ENERGY MARKET CONSEQUENCES
OF AN EMERGING U.S. CARBON MANAGEMENT POLICY

Executive Summary

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September 2010

Acknowledgments

The Energy Forum of the James A. Baker III Institute for Public Policy would like to thank ConocoPhillips for their generous support of this research project. The Baker Institute also thanks the Institute for Energy Economics, Japan, and the sponsors of the Baker Institute Energy Forum for their generous support of this study. The Energy Forum further acknowledges contribution by study researchers and writers.

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About the Study: Energy Market Consequences of an Emerging U.S. Carbon Management Policy

Emerging energy and climate policies in the United States are accelerating the pace of technological changes and prompting calls for alternative energy and stricter energy efficiency measures. These trends raise questions about the future demand for fossil fuels, such that some energy-producing nations are reluctant to invest heavily in the expansion of production capacity. The abundance of shale gas resources in North America could allow the United States to utilize more gas in its energy mix as a means of enhancing energy security and reducing CO_2 emissions. However, this will only occur if U.S. policies promote and allow the benefits provided by natural gas to be realized. To examine these issues and changing trends in the U.S. energy and climate policy, the Baker Institute organized a major study investigating the North American and global oil and natural gas market consequences of emerging U.S. policies to regulate greenhouse gas emissions, as well as the potential role of alternative energy in the U.S. economy.

Study Authors

Joe Barnes
Birnur Buzcu-Guven
Soumya Chattopadhyay
James Coan
Jareer Elass
Mahmoud A. El-Gamal
Carol Graham
Robert Harriss
Donald Hertzmark
Peter R. Hartley
Amy Myers Jaffe
David R. Mares
Kenneth B. Medlock III
Bin Shui
Ted Temzelides
Xinya Zhang

About the Energy Forum at the James A. Baker III Institute for Public Policy

The Baker Institute Energy Forum is a multifaceted center that promotes original, forward-looking discussion and research on the energy-related challenges facing our society in the 21st century. The mission of the Energy Forum is to promote the development of informed and realistic public policy choices in the energy area by educating policymakers and the public about important trends—both regional and global—that shape the nature of global energy markets and influence the quantity and security of vital supplies needed to fuel world economic growth and prosperity.

The forum is one of several major foreign policy programs at the James A. Baker III Institute for Public Policy of Rice University. The mission of the Baker Institute is to help bridge the gap between the theory and practice of public policy by drawing together experts from academia, government, the media, business, and nongovernmental organizations. By involving both policymakers and scholars, the institute seeks to improve the debate on selected public policy issues and make a difference in the formulation, implementation, and evaluation of public policy.

James A. Baker III Institute for Public Policy
Rice University - MS 40
P.O. Box 1892
Houston, TX 77251-1892 USA

http://www.bakerinstitute.org
bipp@rice.edu

The United States accounts for roughly one-fifth of the world's primary energy consumption and is the second largest emitter of greenhouse gases (GHGs), after China. Thus, the United States must play a key role in any global effort to reduce GHGs. The United States' high levels of gasoline consumption have been the single most important factor behind the rising American dependence on foreign oil. In order to lessen long-term demand for gasoline in the United States— and thereby reduce the chances of gasoline price spikes, rising oil imports, and related hardship to the U.S. economy from oil price volatility—political leaders and policymakers have advocated that the United States enhance its diversity of fuels and seek to use more alternative energy. Increased use of alternative energy sources that are carbon-free would also help the United States lower its GHG emissions.

The U.S. federal system has complicated the policy response to climate change and energy security. Individual states and municipalities have forged their own independent pathways, sometimes at odds with federal policies or initiatives. Several options for reducing carbon emissions have been proposed in the United States.

Now, under the leadership of U.S. President Barack Obama, the United States is attempting to forge a more effective U.S. energy and climate response in hopes of achieving a greater consensus of approach both at home and abroad. The United States is considering several different policies to propel greater use of renewable energy. One proposal is to have a national renewable portfolio standard. Renewable portfolio standards (RPS) require specified percentages of electric power sold to be produced from renewable sources. Currently, renewable portfolio standards are imposed at the state level. As of April 2010, 29 states and the District of Columbia have legislated an RPS. Although the definition of "renewable" varies from state to state, wind generation is included in every instance. Some states, notably California, are also actively promoting the use of solar energy.

Interest in a national RPS comes at a time of increasing installations of renewable electricity, driven to a significant extent by federal and state policies. Still, the most widely discussed renewable sources—wind, solar, and geothermal—account for less than 2 percent of total electricity generation in the United States.

The Obama administration has indicated its support for a more aggressive U.S. energy and climate policy. The U.S. is already pursuing a major initiative to propel biofuels into its gasoline system, but distribution and logistical problems remain. The initial energy and climate policy focus of the Obama administration so far has centered on providing stronger support for policies that were already underway, such as the U.S. Renewable Fuels Standard and loan guarantees for nuclear power. The administration is also managing the distribution of more than $80 billion in clean energy technology as part of President Obama's $787 billion American Recovery and Reinvestment Act of 2009.

Legislation to promote a cap-and-trade regime to reduce GHG emissions has also been proposed in the U.S. Congress but has stalled due to a number of political factors, including concerns among individual legislators about upcoming elections—in this case the 2010 midterms—and worries about the impact that any kind of taxes or rising energy costs would have on the high unemployment rate in the United States.

As the country moves forward to deliberate on energy and climate policy, consideration must be given to what policies would best accomplish the stated goals for U.S. policy—a reduction in the need for imported oil and in GHG emissions. Utilizing economic modeling simulations and policy analysis, this study, *Energy Market Consequences of an Emerging U.S. Carbon Management Policy*, aims to evaluate the outcome of various illustrative proposed energy and climate policies in an effort to shed light on what kinds of policies might be more effective than others regarding energy and climate goals. The study also takes into account the relative costs for the various policy options in terms of changes to U.S. energy and electricity prices, as well as American public attitudes about energy costs and climate change.

Key findings for the study highlight the trade-offs between energy costs, climate goals, and national security. Our hope is to help clarify and debunk common myths that currently plague the U.S. energy and climate policy debate. In particular, the study reveals that many of the climate-focused policies under consideration in the United States do not actually contribute to a significant reduction in oil use or lower the extent of U.S. dependence on foreign oil. This includes several of the policy options to propel greater use of renewable energy.

Our research also illustrates the divergence between stringent carbon abatement policies, such as caps and carbon pricing, and the possibility that the United States would achieve energy independence over time. Ironically, the study reveals that business-as-usual, market-related trends might propel the United States toward greater oil and natural gas self-sufficiency over the next 20 years, while scenarios specifically focused on strict carbon caps and pricing, or a high carbon tax of $60 a tonne or more, could lead to a significant increase in U.S. reliance on oil imports between now and 2025. A carbon tax of $30 a tonne would also increase U.S. dependence on imports of foreign liquefied natural gas (LNG) by 2025. Rather, Baker Institute analysis demonstrates that the single most effective way to reduce U.S. oil demand and foreign imports would be an aggressive campaign to launch electric vehicles into the automotive fleet.

Our analysis also shows that implementing a strong carbon cap with active trading in carbon offsets would be the most effective manner to reduce U.S. GHG emissions by 2050 in a manner that limits the cost of carbon abatement from rising above levels that might be deemed acceptable in U.S. political circles. However effective, this approach to climate issues would still raise the electricity costs to American consumers and possibly push domestic industry to shift more downstream refining and petrochemical investment resources abroad.

Natural gas—if not disadvantaged by heavy-handed government intervention that protects competing fuels, such as coal and alternatives—stands to play a very important role in the U.S. energy mix for decades to come. Moreover, Baker Institute research shows that, as long as policy does not greatly restrict drilling, domestic U.S. natural gas resources should keep the United States in a position where it will not need to import LNG from foreign sources for years to come. The emergence of shale gas has fortified this result. By some estimates, a mammoth 1,000 trillion cubic feet is recoverable in North America alone—enough to supply America's natural-gas needs for the next 45 years. The impact of shale gas is already apparent. U.S. import terminals for LNG sit virtually empty, and the prospects that the U.S. will become even more dependent on foreign imports have receded, with terminal owners now petitioning the U.S. government for export licenses. Also, soaring shale-gas production in the U.S. has meant that cargoes of LNG from Qatar and elsewhere are going to European buyers, easing their dependence on Russia. In fact, already, Russia has had to accept far lower prices for its natural gas and is now allowing a portion of its sales to be indexed to spot natural gas markets rather than oil prices. This change in pricing terms signals a major paradigm shift toward commoditization for global gas markets.

The geopolitical fallout from shale gas' increasing prominence will enhance U.S. national security. Ample shale gas development and production will not only stifle any possibility of natural-gas cartels, it will defang the energy diplomacy of petro-nations. Increasingly, as shale gas resources are made available globally, consuming nations throughout Western and Eastern Europe and in Asia will, over time, be able to reduce dependence on more geopolitically risky and insecure sources from Iran, Russia, and Venezuela.

Baker Institute analysis shows that the United States, even with the continued failure to adopt major energy or climate legislation, would still gradually shift away from carbon-intensive coal use to a higher proportion of consumption of domestic natural gas. This would ease the increase in GHGs that would come about from rising U.S. energy use, while at the same time, allowing the development of unconventional oil resources in North America in the 2020s that would reduce U.S. imports of Middle East oil supplies in the intermediate term.

Our analysis also finds that implementation of a national RPS by itself would make virtually no contribution to lowering U.S. oil use or oil imports. A national RPS, while hurting natural gas demand in the short run, would eventually disadvantage construction of new coal-based plants, contributing to a small reduction in projected U.S. GHG emissions of 0.36 billion metric tonnes, or 4.3 percent versus a reference case of no policy. However, adoption of a national RPS would do so at a relatively higher expense to consumers than more direct policies that simply regulate pollution from coal plants. Economic modeling also suggests that subsidizing renewable energy research and development would be more effective than either subsidizing the use of renewable energy or forcing the production of renewable energy by mandate, even when taking into account the decline in costs associated with renewable energy technology in recent years.

Analysis of the impact on U.S. energy markets of a cap-and-trade system for carbon pricing indicates that the ultimate price of carbon could be highly unpredictable, depending on rules for offset programs, the viability of carbon capture and sequestration technology, and policies adopted to protect domestic industries. All cap-and-trade scenarios ultimately lead to higher U.S. electricity prices; the more binding the policies, the more burdensome the electricity bill for the policy.

Moreover, cap-and-trade program design will be critical in determining the costs to average Americans of imposing such a carbon abatement program and the ultimate savings in emissions, because the stringency of offset trading rules can have a major influence on outcomes. Cap-and-trade program design will also be a major factor in whether industry migrates from the United States to other regions of the world that do not have similar carbon abatement policies.

The Chimera of Energy Independence

Historically, periods of supply shortages and high oil prices, beginning in the 1970s, have inevitably been accompanied by calls for the United States to achieve "energy independence" as a matter of national security. In November 1973, during the height of an oil crisis, President Richard Nixon unveiled "Project Independence," a national energy program that aimed to achieve American energy self-sufficiency by 1980. In a televised nationwide address on November 7, 1973, Nixon told the country that the United States "must develop new sources of energy which will give us the capacity to meet our needs without relying on any foreign nation... Let us set as our national goal, in the spirit of Apollo, with the determination of the Manhattan Project, that by the end of this decade we will have developed the potential to meet our own energy needs without depending on any foreign energy sources. Let us pledge that by 1980, under 'Project Independence,' we shall be able to meet America's energy needs from America's own energy resources." In August 1974, then-Federal Energy Administrator John Sawhill opened "Project Independence" hearings by admitting that the United States will always need to import oil.

During their administrations Presidents Ford, Carter, George H.W. Bush, and especially George W. Bush, also called on America to reduce dependence on foreign oil. President Reagan, by contrast, had a different philosophy. He advocated that free market principles would allow "our citizens to have enough energy" and focused his efforts on market decontrol. Coupled with proactive diplomacy in the Middle East, price decontrols produced a surplus of energy supplies by the end of the Reagan presidency. However, that same reliance on unregulated markets and government laissez-faire produced extreme price volatility during the George W. Bush presidency.

Over the long run, the United States has not reduced its "dependence" on foreign oil. American reliance on oil imports has grown from 35 percent in 1973, when Nixon was in the White House, to about 52 percent in 2009. While the percentage of U.S. imports versus total oil use experienced a reprieve in the early 1980s, with major recessions and the institution of better corporate average efficiency standards for automobiles, cheap prices resumed the upward trend again by 1986. Moreover, U.S. oil imports from OPEC, as a share of total U.S. oil imports, hasn't changed all that dramatically in 35 years, with the 1973 average of U.S. imports from the group's producers totaling 47.8 percent, with Persian Gulf supplies comprising 13.6 percent. U.S. oil imports from OPEC totaled 46.1 percent in 2008 and 41 percent in 2009, with Persian Gulf barrels accounting for 18 percent in 2008 and 14.4 percent in 2009 (see working paper by Elass, Jaffe).

High oil prices set the stage as President Barack Obama was coming into office, with public outcry on the issue of U.S. energy independence once again increasing. In the week following his inauguration, President Obama called on the nation to achieve energy independence. He noted that "Year after year, decade after decade, we've chosen delay over decisive action . . . It falls on us to choose whether to risk the peril that comes with our current course or to seize the promise of energy independence . . . Today I'm announcing the first steps on our journey toward energy independence, as we develop new energy, set new fuel efficiency standards, and address greenhouse gas emissions."

As the difficulty of passing comprehensive energy and climate legislation became more apparent in his second year of office, President Obama tempered his focus on "energy independence," and acknowledged that the move from fossil fuels to clean energy will require time and be costly. Still, the president noted: ". . . we can't afford not to change how we produce and use energy—

because the long-term costs to our economy, our national security, and our environment are far greater." (see working paper by Elass, Jaffe)

Indeed, the costs of trying to eliminate oil imports in the short run would be incredibly expensive (see Medlock, Hartley scenarios). U.S. oil imports of roughly 11 million b/d are the equivalent of 18.7 terawatt hours of energy. To replace all this imported oil with non-fossil energy sources would be the equivalent of adding almost 8 times the current U.S. total capacity for nuclear power generation (assuming 24 hour, 100 percent operations). The United States currently operates 103 nuclear plants. There are also over 250 million oil fuel-based motor vehicles in the United States. On average, Americans retire 75 percent of motor vehicles over a seven-year period. Thus, the infrastructure demands alone in shifting the equivalent of 18.7 terawatt hours of oil-based energy use are immense, both in terms of scale and timeline for retiring existing motor vehicle and energy production facility stocks.

Given the scale-up and timing issues, leaders from OPEC oil producing countries remain skeptical of the Obama administration's push for renewable energy development, electric cars, and the administration's initially ambitious commitment to slash U.S. greenhouse gas (GHG) emissions and support a global climate treaty. OPEC's best defense against alternative energy would be to drop the price of oil to levels that would render alternative energy commercially unprofitable. But the producer group is not currently actively concerned about the threat of alternative energy or electrification of the transportation sector because it doesn't believe that such technologies can be scaled-up commercially to a significant level within the next 20 or 30 years.

OPEC leaders are more concerned that a U.S. or global climate regime might penalize petroleum in a substantial fashion. A U.S. border carbon tax that hits all U.S. imports, including the carbon emitted during the extraction and transportation of oil from Saudi Arabia, might be viewed as a more serious trade problem than U.S. policies to promote alternative energy (see working paper by Barnes, Coan).

Still, individual OPEC members, especially the GCC exporters, are aware of the potential impact that tightened U.S. automobile efficiency standards and other carbon management-related policies might have on shrinking U.S. oil demand over time, and are fashioning commercial responses to this new reality. Baker Institute analysis shows that a policy that promotes the widespread adoption of electric vehicles with an aim to reach 30 percent of the vehicle fleet by 2050, in addition to existing corporate average fuel economy standards, would make a substantial dent in U.S. oil use. Electric cars could help oil use fall by an additional 2.5 million b/d by 2050 on top of the savings of around 3 million b/d already expected from the implementation of new corporate average fuel economy standards imposed by the U.S. Congress in 2007 and fortified by the Obama administration's approval of stricter standards for the state of California.

Individually, key OPEC members have reacted to the prospect of a new, more proactive U.S. policy by shifting actively to find alternative outlets for their oil and natural gas, especially in Asia. Such marketing changes are being seen in Saudi Arabia, the United Arab Emirates, Kuwait, and Qatar (see working paper by Elass, Jaffe). Saudi Aramco has boosted efforts to increase oil exports to India and China with an aim to maximize oil revenues and position itself for the longer term. Saudi exports to China overtook volumes to the United States in the last three months of 2009 and into February 2010. But the recent momentum this past spring for Saudi Arabia, Kuwait, and the United Arab Emirates to seek higher oil sales to Asia also has some shorter term geopolitical overtones: the three U.S. allies have been working in close coordination with the Obama administration to wean China and India away from high dependence on Iranian crude in hopes of reducing international support for the Iranian regime and its pursuit of a nuclear program.

Beyond concerns related to geopolitical factors such as Iran and the possibility that the U.S. market for oil will shrink while that of China and India grows, GCC OPEC members are also watching closely the development of massive shale gas resources in the United States and studying the effect that rising supplies of natural gas might have on the oil/natural gas market balance. As prices for natural gas in the United States fall, the prospect that global natural gas prices will become similarly discounted is raising concerns in the Gulf about the long-term implications of U.S. shale gas abundance. Mideast exporters are worried about the chance that cheap natural gas will erode oil demand in the electricity and industrial sectors in the developing economies of Asia at the same time that those countries are trying to shift to alternative energy at the margins.

The Huge Potential of Unconventional Natural Gas

Slowly, since the late 1990s, onshore drilling in the United States has produced something no one expected: a giant surplus of natural gas. Shale gas resources, natural gas that can be developed through non-porous rock formations through the use of water and chemicals injection, are now known to be extensive—perhaps as high as 1,000 trillion cubic feet in the United States alone and with hundreds of millions of cubic feet also in Canada, Eastern Europe, and China. The new shale resources in the United States are large enough to supply current U.S. natural gas consumption levels for the next 45 years. Taken together with other conventional and unconventional natural gas resources, the U.S. resource base is large enough to meet current U.S. natural gas consumption levels for the next 100 years or more.

Environmental critics of shale gas say drilling for shale gas runs a risk to groundwater even though shale is generally found thousands of feet below the water table. If a well casing fails, drilling fluids can seep into aquifers but this has not generally been a pervasive problem. Drilling itself is relatively safe, so critics may have overplayed its dangers. But water pollution can occur if the drilling fluids are disposed of improperly, as has been the case in several locations, so regulations and enforcement must be tightened to ensure safety.

Natural gas from shale will have enormous ramifications. According to Baker Institute market analysis, ample shale resources mean that the United States won’t become highly dependent on LNG imports for years to come, limiting the possibility of a GasOPEC and thereby enhancing U.S. energy security. Since the U.S. uses barely any oil to generate electricity, ample natural gas for electricity generation means a shift to electrified vehicles would lessen our dependence on imported oil at a lower cost than might otherwise have been possible. Already, expanding U.S. shale gas production has curtailed the petro-power of major exporters.

Under the business-as-usual reference case of a no-carbon policy, ample domestic natural gas resources mean that LNG remains a marginal source of natural gas demand for the next several decades. This, in turn, hurts Iran and Venezuela from fully developing their natural gas export industries and limits the possibility of a GasOPEC from asserting market power globally. Under a no policy scenario, natural gas demand rises by over 40 percent by 2040, but prices still remain stable for at least two decades before rising gently.

Under a $30 carbon tax scenario, natural gas demand is projected to increase by 52 percent by 2040 relative to current demand, in part because natural gas burning plants replace inefficient coal plants and also natural gas fuel takes market share from coal in new plant construction to a greater extent than in the reference case. Natural gas' share of the electricity market grows to 44 percent by 2040, compared to 22 percent currently, while coal falls to 23 percent and renewables grow to 17 percent. Under this scenario, U.S. natural gas prices are about 30 percent higher than in the reference case, and the United States sees higher imports of LNG over time, with LNG imports reaching 12 percent of total U.S. natural gas demand by 2030 and 38 percent of U.S. demand by 2050, leaving global gas markets in about the same geopolitical position as they were late in this past decade when the petro-power of Russia was on the rise.

Under a scenario where U.S. carbon emissions are capped at 50 percent of 2005 levels with no offsets trading permitted, the U.S. sees an increase in LNG imports relative to the reference case by 2030. Imports come to represent nine percent of U.S. natural gas demand; this import pressure recedes again by 2050 as new technologies account for a larger portion of the electricity sector. However, interestingly, under this scenario, assuming that Russia and the FSU fail to adopt similar climate policies, Europe's geostrategic position relative to Russia and the FSU deteriorates, with Russia and its FSU neighbor countries exporting increasing amounts of electricity to Europe and European heavy industry migrating to Russia as carbon prices rise (see working paper by Hartley, Medlock).

Policy Conundrum: The Trade-off Between Reducing Emissions and Reducing Oil Imports

Baker Institute analysis reveals that few, if any, of the climate-oriented policies that have been proposed for the United States would do much to reduce U.S. oil imports. For example, our analysis finds that implementation of a national renewable portfolio standard (RPS) by itself would make virtually no contribution to lowering U.S. oil use or oil imports. Over time, a national RPS would likely disadvantage coal, contributing to a small reduction in projected U.S. greenhouse gas emissions of 4.3 percent by 2050 versus the reference case of no policy, but at a relatively higher expense to consumers than more direct policies that simply regulate pollution from coal plants. A national RPS, by propelling use of more wind resources, will influence the kind of construction of natural gas-fired plants needed as backup to intermittent, nighttime wind supply. More gas turbine peaking plants would likely be constructed in preference to the current emphasis on more efficient combined-cycle gas plants, leading to higher costs. The costs to consumers of a national RPS will rise as expanded renewable capacity is pushed forward in time by the regulation. In fact, electricity prices are projected to increase more than threefold under a strict RPS scenario, whereas the reference case indicates electricity prices will likely double by 2050.

Another interesting result found in the national RPS scenario analysis is that subsidies for wind might make less sense than assistance to the geothermal energy industry in the United States, suggesting that U.S. policymakers should review the cost/benefits of providing stronger incentives for geothermal energy rather than expensive subsidies for biofuels or wind. Ultimately, geothermal energy would be more similar to nuclear power in providing around-the-clock base load electricity supply that does not face intermittency problems and is available during peak electricity use periods.

The policy, among those tested, that would most significantly reduce U.S. oil imports over the long term would be one that promotes the widespread adoption of electric vehicles targeted to reach 30 percent of the vehicle fleet by 2050. In this scenario, total U.S. oil use would fall by an additional 1 million b/d by 2030 and by 2.5 million b/d by 2050 on top of the 3 million b/d savings by 2050 from implementation of existing CAFÉ standards, with imports falling from over 60 percent of total U.S. oil use currently to 40 percent under the electric car scenario. Under this electric car scenario, however, U.S. GHG emissions would only be reduced by 7.4 percent by 2050 relative to our reference case, since without a mandated carbon cap system, added electric cars would encourage more electricity generation with coal. An electric car scenario compares more favorably with a policy that would promote the same 30 percent level of penetration for Compressed Natural Gas (CNG) vehicles (see working paper by Hartley, Medlock).

Under the CNG vehicle scenario, the impacts on U.S. oil use are similar to the scenario with electric vehicles. But even with new, more ample, identified domestic natural gas resources, the tremendous increase in natural gas use in the transportation sector, under a high penetration CNG vehicle framework, the United States would more rapidly deplete its domestic natural gas supplies. Thus, as U.S. imports of oil fall as more Americans drive CNG vehicles, imports of natural gas via LNG will eventually rise, Baker Institute analysis shows, especially after 2030, thus offsetting any energy security benefits and also exerting more upward pressure on domestic natural gas prices, which would rise over 30 percent more than under the business-as-usual case. A similar rise in dependence on LNG does not result in the case of a larger penetration of electric vehicles due to differences in vehicle efficiency and the diverse nature of fuels for the U.S. electricity system. Under this CNG vehicle scenario, the global natural gas market would once again fall under greater risk of petro-power geopolitical assertiveness by Iran, Russia, and Venezuela.

CNG vehicles still rely on internal combustion engine technology, which is less efficient in fuel requirements than electric vehicles, whose engines gain energy from braking and have higher operational efficiency. In fact, a recent analysis of best-in-class vehicle technologies indicates that the well-to-wheel energy efficiency of electric vehicles is roughly three-and-a-half times greater than CNG vehicles. Baker Institute analysis shows that if the entire vehicle fleet were converted to CNG vehicles, U.S. natural gas demand would almost double its current level.

Alternatively, if the entire vehicle fleet were converted to electric vehicles and high efficiency natural gas combined-cycle power plants were used to generate all the additional electricity required, the increase in natural gas demand would be significantly less, or approximately 19 bcfd. This calculation also takes into account energy losses from the conversion of natural gas in power stations as well as transmission losses, which overall do not outweigh the average of inefficiency per CNG vehicle. Moreover, overall efficiency of the vehicle is not the only factor at play in a transition to new technology in the transportation sector, since additional electric load for transportation could be met by a variety of fuels, not just natural gas, under a scenario promoting electric car use. In other words, given the variety of fuels used to generate electricity in the United States and the differences in energy loss from engine operation, higher use of electric cars would result in a smaller increase in natural gas demand than similarly high penetration of CNG vehicles.

Concerns about the security of battery materials for electric vehicles also appear to be overstated. While once feared to be a possible constraint on electric car development, global lithium supplies are evolving rapidly, with new discoveries, increased efficiency in production, and technological innovation in recovery techniques. It is now considered unlikely that a cartel of suppliers, and certainly not Bolivia alone, will emerge that would strategically limit output or attempt to keep prices above market levels. Moreover, other vehicle technologies may be employed, such as more efficient internal combustion engines, natural gas in vehicles, and batteries with different chemistries that do not require lithium. Furthermore, unlike gasoline, lithium does not get completely consumed over the life of the battery, and the battery market will likely be able to eventually recycle the lithium once the battery dies (see working paper by Mares).

Implications of Various Programs for Cap-and-Trade

Analysis of the impact on U.S. energy markets of a cap-and-trade system indicates that the price of carbon could be highly unpredictable, depending on rules for offset programs or availability of carbon capture and sequestration technology. Scenario analysis of various proposals for cap-and-trade programs indicates that a cap-and-trade regime seeking an ambitious target of 50 percent reduction in carbon dioxide emissions—with no provision for offsets trading from 2005 levels by 2050 and under calculations using today's actual costs for deploying carbon capture and storage—would produce an incredibly high carbon price of roughly $220 per ton. In turn, this would contribute to a significant increase (roughly tripling) of wholesale electricity prices in the United States. Under a scenario where the cap for emissions is a 20 percent reduction from 2005 levels by 2050, again with no provisions for offsets trading, we estimate a carbon price that increases to about $190 ton and a 2.5-fold increase in U.S. electricity prices by 2050. Under a scenario where the cap for emissions is 50 percent by 2050 but the carbon sequestration and storage costs fall to levels as predicted by the U.S. Department of Energy, a cap-and-trade regime might produce a significantly lower carbon price of $200 per ton in 2050, yielding an increase in electricity price of about two-and-a-half times their current levels.

All cap-and-trade scenarios ultimately lead to higher U.S. electricity prices; the more binding the policies, the more burdensome is the electricity bill for the policy. Thus, a 20 percent cap by 2050 with offset trading leads to an electricity price increase of 22 percent during the period of study over the reference case of no policy, whereas a 50 percent cap by 2050 with no offsets leads to an electricity price increase of 36 percent during the period of study over the reference case of no policy. A straight carbon tax of $30 a ton raises electricity costs by 10 percent compared to the reference case of no policy. A straight carbon tax of $60 a ton raises electricity costs by 20 percent compared to the reference case of no policy.

On the other hand, the most binding scenarios, such as a 50 percent cap with no offsets, would bring about dramatic reductions in GHG emissions of 3 billion metric tons, or half of 2005 levels, by 2050, as compared to an increase in GHG emissions in the no policy reference case of about 20 percent over their current levels.

By contrast, a $60 tax on carbon emissions reduces GHG emissions relative to the reference case by about 8 percent, substantially lower than either a 20 percent or 50 percent cap. Compared to 2005 U.S. GHG emissions, a $60 carbon tax does not produce a drop in emissions relative to 2005 but actually allows emissions to rise by 11 percent by 2050. The implications of this analysis is that it would take a carbon price higher than those being debated on Capitol Hill to actually lower U.S. emissions from 2005 levels. The $60 carbon tax does not help the United States reduce reliance on oil imports, which would rise to 77 percent of total U.S. oil use by 2025 or by 57 percent in 2050 (see working paper by Hartley, Medlock).

In each of the cap-and-trade scenarios, the amount of reduction in U.S. oil demand increases as the carbon cap becomes stricter. This occurs because rising carbon dioxide (CO_2) prices provide incentives for CCS penetration. This then allows electrification of the vehicle fleet over time, as substantial reductions in CO_2 emissions require mitigation of CO_2 from mobile sources, such as automobiles. Thus, as the CO_2 price rises to over $140 per ton, we begin to see increased electrification of the vehicle fleet as a means to further reduce CO_2 emissions.

In fact, in the reference case, U.S. energy demand increases by about 35 percent by 2050 relative to demand in 2010, but in the case where emissions are restricted to 50 percent of the 2005 level by 2050 with no offsets, U.S. energy demand grows only by 18 percent. Use of renewable energy grows by a factor of six to 29 percent of total U.S. energy use.

In terms of U.S. oil demand, it increases by about 17 percent by 2050 relative to demand in 2010, in the reference case. But in the scenario where emissions are restricted to 50 percent of the 2005 level by 2050 with no offsets, U.S. oil demand falls by about 45 percent. While U.S. oil demand under this scenario does not fall significantly for the next 20 years, the drop by 2050 is the result of a large general decline after 2030 in total energy use across the United States, partly because of an eventual adoption of an electric vehicle with electricity generated by coal utilizing CCS technology. To make this plausible takes a carbon price rising from $170 a ton in 2030 and rising to $250 a ton by 2050.

Ironically, even though this case is highly effective in both reducing carbon emissions and lowering oil use in the United States, it does not have as dramatic an impact on reducing U.S. oil imports. U.S. imports rise to 82 percent of total U.S. oil use by 2025 as development and production of domestic shale oil and other unconventional oil resources is inhibited but technologies to lower oil use have not yet kicked in. By 2040, the share of imports begins to fall again to 67 percent and ends at 28 percent by 2050 as oil demand finally becomes so greatly curbed that it reverses the import trends. That is in contrast to the reference case of no policy, where the United States increasingly relies on domestic oil shale and other unconventional oil resources to lower imports. Under this reference case, U.S. oil imports rise from 60 percent currently to 74 percent in 2025, but declines to 41 percent by 2050 as domestic unconventional oil production ramps up (see working paper by Hartley, Medlock).

The implication of this analysis is that although a stringent cap-and-trade system will reduce oil demand over the long term, it may actually be detrimental to broader goals related to U.S. oil security in the intermediate term as long-term development of unconventional oil resources are hampered. High CO_2 prices leave the balance of oil production with traditional oil exporters and allow Venezuela to become more important to the global oil market balance.

Under a 20 percent cap with no offsets, the impact on the development of domestic U.S. unconventional oil resources is less restrictive, allowing for modestly higher production of domestic oil, and limiting imports somewhat.

International Trade and Carbon Leakage

It is difficult to overestimate the importance of U.S. participation in any international regime limiting GHG emissions. While China may have surpassed the United States in total GHG emissions, our per capita emissions exceed China’s by a factor of four. Historical U.S. emissions—reflecting our early industrialization and significant use of hydrocarbon fuels for over century—exceed China’s by a similar ratio.

It is unlikely that developing, populated countries like China and India will agree to GHG emission limits without United States participation in similar controls. So far, China has only agreed to targets to reduce the carbon intensity of its economy but not to a binding cap or target for its total GHG emissions. But significantly, it announced this commitment just one day after President Obama declared a target for U.S. emissions. The fact that the U.S. Congress is having difficulty passing climate legislation is likely to put a future binding international agreement at risk by potentially letting China and other developing countries off the hook. Extensive polling in the United States shows that a plurality of Americans has never heard of cap-and-trade. According to a February 2010 Pew Center for the People and the Press poll, only 17 percent said they have heard a lot about the policy, compared with a plurality (46 percent) who have heard *nothing* about it.

Perhaps the most significant accomplishment of the December 2010 Copenhagen Summit—formally the 15th United Nations Climate Change Conference, or COP15—was a commitment by developing countries to be open in providing an inventory of their greenhouse gas emissions, a critical first step to an eventual legally binding, verifiable international regime. Copenhagen also demonstrated the extent to which major developing economies such as India, Brazil, and, especially China, have become even more important players in international climate negotiations. This is likely to mean that aid assistance flows related to mitigation or adaptation costs will have to be a major element of any global agreement on global climate change. Such foreign aid will represent a special internal political challenge to the United States, a country with a historically low level of foreign developmental assistance as percentage of gross domestic product (GDP) (see working paper by Barnes, Coan).

Arguments about American economic competitiveness and the health of the U.S. economy will likely be influential factors in the debate in the United States about cap-and-trade oriented climate policies. Baker Institute analysis shows that a cap-and-trade program design will be a major factor that determines whether industry migrates from the United States to other regions of the world that do not have similar carbon abatement policies. For example, under the scenarios of a 50 percent reduction in GHG emissions by 2050, both with and without offsets, and of a 20 percent reduction in GHG emissions, both with and without offsets, industrial activity dramatically relocates to North Africa, the Middle East, China, and Russia from the United States, Canada, Europe, and Northeast Asia. The industries that relocate tend to be those that are energy intensive such as refining, aluminum smelting, steel and minerals processing, and chemicals. Under less stringent policies such as a carbon tax of either $30 or $60 or implementation of a national RPS or promotion of electric cars, relocation of industry is not prevalent (see working paper by Hartley, Medlock).

The shift of heavy, carbon intensive industry to regions that are not carbon constrained, such as the Middle East, could put a strain on any global climate agreement and negatively impact U.S.

and EU relations with the Gulf. OPEC members made their disapproval of a U.S.-backed U.N. climate treaty well known during U.N. climate talks attended by 175 nations in Bonn, Germany, on March 30, 2009. In a surprisingly unique argument against carbon taxes and policies that seek to reduce GHG, Saudi Arabia has insisted that oil exporters should be granted access to funds for "victims" of global warming to compensate for hardships to oil exporters caused by climate change policies.

Energy intensive industries and construction are a major focus of economic activity in the Middle East at present and, therefore, one potential side effect of increased industrialization in the region could be a significant increase in carbon emissions. Construction, in particular, has been one of the main engines of growth in the Middle East, but the link between construction, even infrastructure building, and eventual industrialization in the sense of increased manufacturing share in GDP, is very weak. Moreover, construction supporting industries such as cement are carbon intensive. But it is important to the global economy for the Middle East to enhance its absorptive capacity for new investment and job creation, This would provide greater stability to the region and ameliorate the cycle of petrodollar flows and related destructive credit crises that follow from sudden rises in petrodollar flows. One way for the region to expand its economy while not necessarily significantly increasing its carbon emissions would be to enhance intra-regional trade, especially in manufactured goods (see working paper by El-Gamal).

A decade of tremendous economic growth in East Asia was mainly fueled by intra-regional trade, which eventually gave rise to an acceleration of exports to the rest of the world. It is interesting to note that the relative size as a percentage of intra-regional trade was higher in the Middle East than for developing Asia in the 1980s and 1990s, before it stagnated, but the Middle East has traditionally relied excessively on exports of low value-added, such as crude oil and agricultural goods. For countries that have pursued export-oriented growth strategies successfully, trade-oriented policies have been conducive to industrialization, which enhances total factor productivity and eventually leads to higher income levels for all, even if some in the traditional sectors may suffer from increased income inequality in the short term. Intra-regional exports provide incentives for specialization and increased efficiency, eventually enhancing competitiveness in world markets and making industrialization through export-oriented growth successful.

Intra-regional trade in the Middle East remains anemic despite free trade and other regional preferential trade agreements. One explanation is that many countries may be taking a mercantilist approach, hoping to gain access to new markets, rather than cooperating on policies that will promote regional growth and development. Investment emphasis on heavy industry also has meant a failure to increase employment and revenue from higher value-added exports. But if the region were to shift to an agenda of increased trade and investment integration in the direction of a higher manufacturing proportion in output, this might be accomplished without an acceleration of CO_2 emissions (see working paper by El-Gamal).

Given concerns about U.S. competitiveness under a cap-and-trade or carbon tax regime, a critical part of any future U.S. carbon legislation will be a "carbon tariff"—a border tax levied to ensure that imports face the same carbon price as domestic producers. Such a tariff, at least in theory, is seen in the United States as one mechanism to "encourage" other countries to join a global cap-and-trade regime. There are also clear political advantages to a carbon tariff; it can be used to assuage fears by domestic industry that it will be left at a competitive disadvantage. Unsurprisingly, Waxman-Markey includes a provision permitting border adjustments beginning in 2020. So did, originally, the Boxer-Kerry proposal, though a border adjustment was subsequently cropped from their draft. Ten Democratic senators have written a letter to Obama saying that they will only support climate change legislation if it includes a border adjustment. The Cantwell-Collins proposal included a border carbon levy. So does the Kerry-Lieberman-Graham "framework." Even assuming that a border levy is compliant with the World Trade Organization (WTO), the scope for abuse of a border levy is substantial. Most free traders are, understandably, vehemently opposed to carbon tariffs. Not only are there technical difficulties associated with assessing such a tariff, its enforcement raises the prospect of retaliation from countries such as China and, potentially, a trade war (see working paper by Barnes, Coan). As already discussed, the prospect of a border adjustment could raise tensions with oil exporters as well.

An important complication to imposing a carbon border tariff is the problem of embedded carbon in trade. International trade in commercial commodities is a significant factor contributing to the growth of atmospheric carbon dioxide concentrations. For the past several decades, growth in international trade has outpaced the growth of global gross domestic product (GDP), energy consumption, and world population. This surge of economic globalization has resulted in a dynamic shifting in the geographic patterns of production and consumption of consumer goods, fossil fuels use, and CO_2 emissions.

Increasingly, with globalization, the production of consumer goods is shifting to geographies with the lowest possible costs while consumption remains unchanged in the higher income countries of the developed world. One, perhaps unintended, consequence of economic globalization has been a shifting of the burden of additional CO_2 emissions and other environmental pollutants from developed to developing countries. This phenomenon raises fundamental policy questions concerning country-level responsibility for emissions. The emissions generated during the manufacturing and distribution of an exported commodity is most often known as "embodied carbon in trade." The terms "embedded carbon in trade" and "virtual carbon in trade" have also been used in the same context.

The challenge of designing an analytical framework for quantifying the impacts of traded goods requires consideration of the economic, environmental, spatial, and temporal dimensions of the entire life cycle of a product. Currently, there is not a standard analytical methodology capable of providing comprehensive assessments of embodied carbon international trade.

A state-of-the-art analysis of embodied carbon in international trade recently published in the *Proceedings of the National Academy of Sciences* (PNAS) reported that in 2004 the embodied carbon in commodities imported for consumption in the United States would be equivalent to transferring approximately 11 percent of U.S. national CO_2 emissions to the exporting countries (see working paper by Harriss, Bin Shui). On the flip side, nearly one-quarter of China's CO_2 emissions, for instance, were dedicated to making goods for export and consumption in wealthy countries. More recently, scholars Yunfeng and Laike indicated that 26.5 percent of China's annual CO_2 emissions were produced as a result of the manufacture of exported goods in 2007.

The embodied carbon in imported goods was equivalent to 9.1 percent of China's 2007 CO_2 emissions. These results implied that, in 2007, the rest of the world avoided emitting approximately 593 $MtCO_2$ through importing Chinese products.

Given these and other studies, China is likely to demand consideration of embodied carbon as an issue in determining a global framework for measuring responsibility for CO_2 emissions. China's energy intensity (amount of energy consumed per unit of GDP) and carbon intensity (amount of energy-related carbon emissions per unit of GDP) increased in recent years as the country experienced growth of coal-based energy and carbon-intensive industries to meet demand for consumer goods and urban expansion.

China-U.S. trade may offer an opportunity to create a collaboration that could dramatically accelerate the decarbonization of global manufacturing and trade. The combination of the rate and scale of China's economic development, and the sophistication of U.S. research and development capabilities, could be crafted into an arrangement for large-scale experimentation and deployment of clean energy technologies. This collaboration could also provide advances in strategies for the sharing of intellectual property between developing and developed countries.

Trade between developed and developing countries will be an important avenue for the spread of environmental technologies needed to mitigate and adapt to climate change. Trade liberalization alone will not result in greater access to emerging climate-friendly technologies and goods if costs are kept high by licensing fees or royalty payments. A 2007 World Bank report estimated that the removal of tariffs for four basic clean energy technologies (wind, solar, clean coal, and efficient lighting) in 18 developing countries would result in trade gains of up to 7 percent (see working paper by Harriss, Bin Shui).

The international community needs to address the question of whether it is better to import such goods more cheaply, thereby fostering greater environment improvement, or whether individual countries should be permitted to protect domestic clean tech industries with the consequence of delaying mitigation of greenhouse gases.

Attempts to institute border tax adjustments based on the carbon content of imported goods will be complicated by the debate on embedded carbon. Border tax adjustments are being proposed in consuming countries such as the United States as a trade measure that aims to level the economic playing field between OECD domestic industry facing climate change regulations and developing world producers facing few or none. In the case of a border tax, imported goods would be charged a fee equivalent to the carbon tax paid if the product had been produced in the consuming country subject to carbon emissions regulations.

The reaction to a border tax adjustment scheme will be highly contentious and, at the very least, result in challenges to the WTO process. A recent study suggests that the imposition of a border tax could lead to substantial tariff rates on imports from developing countries. For example, Chinese imports into the United States could be subject to an average tariff rate of 10.3 percent if carbon was taxed at $50 per ton of $CO_{2.}$ Given the pressures to include major developing economies into a global climate policy framework, ongoing climate change negotiations addressing a post-Kyoto policy framework for CO_2 and other greenhouse gas inventories may require a rethinking of the role for embodied carbon and consumption-based accounting in future climate negotiations (see working paper by Harriss, Bin Shui).

Flaring and venting of natural gas remains another emissions challenge attracting international cooperation. The World Bank started a public-private partnership initiative called Global Gas Flaring Reduction (GGFR) in 2002 with the purpose of reducing gas flaring and venting worldwide. According to the estimates provided by the GGFR and the National Oceanic and Atmospheric Administration (NOAA) based on satellite data, global gas flaring volumes were estimated at about 146 bcm in 2009, or less than 1 percent of global emissions. Nigeria and Russia alone accounted for 42 percent of the total flaring volume. Estimates of venting volumes are more difficult to obtain, since current satellite technology is not capable of detecting and tracking venting. However, venting is more damaging environmentally, since unburned CH_4 is approximately 25 times more potent as a greenhouse gas than is CO_2.

The mission of the GGFR is to address the issue of gas flaring by promoting strong cooperation among the primary players and encouraging regulatory frameworks and gas transmission infrastructure investments. While this initial approach showed some success, it has not generally been successful at the upstream end of the gas value chain, since it does not deal with the fundamental under-pricing error that is normally responsible for gas flaring. Recent initiatives to price associated gas at more market-related levels in such major flaring nations as Russia, Nigeria, and Indonesia show positive signs, although more progress needs to be made.

Taxation and emission fees, introduced in some countries, have not been proven effective as means of reducing flaring. In some countries, most notably Nigeria and Russia, the emission fees were too low and affordable for companies that did not change practices. In some other countries, fees cannot be enforced due to the lack of monitoring and metering as well as the lack of authority. However, other fiscal incentives such as tax reductions, duties, and government share in production are usually more effective in reducing flaring and venting activities when they are financially attractive to the oil producing entities. Some successful examples include the petroleum tax incentives in Nigeria, the CO_2 tax in Norway, and a royalty waiver program in Alberta, Canada (see working paper by Buzcu-Guven, Hertzmark, Harriss).

Carbon reduction credits that can be sold on an emissions trading market under the Kyoto Protocol's Clean Development Mechanism can also serve as a potential financial incentive supporting projects and investments for reducing flaring and venting. Nigeria, Algeria, and Indonesia are taking steps to achieve emission reductions that will make them eligible for carbon trading with developed countries (see working paper by Buzcu-Guven, Hertzmark, Harriss).

Energy Clean Tech R&D and the U.S. Economy

Currently, there is an extensive, ongoing policy discussion in the United States about innovations in the green economy and their potential to act as a new engine of economic growth. As the new administration devotes substantial resources to production and investment subsidies in the renewable energy and biofuels sector, it is important to evaluate the validity of such a strategy.

There are some theoretical arguments, as well as certain empirical indications, that research and development (R&D) in the energy sector is low in relative terms. The strongest theoretical reasoning can be developed around the notion of "creative destruction." Innovation often results in old technologies becoming obsolete. In the energy sector, this is exacerbated by regulatory uncertainty. Profit maximization therefore might lead energy companies to be reluctant to invest substantial resources into R&D to seek revolutionary changes, as opposed to investing in improvements to the existing technologies. This problem may indeed indicate the possibility that energy is suffering from a market failure, resulting in a discrepancy between profit maximizing and a socially efficient level of R&D. Under such circumstances, it might be justifiable to adopt government subsidies or related measures—such as taxing fossil fuels—that could induce additional R&D in renewable energy and, thus, speed up the transition toward a renewable energy-based economy (see working paper by Temzelides, Zhang, et al.).

Data show a sharp decline in energy R&D that has not fully recovered. In the early 1980s, energy companies invested more than drug companies in R&D. However, the trend turned sharply negative, and R&D has not fully returned to its late 1970s and early 1980s levels. According to the Belfer Center at Harvard University, total government energy technology research, development, and demonstration (RD&D) fell from over $6 billion per year between 1978 and 1981 to a low of $1.4 billion in 1998 (in 2005 dollars). It then slowly rose but did not reach $3 billion again until 2009. The fall in government RD&D for renewable energy was even steeper from peak to trough, falling nearly 90 percent from 1979 to 1990. In 2005 dollars, the government spent at least $1.5 billion/year between 1978 and 1981, but less than $500 million/year from 1984 through 2006.

The same general trajectory has been seen with private R&D. According to data from the Global Energy Technology Strategy Program and Pacific Northwest National Laboratory, private energy R&D spending basically mirrored the trajectory and magnitude of government R&D energy spending through 2003. Even together, private and public energy R&D have accounted for a relatively small portion of total R&D spending, reaching a peak of about 10 percent around 1980 and falling to only about 2-3 percent by the late 1990s.

Recently, government investments have increased alternative energy R&D, and the private sector also seems more willing to invest in clean technology projects. The 2009 American Recovery and Reinvestment Act (ARRA), often referred to as the stimulus package, provided over $6 billion in RD&D spending; the government spent nearly $900 million on renewables in 2009 in addition to the ARRA. As of September 2010, the ARRA made available $31.2 billion to the U.S. Department of Energy (DOE), although much of the money was slated for issues like deployment of technology or weatherization that have no R&D component. In the private sector, venture capital funding has been flooding into the "green tech" industry. By the third quarter of 2009, 27 percent of venture capital went into green tech, more than the biotech or software ventures received. This compares with less than 5 percent for green tech through much of the 1990s and early 2000s.

Still, there is no legislated plan for long-term government commitment to R&D spending. President Barack Obama as a candidate proposed spending $150 billion over 10 years, focusing on three areas—basic research, technology demonstration, and aggressive commercial deployment and clean market creation—but it has not been implemented into law. More recently, Obama has proposed increasing and permanently extending a popular tax credit for businesses research expenses. This credit has existed in some form since 1981 and has generally received bipartisan support.

Government support for R&D can come at many points along the value chain, from initial research to assistance with commercialization. Government support can also come before this process in the form of basic science research without clear or direct commercial applications — compared with the applied research implied by R&D—funded by the government through entities such as the National Science Foundation. On the other hand, many policies can help to support demand for renewable technologies once they are commercially deployed by subsidizing or mandating installation or production. Examples of such policies in the United States include the production tax credit granted per kilowatt-hour generated, and state-level renewable portfolio standards that usually mandate a certain percentage of electricity be generated from renewable sources. In Europe, a popular incentive designed to increase renewable generation is known as a feed-in tariff, which requires utilities to pay renewable operators a high rate for their electricity, a cost that is then borne by consumers through higher electricity rates (see working paper by Temzelides, Zhang, et al).

A number of prominent policymakers and businessmen are now calling on the U.S. government to promote clean energy innovation as an engine of U.S. economic growth. For example, the American Energy Innovation Council (AEIC), whose members include prominent business leaders such as Bill Gates, Jeff Immelt, and Norman Augustine, released a report that calls on the federal government to spend $16 billion/year on clean energy innovation. With energy legislation looking harder to pass in the U.S. Congress, some legislators are looking to R&D spending as a major fallback piece of U.S. energy policy.

Supporters of increased government R&D spending use a variety of arguments to show it would increase economic growth. Some speak of the aforementioned “creative destruction” argument that private maximizing firms could under-invest in R&D from a social perspective because they are reluctant to take risks, given the large fixed costs and longtime horizons. The implications of this argument would be that it is preferable for the United States to subsidize R&D for alternative energy rather than subsidize renewable energy production, as is currently the case, because subsidies on R&D more directly address the market failure of low R&D investment that the policy is attempting to redress.

Subsidizing renewable energy production can create other energy pricing and energy use market distortions while at the same time still fail to provide adequate incentives for optimum levels of investment in R&D. Baker Institute analysis finds, for example, that average wind capacity utilization has declined in recent years, despite a rapid increase in installations and operating improvements that might have led expectations of the opposite. This implies the possibility that, eventually, future development might become more constrained, if, as seems likely, fewer good sites remain available. Limited transmission capacity may also have prevented the exploitation of some otherwise favorable sites. Future growth in wind generation, taking into account long-term investment decisions, may favor construction of single-cycle natural gas turbines over combined-cycle natural gas plants, hindering efficiency of natural gas-fired capacity and ultimately raising costs to consumers (see working paper by Hartley).

At present, onshore wind has the lowest cost of the renewable energy sources covered by pro-renewable energy regulations and subsidies and has, in the immediate term, displaced more natural gas than carbon-intensive coal over the past several years, based on existing infrastructure and regulations. In the longer run, the intermittency of wind and the fact that wind generation satisfies base-load, 24-hour demand more than intermediate or peaking loads should discourage future investment in base-load coal and nuclear capacity (see Hartley).

A separate and very widely articulated mechanism for how increased clean energy R&D investment can increase economic output—and one that appears to be getting the most political traction currently—posits that the U.S. economy could benefit greatly from moving first on clean energy before other countries establish their own industries. Part of this first mover advantage argument is focused on fears that China's economic performance will outpace that of the United States. China, which passed a landmark renewable energy law in 2007, initially pledged to spend $200 billion on renewable energy development over 15 years; however, more recently, Beijing announced spending of 5 trillion yuan (over $700 billion) over the next decade aimed at developing cleaner energy and reducing reliance on coal. Additionally, many of the leading solar companies are already based in China.

The first-mover argument has significant deficiencies, however. Any clean technology or process developed in one country can be relatively easily moved to another country or adopted by a rival producer in another country. Companies based in the United States can build manufacturing capacity outside of the country and sell products to consumers in other countries as well, leading to little, if any, domestic GDP increase. For instance, the leading manufacturer of solar cells in 2009, First Solar, is a U.S. company that produces over 83 percent of its panels abroad. Additionally, high labor costs in the United States, coupled with new sources of cheaper labor in Asia, have steadily eroded manufacturing as a percentage of GDP, and it is difficult to imagine that the United States, therefore, could become a consistent lowest-cost manufacturing center of clean energy technologies.

While Baker Institute analysis looks specifically at output as measured by GDP, some supporters of green technology R&D base their position on the creation of "green jobs." For instance, a 2008 University of Massachusetts study released by the Center for American Progress found that a $100 billion investment in green programs would create about two million jobs over two years, although the report was specifically related to Keynesian economic stimulus at the peak of the current economic crisis.

The idea that technological advancements are a major or primary driver of economic growth is not a new one. During the Clinton administration, the Council of Economic Advisers issued a report that argued that half or more of the increase in output was due to investment in R&D. The Apollo Alliance has suggested that a major investment in alternative energy technologies could add more than 3.5 million new jobs to America's economy, stimulate $1.4 trillion in new GDP, and pay for itself within 10 years. The AEIC points to what it sees as successes from the $30 billion/year in federal funds spent on the National Institutes of Health, which it suggests has made America the leader of the pharmaceutical industry.

GDP and unemployment are usually connected by Okun's Law, which states that rising GDP tends to be correlated with falling unemployment, but they do not always move in perfect sync. The important factor would be "net jobs," or the increase in jobs in the renewable sector compared with the loss of jobs in the fossil fuels sector. In the long run, the number of jobs in the two sectors would be determined by the number of people needed to produce a certain amount of energy from a fuel source, which can be called the "job intensity" of the fuel. A recent paper by Wei, Patadia, and Kammen analyzes the job intensity of various fuels and concludes that renewables are somewhat more job intensive than fossil fuels. However, the job intensity for a particular fuel can change substantially over time; the output of an hour of a coal miner's labor in 2006, for instance, was about three times that of his labor in 1970, and over eight times that of the labor in 1950. Since many renewable sources may in fact require less oversight than finding, producing, burning, and processing fossil fuels, it does not seem intuitive that renewables will permanently be more job intensive.

In practice, the implementation of government subsidies for renewable energy may not always be accompanied by particularly desirable effects on economic activity and job creation, although specific details of the policies implemented will affect the final results. A Universidad Rey Juan Carlos study on the Spanish experience finds that a $36 billion total subsidy for renewable energy between the years 2000 and 2008 created an estimated 50,000 related jobs (mainly in construction, maintenance, operation, and administration). However, the study concludes that the implied average subsidy of 571,000 euros per job in renewable energy led to an estimated 9 jobs lost in the economy for every 4 created. It is notable that the primary policy mechanism in Spain was a feed-in tariff, which guarantees that the prices consumers pay for electricity will be higher; this policy mechanism is very different from an R&D subsidy because it subsidizes the installation of technologies that are already commercially viable. Spain's oil imports increased from 1.1 million barrels a day in 1995 to 1.6 million barrels a day by 2008 since promotion of renewable energy, without additional policies promoting diversification in residential, industrial, and transportation use, will not necessarily reduce oil use, as this Baker Institute study notes.

Extra R&D expenditures can increase energy costs if fuels are taxed to pay for the subsidy. Higher energy prices, taxes, or debt can all reduce employment. Subsidies also could "absorb" capital away from other, perhaps more productive, parts of the economy.

Using an economic model to study the technological progress of renewable energy as a potential engine of macroeconomic growth, the Baker Institute computed the equilibrium optimal path of investment in both the fossil fuel and the renewable energy sectors. Using this model, we evaluated different policy scenarios regarding the imposition of taxes on the use of fossil fuel and the effect of government subsidies (financed by taxation) on the use and development of renewable energy.

Our analysis finds that taxing fossil fuels would accelerate the rate of adoption of the renewable energy technology, but at the expense of economic growth. The exercise shows that the elasticity of the adoption rate appears to be small. A tax as high as 20 percent accelerates the renewable technology adoption by about 11 years, while a more modest 2 percent tax accelerates the transition by only five years. While the tax leads to less intensive fossil fuel use, it also curbs economic welfare. The resulting distortion of the tax creates a wedge between the equilibrium and the socially optimal level of investment. As a result, it can be shown that welfare in the economy declines in line with the tax size. So for example, a 20 percent tax would restrict GDP growth significantly while the less effective 2 percent tax has only a negligible impact on GDP trends (see working paper by Temzelides, Zhang et al.).

We also study the impact of cost-saving RD&D subsidies on renewable energy investment and find that subsidies would be more effective in accelerating the rate of adoption of the renewable energy technology than a tax of similar size. Indeed, generally speaking, a renewable energy subsidy appears to be more effective than a tax on fossil fuels, with a 2 percent subsidy accelerating the introduction of the renewable energy regime by 16 years. As a result of the renewable energy subsidy, the fossil fuel reserves are used more intensively in the short run. This somewhat paradoxical conclusion can be explained as follows. Since the adoption of renewable fuel is accelerated as a result of the subsidy, the opportunity cost of fossil fuel use declines in the short run. Thus, while the subsidy on renewables leads to a faster transition toward renewable energy, it also implies that fossil fuel producers, sensing the shortened time horizon for selling their fuel, would develop and produce remaining fossil resources at a higher rate in the short term. While we do not model carbon dioxide or other emissions explicitly in our analysis, it is worth mentioning that this could imply a short run increase in greenhouse gas and other emissions associated with fossil fuel combustion (see working paper by Temzelides, Zhang, et al.).

If U.S. GDP growth would be hampered by either taxes on fossil energy or subsidies on renewable energy, then the notion that renewable energy subsidies would be a stimulus for additional jobs seems unfounded. Given these findings, we conclude that the most economical way to propel renewable energy into the U.S. economy would be to subsidize energy R&D and not to subsidize renewable energy production as is currently practiced.

Policy Implications: U.S. Leadership on Global Climate and Energy Issues

Domestically, the United States needs to move away from the "energy independence" mantra. The lessons learned from the administrations of Nixon through Reagan are that policymakers need to be careful not to overregulate an apparent problem to create new, unanticipated problems in the energy sphere. History has shown that price controls, import quotas, overly comprehensive environmental bans on different kinds of energy supply development and production, policies that discouraged natural gas use in power generation the 1970s, and wasteful subsidies to the alternative energy industry did not solve U.S. energy problems but, in fact, worsened America's energy dilemmas. In many cases, markets can respond to discontinuities, with proper oversight by government agencies. The history of U.S. energy policy highlights that often there are practical and less costly solutions than a legislator can fabricate under political pressure and against the backdrop of vocal regional and special interests to appease angry consumers.

The United States currently faces unique opportunities from emerging trends brought about during the latest energy price boom cycle. One such trend is to shift to an electric drive train in long-term automobile design. The other is the identification of ample domestic natural gas resources in the lower continental 48 states. Government policies can support the energy security gains that can come from these emerging U.S. domestic opportunities. Both enhanced electrified automobiles and a wider shift to natural gas will help the United States diversify its fuel base, thereby creating broader flexibility for the United States in its oil diplomacy. Our findings also suggest that subsidizing R&D for renewable energy would most directly address historically low investment in clean tech with the least distortionary or negative impact on economic growth.

The U.S. success in the early 1980s in constraining unfettered growth in oil demand through efficiency gains in the American automotive fleet bode well for the recently passed tightening of car efficiency standards by the U.S. Congress. Saudi Arabia's leadership role in the G-20 also bodes well for a more cooperative diplomacy between the United States and OPEC at present. The Obama administration has a unique opportunity to try to institutionalize some of the gains that it has made in the past two years in oil consumer-producer cooperation to stabilize the global economy. The administration's focus on discussions with China on the subjects of Iran, oil, and climate could lay the groundwork for larger gains in energy policy, including a broader dialogue with oil producers to fashion better strategies for managing oil trade, investment, and revenue recycling.

Were the United States to implement a cap-and-trade system, it would allow the country to more easily participate in a global trading system; the absence of the U.S. cap-and-trade system would surely impair future efforts to encourage major less-developed countries to join a global regime of quantitative limits on GHG emissions. But a more thoughtful approach to cap-and-trade is needed because, as this study illustrates, the impacts on U.S. dependency on foreign oil and natural gas, on migration of U.S. industry, and on energy prices can be dramatically different under varying cap-and-trade system designs. The U.S. public must be made more aware of the trade-offs between energy security and emissions reductions. To that end, policies that best optimize emission reductions but at a lower cost to energy security and to consumers should be given priority. In designing an effective cap-and-trade system that would lower emissions without greatly harming U.S. energy security, policymakers should consider how in the intermediate term to best protect U.S. domestic unconventional oil production while still tapping gains from emissions reductions in other sectors and setting the stage for new technologies to kick in after 2030. We also highly warn against calls for the widespread adoption of CNG natural gas vehicles, except maybe in discreet uses, and instead favor programs that would facilitate wider use of electrified vehicles to achieve the best benefits of diversification but at a relatively lower cost to average consumers.

Still, given the domestic political constraints that might prevent a broad climate bill from passage in the next few years, the United States may have to be prepared to work for the second-best in international negotiations, such as trade agreements that would facilitate the adoption of clean technologies, as discussed above. Most importantly, the United States should be prepared to explore alternatives to the current UN-centered approach to climate change negotiations. Moises Naim, the editor of *Foreign Policy*, has endorsed a concept called "minilateralism." The idea is simple: bringing to the table the smallest number of players with the biggest possible impact. The Major Economies Forum on Energy and Climate surely fits the bill. At a minimum, the Forum could be used to hammer out differences between major emitters before global summits. The Obama administration's emphasis on bilateral negotiations with China is also a sensible approach.

Global diplomacy, under strong U.S. leadership, is also a necessary component needed to discourage OPEC from seeking investment or market supply policies that will produce long-term damage to the global economy and stability of the financial system. During the administration of President Ford, the United States used effective international diplomacy to influence OPEC to adopt more constructive policies toward global oil markets. Today, multilateral monitoring through the G-20, the International Monetary Fund, and other bodies promoting greater dialogue between Asian and oil-exporting creditor nations and the West, could serve to pull the United States and OPEC out of counterproductive short-term strategies on oil policy to the detriment of the global system. Counter-cyclical investment, including by the very sovereign wealth funds who gain massive revenues when prices are rising, could serve as a cornerstone to market stability.

History also shows that signaling and following through on a willingness to release strategic emergency oil stockpiles like the U.S. Strategic Petroleum Reserve and IEA emergency stockpiles are a critical tool in managing oil market expectations and promoting OPEC cooperation on acceptable price ceilings. Each U.S. president upon coming to office should make his administration's SPR policy publicly known and clear, something the Obama administration has not pursued and needs to consider.

While consuming countries have generally focused on managing oil demand by reducing the oil intensity of their economies through investments in alternative energy and mandating more efficient technology for fuel consumption, consuming countries have done little to try to promote investment in future energy supply by producers. No emphasis has been placed on discussion in existing and emerging bilateral and multilateral trade institutions or the G-20 to ensure that there is sufficient investment to meet global demand in the years and decades ahead.

Trade in energy goods, while technically covered by the World Trade Organization (WTO) rules, is not being discussed in any significant diplomatic manner to proactively create a policy that would better manage the cycles of investment in oil and natural gas. International trade negotiators are primed to put energy issues more front and center because the negative impact of extreme oil and gas price volatility in 2008 harmed the economies of both consumer and producer nations equally, highlighting the benefits to both sides of an improved international architecture for energy markets. Oil producers may have enjoyed rising state revenues from 2005- 2007, but they have also been hit by the current contraction in the global economy. Indeed, the sudden collapse in oil prices in 2008-2009 was a warning that state budgets and national economies could quickly become vulnerable again. Longer term, per capita income trends clearly show that securing more stable, durable revenues would be preferable to the peaks and valleys seen in the last two decades.

International architecture that would promote adequate, steady investment in oil and natural gas resources is sorely lacking in the existing financial and global economic system. More consideration should be given as to how to remedy this deficit. There is currently little debate on the policies of sovereign wealth funds (SWF) of the oil exporters. Unlike Kissinger's economic development commissions, there is no bilateral or multilateral structure at present to discuss the need of SWFs to invest counter-cyclically in financing investment in oil-production capacity and accumulating above-the-ground reserves when prices are low, and selling out of their saved reserves when prices are high. Diversification strategies for SWFs are also important to reduce the impact of sudden petrodollar flow changes.