or 1,512,526 kCERs (1.5 billion tons CO2, around $15 billion Euro at the minimum). The outstanding thing about CDM in China is in fact its speedy deployment; in just three years, from 2006-2009, China has increased its share of the global CDM market from zero to 40 percent.

CDM Project Breakdown by Country, 2004-2009



Source: UNEP Risoe Centre.
http://www.cdmpipeline.org/cdm-projects-region.htm

The mid-term financing solution for China is to push for incorporation of CCS into the Kyoto Protocol to create an economically viable financing structure for CCS projects. According to Morse et al., “Firms would earn the market price of CERs for every ton of CO2 abated by a CCS project,” even though the challenge of carbon price volatility still remains for capital-intensive

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[173] UNEP Risoe Centre.
http://www.cdmpipeline.org/cdm-projects-region.htm.

projects like CCS that require steady revenue streams.[174]

Long-term financing solutions

Last but not least, China still needs to create a market-based environment to sustain the economics of CCS and other Clean Coal technologies in the energy market by considering these options, or a combination of them.

- Market-wide averaging basis. Under this mechanism, the cost of CCS deployment is passed to the electricity consumer on a market-wide averaging basis. The economic costs of cutting a country's GHG emissions are ultimately borne by the public, therefore the benefits from the deployment of CCS or the reduction of mitigation costs should accrue to the public as a lower economic cost.

Supporting CCS through the electricity market has a number of advantages, such as greater political acceptability due to lower costs to taxpayers; generation of significant funds from the public from very small incremental electricity costs; and promotion of technological innovation and cost reductions by market-based tendering systems.

- Auction and carbon tax revenues. Under this option, governments raise revenues through emission trading schemes auctioning or a carbon tax. These revenues should be reinvested into low carbon technologies, like clean coal and CCS.

- Bonus allowances. Under this mechanism, free or bonus emissions allowances could be issued for CCS plants. These could then be sold at market prices to offset CCS costs. The number of permits that would be needed to support CCS is low relative to the total allowances and would not distort the market. The formula for these bonus allowances rewards coal plants that deploy higher levels of CO2 capture.

- Feebates. Using this option, revenues would be raised by charging a fee directly on unabated fossil fuel use. The funds generated could then be used to support CCS costs. Since the installed capacity of unabated fossil fuel plants is many times greater than the total capacity of CCS plants that would be funded under the program, fee levels would only need to be low to generate the funds needed for commercial-scale CCS demonstration plants. Fees can be applied either to utilities' costs or to customers' bills and can also be used to assist CCS if there is no direct price on carbon.

- Tendering. Most options to accelerate CCS deployment require allocation of funds to bridge the cost gap between conventional generation technologies and those involving CCS. Tenders ensure minimum costs and provide transparency in allocating funds. Tendering also allows governments to focus on specific technology aspects that warrant priority development, even if they are not currently the lowest cost option.

See the figure below for a summary of what China needs to do to make cutting emissions by 50

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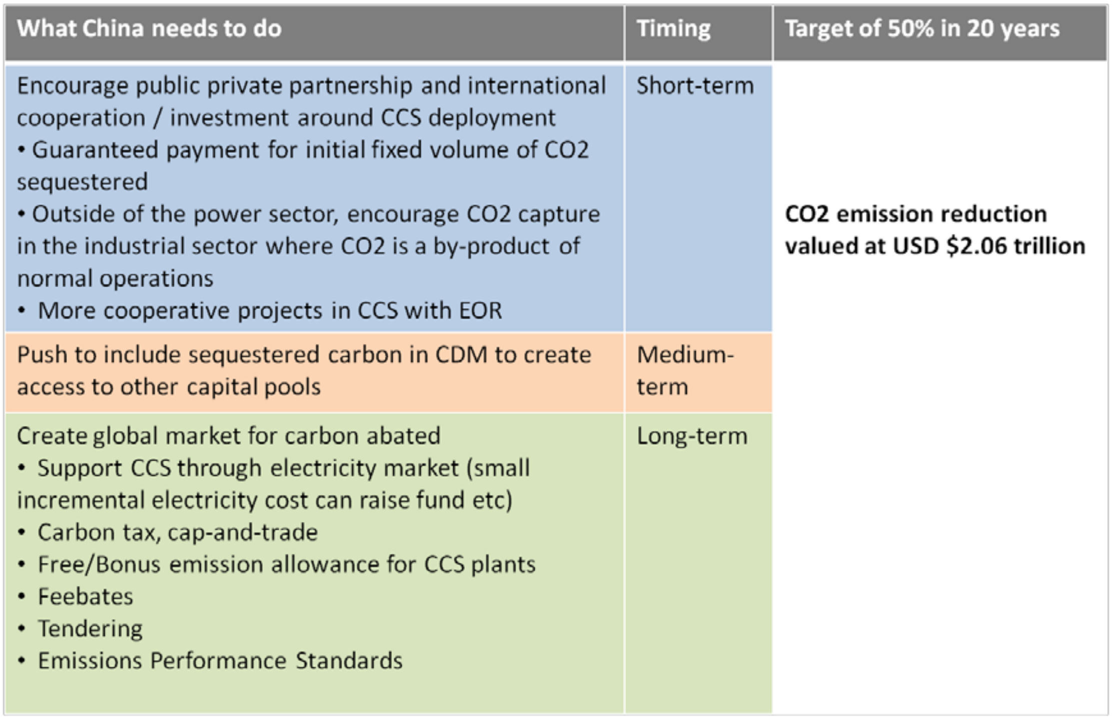
[174] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy," Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009, p. 19.

percent over 20 years financially feasible.



What China needs to do	Timing	Target of 50% in 20 years
Encourage public private partnership and international cooperation / investment around CCS deployment • Guaranteed payment for initial fixed volume of CO2 sequestered • Outside of the power sector, encourage CO2 capture in the industrial sector where CO2 is a by-product of normal operations • More cooperative projects in CCS with EOR	Short-term	**CO2 emission reduction valued at USD $2.06 trillion**
Push to include sequestered carbon in CDM to create access to other capital pools	Medium-term	
Create global market for carbon abated • Support CCS through electricity market (small incremental electricity cost can raise fund etc) • Carbon tax, cap-and-trade • Free/Bonus emission allowance for CCS plants • Feebates • Tendering • Emissions Performance Standards	Long-term	

Technology

On the technology front, collaboration between the U.S. and China is critical to achieving ambitious emissions reduction goals. Collaboration benefits both countries by accelerating the pace of technology development, increasing joint expertise in CCS, fostering ongoing attention to other renewables, enabling direct cost savings on retrofits and new construction, spreading out risk across two nations rather than one, and accelerating the pace of CO2 emissions reductions.[175] Although the U.S. and China have taken steps toward collaboration – through the US-China Clean Energy Research Center and a number of industry MOUs – these steps have been little more than token gestures. They indicate progress in the right direction, but greater cooperation needs to characterize any effective solution.

In order to achieve 50 percent reductions over 20 years, China should pursue many technological solutions simultaneously. Right off the bat, China should shutter all of its subcritical pulverized coal plants and replace them with IGCC+CCS plants. The PRC’s next step – which would take between two to five years to implement – should be to add CCS to its >100 existing coal gasification plants that currently emit pure streams of CO2. Since capture is the expensive part of CCS, using this CO2 for sequestration R&D offers good bang for the buck. Each project would cost between $50-100 million, with China contributing project sites and $20-40 million per project and the U.S. pitching in equipment, scientific expertise, and $30-60 million per

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[175] Schnell, Orville, Albert G. Chang, Laura Chang, et al. "A Roadmap for U.S.-China Collaboration on Carbon Sequestration,” Asia Society Report. November 2009.

project.[176]

China should also begin identifying plants suitable for retrofit. Once retrofitted, old plants would function as R&D centers providing information on carbon capture (in order to reduce capital and operational costs of retrofitting), sequestration (specifically monitoring and mitigating environmental impact), and design, drilling, and technology transfer efforts. This process would likely take about five years from inception to breaking ground.[177]

Once China has developed all of these research facilities, it could refine CCS technology to the point where uncertainties over feasibility and financing disappear. The elimination of those hurdles, coupled with partnerships with U.S. government and industry, should create a climate more conducive to the PRC's scaling of CCS. Since IEA climate mitigation scenarios predict that 14-19 percent of total emissions reductions will need to come from large-scale implementation of CCS (making it a key component of the overall strategy,) [178] China must scale CCS in order to achieve stress case success, unless a disruptive technology emerges that outstrips CCS in terms of cost and scalability.

CONCLUSION

China's energy goals can be summarized in decreasing order of importance as:

1. Maintain social stability
2. Promote economic growth
3. Protect national energy security
4. Cultivate the image of "a responsible global citizen" in the eyes of other nations

CCS is an expensive technology that would necessarily increase electricity prices, thereby hurting social stability and impeding economic growth. These downsides are far more significant for China than the reputation benefit of adopting CCS. Therefore, as Morse and his colleagues already have pointed out,[179] it is not surprising that China has adopted a position of resistance to scaling technologies like CCS unless the developed world is willing to fund this process and mitigate the negative effects.

In the stress scenario in which China commits to cutting emissions by 50 percent over 20 years, CCS would have to be part of the solution. China would have to vastly accelerate and expand its pilot programs to prove CCS at the commercial scale. Additionally, China would have to go from having no CCS plan today to mandating that all subcritical pulverized coal plants be shut down and replaced with IGCC+CCS plants. Finally, China would need sign on to an enforceable international cap-and-trade treaty that would create the financial infrastructure to support the huge costs of CCS implementation.

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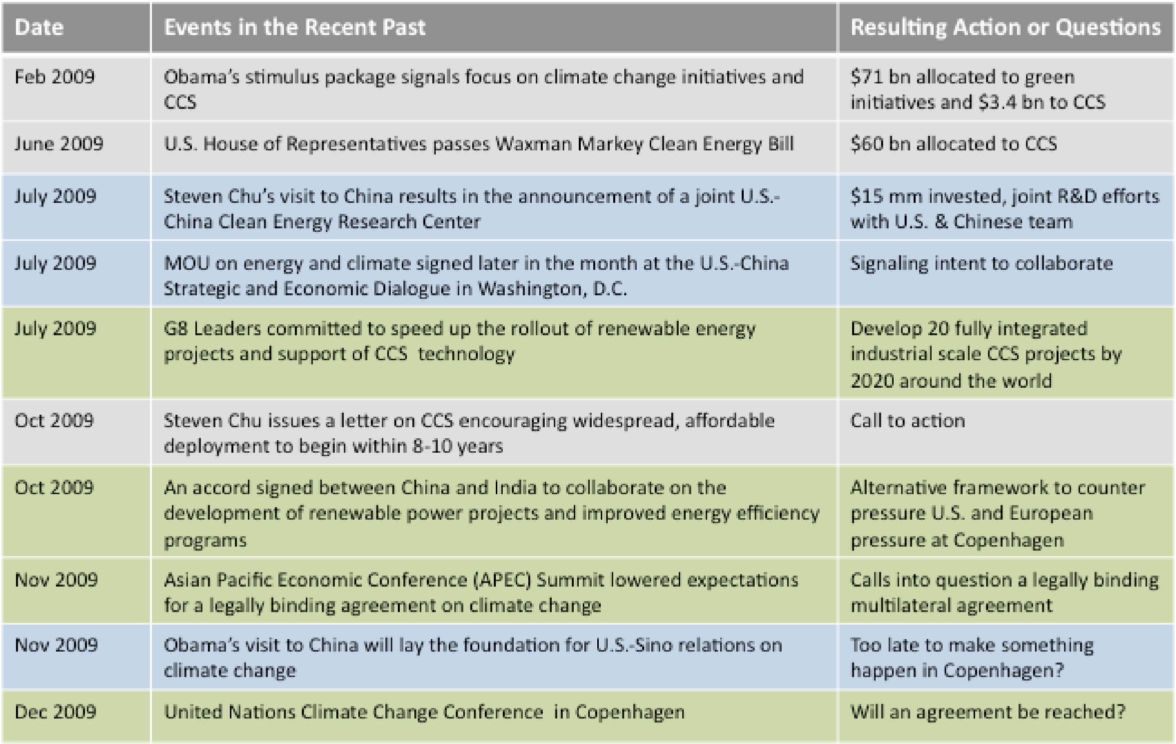
[176] Ibid.

[177] Ibid.

[178] Ibid

[179] Richard K. Morse, Varun Rai and Gang He, "The Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy." Stanford: Program on Energy and Sustainable Development Working Paper #88, August 2009.

Appendix A: U.S. and China Events in the Recent Past



Date	Events in the Recent Past	Resulting Action or Questions
Feb 2009	Obama's stimulus package signals focus on climate change initiatives and CCS	$71 bn allocated to green initiatives and $3.4 bn to CCS
June 2009	U.S. House of Representatives passes Waxman Markey Clean Energy Bill	$60 bn allocated to CCS
July 2009	Steven Chu's visit to China results in the announcement of a joint U.S.-China Clean Energy Research Center	$15 mm invested, joint R&D efforts with U.S. & Chinese team
July 2009	MOU on energy and climate signed later in the month at the U.S.-China Strategic and Economic Dialogue in Washington, D.C.	Signaling intent to collaborate
July 2009	G8 Leaders committed to speed up the rollout of renewable energy projects and support of CCS technology	Develop 20 fully integrated industrial scale CCS projects by 2020 around the world
Oct 2009	Steven Chu issues a letter on CCS encouraging widespread, affordable deployment to begin within 8-10 years	Call to action
Oct 2009	An accord signed between China and India to collaborate on the development of renewable power projects and improved energy efficiency programs	Alternative framework to counter pressure U.S. and European pressure at Copenhagen
Nov 2009	Asian Pacific Economic Conference (APEC) Summit lowered expectations for a legally binding agreement on climate change	Calls into question a legally binding multilateral agreement
Nov 2009	Obama's visit to China will lay the foundation for U.S.-Sino relations on climate change	Too late to make something happen in Copenhagen?
Dec 2009	United Nations Climate Change Conference in Copenhagen	Will an agreement be reached?

Appendix B: China and International CCS Partnerships

The Carbon Sequestration Leadership Forum

China was one of the initial members of CSLF, and its participation is managed by MOST (Ministry of Science and Technology)

COACH (Cooperation Action with CCS China-EU)

This initiative was kicked off in November 2006

NZEC (Near Zero Emissions Coal) is a joint venture initiative between the UK and China.

COACH and NZEC are part of the EU-China Partnership on Climate Change. Chinese partners in both include Administrative Centre for China's Agenda 21 (ACCA21), Tsinghua University, Zhejiang University and GreenGen.

The Asia-Pacific Partnership on Clean Development and Climate (APP) is a voluntary partnership among seven major Asia-Pacific countries. APP addresses increased energy needs and the associated issues of air pollution, energy security, and climate change

China is co-chair with Australia of the Cleaner Fossil Energy Task Force, and co-chair with the USA of the Power Generation and Transmission Task Force.

GeoCapacity: co-funded by EU to build a framework for international cooperation, especially with other CSLF countries (notably China, India and Russia), focusing on technology transfer facilitating the countries to undertake similar studies

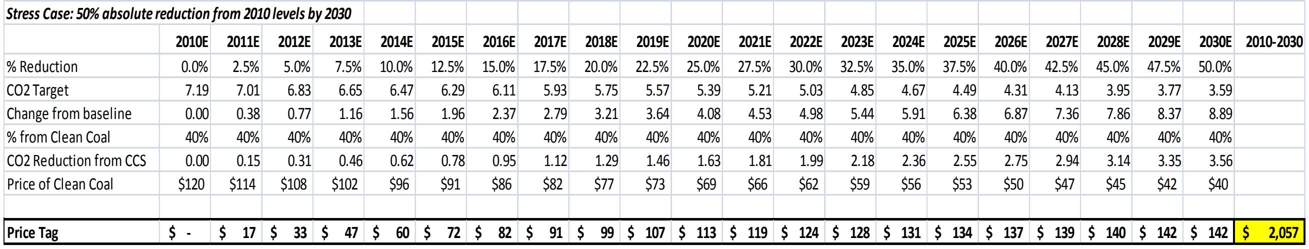
MOST is a full project partner, Tsinghua University and Chinese Academy of Sciences also participate in research project

Appendix C: China's Status Quo Carbon Intensity Projections

Status Quo Scenerio	**2005A**	**2006A**	**2007A**	**2008A**	**2009E**	**2010E**	**2011E**	**2012E**	**2013E**	**2014E**	**2015E**	**2016E**	**2017E**	**2018E**	**2019E**	**2020E**
CO2 Baseline (Billions of Metric Tons)	5.43	6.02	6.40	6.80	6.99	7.19	7.39	7.59	7.81	8.03	8.25	8.48	8.72	8.96	9.21	9.47
GDP Projections (Trillions of Real 2008 USD)	3.11	3.43	3.83	4.33	4.68	5.05	5.45	5.89	6.36	6.87	7.42	8.01	8.66	9.35	10.10	10.90
Baseline Carbon Intensity	1.75	1.75	1.67	1.57	1.49	1.42	1.35	1.29	1.23	1.17	1.11	1.06	1.01	0.96	0.91	0.87
Normalized around 2005	1.00	1.00	0.96	0.90	0.86	0.81	0.78	0.74	0.70	0.67	0.64	0.61	0.58	0.55	0.52	0.50
Reduction in Carbon Intensity		-0.4%	4.3%	10.1%	14.4%	18.5%	22.4%	26.2%	29.7%	33.1%	36.3%	39.4%	42.3%	45.1%	47.7%	50.2%

Source: Created by research paper authors.

Appendix D: CCS-Related Price Tag of Implementing the Stress Case Scenario



Stress Case: 50% absolute reduction from 2010 levels by 2030																					
	2010E	**2011E**	**2012E**	**2013E**	**2014E**	**2015E**	**2016E**	**2017E**	**2018E**	**2019E**	**2020E**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**2028E**	**2029E**	**2030E**	**2010-2030**
% Reduction	0.0%	2.5%	5.0%	7.5%	10.0%	12.5%	15.0%	17.5%	20.0%	22.5%	25.0%	27.5%	30.0%	32.5%	35.0%	37.5%	40.0%	42.5%	45.0%	47.5%	50.0%	
CO2 Target	7.19	7.01	6.83	6.65	6.47	6.29	6.11	5.93	5.75	5.57	5.39	5.21	5.03	4.85	4.67	4.49	4.31	4.13	3.95	3.77	3.59	
Change from baseline	0.00	0.38	0.77	1.16	1.56	1.96	2.37	2.79	3.21	3.64	4.08	4.53	4.98	5.44	5.91	6.38	6.87	7.36	7.86	8.37	8.89	
% from Clean Coal	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	
CO2 Reduction from CCS	0.00	0.15	0.31	0.46	0.62	0.78	0.95	1.12	1.29	1.46	1.63	1.81	1.99	2.18	2.36	2.55	2.75	2.94	3.14	3.35	3.56	
Price of Clean Coal	$120	$114	$108	$102	$96	$91	$86	$82	$77	$73	$69	$66	$62	$59	$56	$53	$50	$47	$45	$42	$40	
Price Tag	**$ -**	**$ 17**	**$ 33**	**$ 47**	**$ 60**	**$ 72**	**$ 82**	**$ 91**	**$ 99**	**$ 107**	**$ 113**	**$ 119**	**$ 124**	**$ 128**	**$ 131**	**$ 134**	**$ 137**	**$ 139**	**$ 140**	**$ 142**	**$ 142**	**$ 2,057**

Source: Created by research paper authors.

Chapter 8

Conclusion: The Challenges of Transnational Strategic Leadership

Our comparative studies indicate that change toward adoption of the electric car and clean coal within the U.S. and China, as well as transnational change toward developing clean energy and reducing global warming, is likely to be slower than many would wish. While it is frustrating to have to come to grips with the slowness with which large-scale national and global change is likely to happen, it should perhaps not be surprising. This is so, first, because there exists a hierarchy of complexity in terms of levels of systems - organizational, national, transnational - at which strategy-making plays out. Bounded rationality implies that the higher the complexity of a system, the greater the need to decompose it into more tractable sub-systems, which then formulate strategies optimized for those sub-systems, but the ensemble of which is not necessarily optimal from the higher-level system perspective.[180] A second limitation is what we call "bounded execution capability" (BXC), which is especially acute when ill-understood technical problems exacerbate the normal difficulties associated with translating strategy into action. While the issue of reconciling sub-system strategies - for instance as relates to resource allocation - is typically resolved in organizational and national systems by concentrating strategic decision-making power in a central authority, this is not easy to accomplish at the transnational level.[181] This has important implications for considering the *definition* of the complex problems that span the various levels of systems, and the *sequence* in which they need to be addressed to maximize progress and the chances of success. While better-informed approaches pave the way for progress at the national level, they only put the transnational problem on hold. Our typology of strategy-making models presented in chapter 3, however, can be used to suggest some ways in which strategic leadership can arise to alleviate the transnational problem.

Hierarchy of Complexity

It is difficult to find industries that are as complex and interrelated as the energy industry. The complexity is further increased when the impact the strategic actions have on the environment are considered. This complexity will either result in the observers concentrating on specific segments of the total energy problem, or these interrelations will be considered in too superficial a manner. The limitations ascribed to bounded rationality are very much evident.

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[180] Simon, H. A., *Administrative Behavior*, 1957; Simon, H.A., *The Sciences of the Artificial*, MIT Press, 1969.

[181] The European Union may be farthest advanced in creating transnational governance systems that can impose a fairly broad range of strategic decisions on the national member states. The United Nations, in contrast, has only been able to create governance mechanisms whose strategic decisions remain subject to the veto power of each of the great powers.

The complexities of the energy industry also limit the ability to carry out the similarly complex actions that are called for. We ascribe this to “bounded execution capabilities” (BXC). The complexities can be due to the technical nature of the solutions (for example, reengineering the electric grid with attention to local generation and local storage of electricity), the scale that is required for solutions to have a meaningful impact (as in the investments required to achieve carbon emission reduction through coal sequestration) and, above all, the inevitably transnational nature of strategy-making concerning energy production and related environmental impact.

The complexities of strategic actions grow in steps. Least complex are those that can be executed within national boundaries, as in the case of reengineering the grid. Next in increasing complexity are actions that require complementary activities between nations, as is the case with high-volume battery production built up in China to support the demand for electric cars by U.S. consumers. The complexity of strategic actions is greatest when collaboration between sovereign nations is required to achieve the desired aim, as is the case in reducing carbon emissions.

The Limitations of BXC

Scaling within national boundaries and pursuing complementary international development have precedence in business. The development of the present grid and the development of railroads crossing the United States provide examples where large scale developments were performed by multiple independently acting U.S. corporations. Complementary strategies executed by companies in a bilateral relationship, while rare, do exist. Consider the recent case of Intel microprocessors and Microsoft software that has been the basis of the development of the personal computer industry. However, when we look for examples of the collaborative case, business history provides little help. If anything, the learnings of business suggest that in such situations we are up against some very hard behavioral dynamics.

Consider, for instance, how resource allocation, a key task of corporations, is performed. In the absence of a strong top-down force, groups of equal-level managers – peers – have a difficult time in achieving any allocation that is workable. Proper resource allocation simply does not happen without the competition for the resource being mediated by superiors. Colloquially, what we need in such cases is the dynamics provided by a “Peers + 1” structure. In a corporate setting, the conflicting demands of the various parties involved in the resource allocation process require the involvement and intervention of the CEO. In nation states, the central government - within a set of tighter constraints in democracies than in one-party systems - serves as the “+1.”

The philosophy of the approach to global warming, however, is predicated on allocating carbon emission among sovereign nations (peers). There is no superior entity that can resolve conflicts and monitor compliance. Business experience clearly suggests that these efforts will come to nothing without the formation of an entity capable of acting the role of the “+1”.

We can conclude from the above reasoning that the difficulty of execution will differ if we concentrate on national energy resilience first, and then progress instead toward addressing global warming, as contrasted to an approach that is driven primarily by global-warming considerations. The latter chase will end up getting nowhere as it gets mired down by the hardest of the hard problems that need to be addressed first: collaboration among sovereign nations. Addressing national energy issues first may be more practical. However, we face the dilemma that the fervor of the activist community, which tends to be one of the stronger forces for change, is driving us toward the environment first.

Copenhagen was not an accident. Its outcome was determined by the bounded execution capability of sovereign nations operating without a "Peers +1" structure.

Strategic Leadership at the Transnational Level

One of the lessons from our studies is that "self-similarity of scale" with respect to strategy-making processes - i.e., the applicability of organizational-level conceptual frameworks – does not fully apply at the transnational level because there can be no Peers + 1 mechanism imposed on sovereign nations to force change. In other words, the "rational actor" model -concentrated strategic decision-making power and simultaneous execution -, by definition, never applies. Hence, it is impossible to enforce top-down solutions for transnational problems such as global warming and environmental pollution. Yet, this does not necessarily preclude strategic leadership at the transnational level.

As suggested in chapter 3, one way in which the lack of a Peers + 1 mechanism becomes resolved is when one of the independent nations is able to contribute a disproportional amount of key resources needed for the collectivity's shared interests to prevail in the face of a "clear and present danger." In such situations transnational strategic decision-making authority inexorably arises. This is what happened during WWII when the President of the U.S. increasingly gained the power of the "+1" in relation to the decision-making involving the allied nations (even to some extent the USSR), and later in the bi-polar world of the Cold War. In an increasingly multi-polar world with the rise of China and India as new world powers, however, it is unlikely that the U.S. will be able to take on the "+1" role in the same way has it has since WWII. In the multi-polar world, the "ecological model" of strategy-making - distributed strategic decision-making power and simultaneous strategic action of multiple players - may be the most relevant for thinking about the transnational problem.

Strategic leadership in the ecological model of strategy-making requires innovative approaches for dealing with strategic interdependence. In the global ecology of transnational relations, strategic interdependence implies that each great power is able to pursue its own strategic goals only to the extent that the other great powers are also able to achieve their goals. And all the great powers understand that there is some level of common interest in maintaining the viability of the ecology. The tasks of strategic leadership of a great power in this situation are (1) to gain credibility by addressing its own problems, (2) to help create the common interests, and (3) to define the level of common interest that must be maintained over time.

The logic developed in this final chapter thus implies that each great power should focus on its own energy resilience and quality of environment first. The ways in which these goals are achieved, will be different for each power. For instance, the U.S faces a greater problem of oil dependence than China and should therefore focus first on the electrification of its transportation sector. China faces more severe environmental pollution problems than the U.S. and should focus on these first. To the extent that both powers show significant progress on the issues that are of their own greatest concern, some progress will actually also be made to the transnational problem of global warming. In the process of seriously addressing their own problems, each power gains credibility in the eyes of the other.

Simultaneously, common interests need to be increased by encouraging rather than impeding forms of organizational-level inter-country collaboration. Such collaborations between US and Chinese companies exist already in the areas that we have investigated. They can only be sustained if the partners constrain their opportunistic behavioral tendencies. It is therefore the strategic leadership task of each company-level top management to help its partners see that continuing the collaboration will be in their own interests.

Finally, at the level of transnational collaboration, nation-level opportunistic behavior can be constrained, to some extent, by the increased organizational-level inter-country collaboration and by the shared imperative of global system-level survival. The major task of transnational strategic leadership resides then in fostering the wide appreciation and adoption of this shared imperative among the other powers and to get them to see that it is in their interest to align their actions accordingly. This can only be achieved if the transnational leader is perceived to be strong technologically, economically and militarily, and truly committed to maintaining those strengths for the long run.