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Introduction

Chairman Boucher, Ranking Minority Member Hastert, and other members of the House Subcommittee on Energy and Air Quality, thank you for the opportunity to come to talk with you today about alternative fuels. **My main point today is that the United States must act to address all three of the challenges in the transportation fuel sector—strategic, economic, and environmental—or it faces the prospect of failing to solve any of them (Farrell and Brandt 2006).**

My second point is that by themselves, requirements for "alternative" or "renewable" fuels are inadequate and can even make the problem worse; strong environmental regulation is required to ensure good environmental performance. Alternative fuels are not created equal and can either improve or degrade the environment (Farrell, Plevin et al. 2006). Research by my group shows that the current set of laws and regulations do not give the private sector adequate incentives to produce "green" fuels, but that the American energy and agriculture industries can do so if properly motivated (Turner, Plevin et al. 2007). **My third and final point is that a sectoral approach to managing greenhouse gas emissions will be far more successful in addressing all three challenges in transportation fuels than a single economy-wide approach.** I will mention one such approach, California's Low Carbon Fuel Standard and invite Subcommittee members to attend an international symposium on this topic at the Lawrence Berkeley National Laboratory on May 18th.

For reference, I am an Assistant Professor of Energy and Resources at the University of California Berkeley and Director of the Transportation Sustainability Research Center. I am also a member of the National Science Foundation-sponsored Climate Decision Making Center and of California's Economic and Technology Advancement Advisory Committee under AB32, the California Global Warming Solutions Act. I have published over two dozen peer-reviewed papers in journals such as *Science*, *Energy Policy*, and *Environmental Science & Technology*. While most of my recent work is on energy and climate change policy, as a graduate of the U.S. Naval Academy and former submariner, I can assure that I take national security very seriously.

This background is why I find the current policy failures are so disappointing, two important goals of the United States—national security and economic growth—are frustrated by failing to act responsibly on environmental protection, and in particular on climate change. **Let me be clear, failing to adequately address climate change increases the national security and economic risks facing America**. I hope my comments today can help the Subcommittee better understand the problem and what we can do about it.

Three challenges in transportation fuels

A transition in transportation energy production has begun; transportation fuels are increasingly coming from sources other than conventional petroleum. The development of tar sands in Alberta is one example, yesterday's announcement by ConocoPhillips and Tysons of new renewable diesel production is another. This transition involves a shift to alternative fuels that substitute for conventional petroleum, and it is critical to understand and manage the strategic, economic, and environmental risks this transition will bring. This as an integrated problem, as we act to achieve one goal we unavoidably affect our prospects in dealing with the others.

Alternative fuels include low-grade and synthetic petroleum (e.g. tar sands and coal-to-liquids, or CTL), biofuels, electricity and hydrogen. It is important to recognize that whatever the course of development of biofuels, electric vehicles, and hydrogen, the fossil portion of the liquid fuels will become increasingly supplied by low-quality and synthetic petroleum because we have enormous, readily accessible resources and we have the technologies to turn them into fuel. Currently, fossil-based alternative fuels equal about 2.5 million barrels per day (Mbbl/d), of which the largest portion is tar sands and extra-heavy oil production, and experts forecast global additions of SCPs by 2010 to be almost 0.5 Mbbl/d annually (National Energy Board 2004; Lynch 2005; Moritis 2006; Simbeck 2006). Thus, fossil-based alternative fuels now account for about 3% of global oil production and could double within the next five years. These fuels have much higher GHG emissions than does conventional petroleum.

Some of the strategic implications of alternative fuels are obvious, by diversifying both the types of resources and the geographic locations they come from, we apply the first principal of energy security (Yergin 2006). **Moreover, developing alternative fuels without a strong climate policy framework brings additional strategic risks.** This is because climate change itself presents strategic risks and failing to address climate change increases these risks (Holdren 2001; CNA Corporation 2007). In addition, continuing to ignore climate change will make national consensus on energy policy more difficult, delaying the implementation of alternative fuel development and thereby delaying any reduction in strategic risks and tend to encourage disrespect for international processes and agreements on common problems. This lessens the security of the United States directly and also inhibits the development of the global agreement necessary to solve the climate change problem.

Because alternative fuels require greater initial capital per unit of production relative to conventional oil, and are also more expensive in the long run, they are financially risky to investors and may become uneconomical should oil prices fall, as they have in the past. On the other hand, consumers face the prospect of high and variable fuel prices. Thus, the key economic risk of the oil transition is how to manage the complementary risks to consumers and investors. **Government policies to mitigate some economic risks may be needed, but they should involve moderate costs and should also address environmental or strategic risks. And if such policies involve subsidies or payments of some sort, they should not tax current income or borrow (further) from future generations, they should come from taxes that serve to solve the problem. Thus, any policy to mitigate the economic risks of alternative fuels should be paid for by a carbon tax.**

The environmental risks posed by the production and use of alternative fuels are myriad, including water use, soil erosion, land disturbance (e.g. moutaintop removal), air pollution, and many other issues. In this testimony, I will focus only on the risks of the climate change due to greenhouse gas emissions, which are addressed in some detail in the next section.

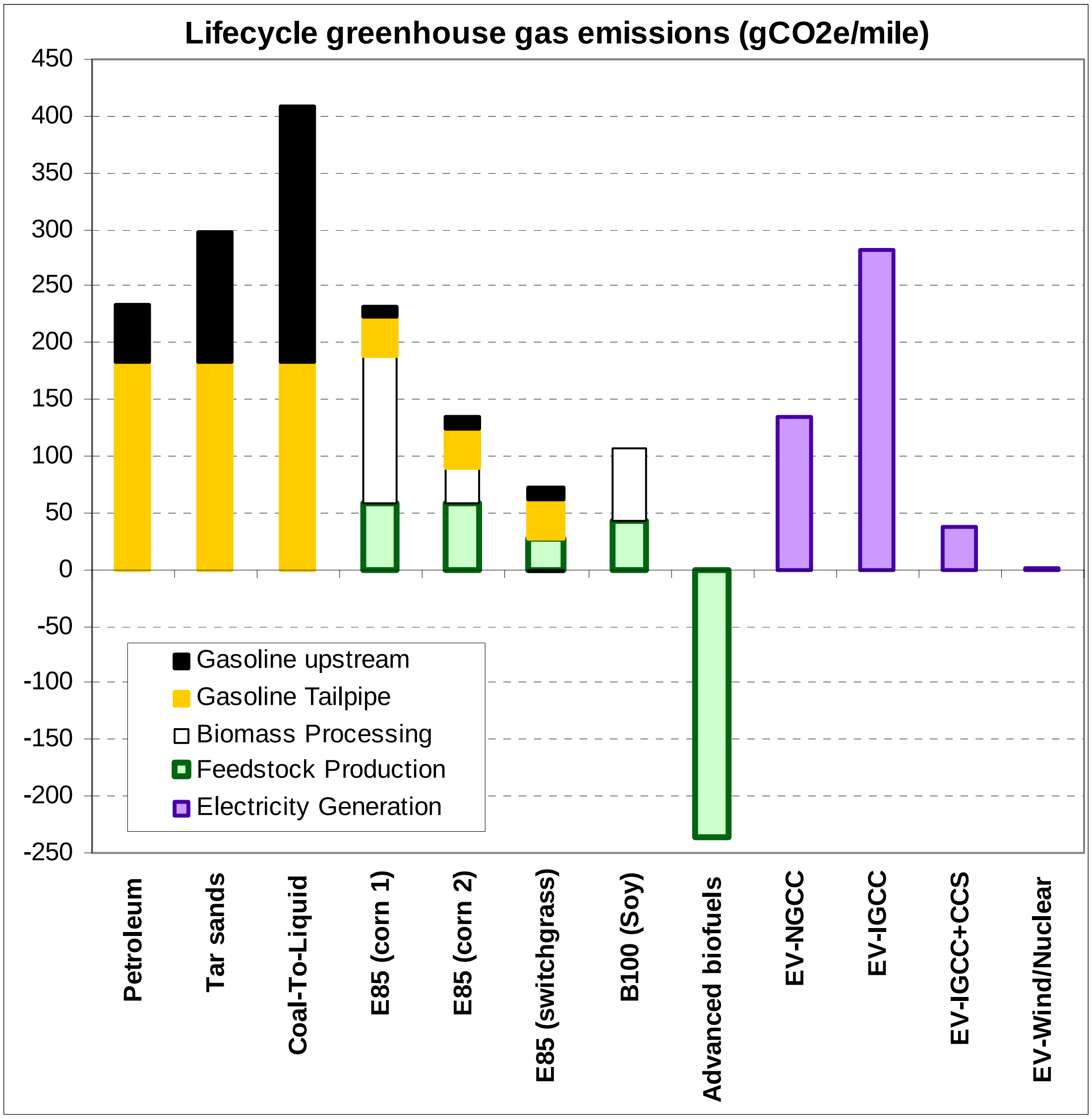
The current uncertainty associated with climate change policy only adds to these risks by making it difficult for firms and investors to make long-term decisions about energy investments (Echeverri 2003; United States Climate Action Partnership 2007). The absence of a national climate policy also inhibits investment and innovation in new technologies, which is a critical aspect of solving the climate change problem (Margolis and Kammen 2001; Rubin, Taylor et al. 2004; Taylor, Rubin et al. 2006).

Greenhouse gas emissions of alternative fuels.

All alternative fuels entail tradeoffs among positive and negative environmental effects, and among cost and convenience as well. Figure 1 illustrates the lifecycle greenhouse gas (GHG) emissions of three categories of fuels, fossil-based liquid hydrocarbons (on the left), biofuels (in the center), and electricity (on the right). Lack of data (and space) kept me from including hydrogen today.

Figure 1 illustrates that there is no automatic relationship between any particular fuel and GHG emissions, it depends on how that fuel is produced. These values are estimates because the GHG emissions of fuels are not measured today.

However, we can say a few things about specific fuels. **First, fossil-based liquid hydrocarbons have significant tailpipe emissions due to the fact that the carbon atoms in those fuels were locked in fossil formations until just a few weeks before being used.** There’s just no way around it. However, the “upstream” emissions from production and refining are a different matter. Some of those emissions, possibly a large fraction, could be captured and sequestered using CCS technologies, although these are not yet commercialized (Intergovernmental Panel on Climate Change 2005). Successful development of safe, cost-effective CCS technologies is an important goal, and multiple large scale demonstration projects are likely to help the United States address the challenges in transportation fuels as well as lower GHG emissions associated with coal-fired electricity (Katzer 2007). However, because CCS technologies increase the cost of fuel production without adding value to a firm’s production, they will not be implemented without a mandatory climate policy, so this is needed in addition to research and development efforts.



NOTES:

a) Petroleum, Tar Sands, and Coal-To-Liquid values are from (Brandt and Farrell 2006). Upstream values here are averages over of values reported in the literature, actual emissions from values will vary. If applied, carbon capture and sequestration (CCS) technologies may capture some upstream emissions.

b) Ethanol and Biodiesel values are from (Turner, Plevin et al. 2007), which uses a modified version of GREET v1.7. This model does not fully account for land use and other effects, so actual greenhouse gas emissions may be higher. Corn 1 is based on a dry mill using coal. Corn 2 is based on the best technology currently in use today, a dry mill using biomass for energy supply.

c) Advanced Biofuel values are from (Tilman, Hill et al. 2006) but these technologies are not yet proven. Actual GHG emission rates may vary significantly from the values shown.

d) Electric Vehicle (EV) values are from (Arons, Lemoine et al. 2007). NGCC is natural gas combined cycle, IGCC is integrated coal gasification and combined cycle.

e) In order to focus on fuels, all calculations assume identical plug-in hybrid electric vehicles per (EPRI 2002). These technologies are not yet commercialized. Emission rates will be higher for liquid fuels used by conventional vehicles.

f) These data are available at http://erg.berkeley.edu/erg/people/faculty/farrell_publications.shtmlr

The use of CCS technologies is no panacea, however. **The GHG emissions of fuels made from tar sands and coal-to-liquids could be about the same as from conventional gasoline production if CCS technologies are used, but not much better.** Further emission reductions that could come about because of vehicle technologies are not linked to these alternative fuels, they could apply to conventional gasoline and other alternative fuels as well. Figure 1 holds the vehicle technologies constant to illustrate the actual comparison among fuels. Therefore, the use of fossil-based alternative fuels in a way that addresses all three challenges–strategic, economic, and environmental–will require careful consideration and balancing.

Figure 1 also shows that there is an enormous range of potential GHG emissions from biofuels. These emissions come not only from the gasoline that is blended into some biofuels, but also from production of feedstocks (e.g. corn) and processing of the biofuels (e.g. fermentation) (Farrell, Plevin et al. 2006; Kim and Dale 2006). The two values for corn-ethanol-based E-85 (85% ethanol by volume) represent approximately the most GHG-intensive ethanol produced in the United States today, and the least (Turner, Plevin et al. 2007). The lower value assumes biomass is used to power the bio-refinery, as several are doing today so no technological innovation would be required to achieve these levels. Similar for soy biodiesel. In contrast, the values for switchgrass-based E85 and “Advanced Biofuels” assume advances in technology and can result in very low or even negative GHG emissions (Wyman 2003; Morrow, Griffin et al. 2006; Tilman, Hill et al. 2006). Negative emissions come about because these feedstocks are perennial grasses that sequester carbon in the soil when they grow, improving it’s health along the way. It is not clear how large these resources might be, due to competition for land, but residues and wastes might also be used to produce biofuels at significant scales (Broder, Harris et al. 2001; Martin and Chester 2006). There is some controversy over the “Advanced Biofuels” concept (which has various names) but this seems like a potentially valuable area for future research.

However, because the environmental performance of biofuels is not measured today, consumers have no information about how to buy biofuels with low GHG content and supplier have no incentives to lower the GHG content of biofuels. **In my view, the American agriculture and energy industries can certainly develop and market affordable, low-GHG and sustainable biofuels, but only if given the appropriate regulatory and incentive structure, including mandatory GHG emission controls.** Without appropriate information, incentives and rules, however, the biofuels industry is likely to expand production in environmentally harmful ways.

One possibility that is not shown on Figure 1 is to combine Coal-To-Liquids with both CCS and Advanced Biofuels (Williams, Larson et al. 2006). By combining both geological and soil sequestration, it might be possible to manufacture large volumes of fuel with very low GHG emissions. **The combination of Coal-To-Liquids with both CCS and Advanced Biofuels is a relatively new concept that includes several uncommercialized technologies and its prospects are quite uncertain, but, in my view, it merits significant investigation.**

Finally, Figure 1 shows the GHG emissions from the use of electricity as a fuel (Arons, Lemoine et al. 2007). **As with the other fuels, there is no automatic linkage between electric vehicles and GHG emissions, it depends on how the power is generated.** However, the very low GHG emission rates of some technologies might make electric vehicles (whether plug-in hybrids or pure battery) attractive options. In addition, EVs offer a significant opportunity to diversify transportation energy supplies and source more of this energy domestically, which can help reduce strategic and economic risks. Interestingly, America's abundant coal resources might be better used as a transportation fuel through the use of CCS technologies in electric power generation and the use of EVs. This requires advances in battery technologies to enable electric vehicles to become widely used (Lemoine, Kammen et al. 2006). Opinion about the prospects of such innovations differ (EPRI 2001; EPRI 2002; Carlsson and Johansson-Stenman 2003; Schafer and Jacoby 2006). **Nonetheless, EVs offer such significant benefits that research and development in this area also seems very appropriate.**

Managing greenhouse gas emissions

A prerequisite to controlling GHGs, and therefore to any mandatory climate policy, is cost-effectively measuring GHG emissions. This is likely to include imperfections and uncertainties, especially at first, but this is true for any activity and should not stand in the way of implementing climate policy.

Because the environmental performance of fuels is not measured today, consumers have no information about how to buy low-GHG fuels and producers have no incentive to produce and market them. To solve this problem, The first step toward markets for low-GHG fuels is to develop methods for measuring the global warming impact of fuel production and use. Several official processes for evaluating individual biofuels in a regulatory framework are currently under development around the world, including the United Kingdom's Renewable Transport Fuels Obligation (http://www.dft.gov.uk/pgr/roads/environment/rtfo/) and the Low Carbon Transport Fuels Standard in California (http://www.its.berkeley.edu/sustainabilitycenter/carbonstandards.html). The Renewable Fuel Standard could be adapted and extended for measuring the global warming impact of transportation fuels in the United States (http://www.epa.gov/otaq/renewablefuels/). To do so might require extending the Renewable Identification Numbers (RINs) established in this rulemaking to more general Fuel Information Numbers (FINs). This is feasible today and would produce meaningful results. While there would still be uncertainties, these are insufficient to justify not starting a GHG emission measurement system.

If the GHG emissions associated with transportation fuels can be measured, than they can be managed. This is a major task. Very large reductions in GHG emissions will be required to avoid more than doubling GHG concentrations in the atmosphere and the harmful effects that are likely to follow (Wigley, Richels et al. 1996; Hayhoe, Cayan et al. 2004; Stern, Peters et al. 2006; Intergovernmental Panel on Climate Change 2007). I will use the year 2020 as a reference point between near-term and long-term goals.

Technologies to accomplish this task are not currently available, so technological innovation is a necessary component of the strategy to achieve climate stabilization (Taylor, Rubin et al. 2006). These changes will not come about without some form of government action, because avoiding dangerous climate change, like most environmental protection, is a public good and so under-provided by markets. Innovation designed to achieve public goods typically requires government action (Arrow, Bolin et al. 1995; Norberg-Bohm 1999). Any such large change will affect many other key priorities, including economic growth, improved air quality, affordable energy prices, environmental justice, energy source diversification, environmental protection and others. This frames the specific goals that national climate policy meet:

1. Encourage investment and improvement in current and near-term technologies to meet long-term goal of cost-effective emission reductions through about 2020.
2. Stimulate innovation and development of new technologies that can help attain the long term goal 2050 of dramatically lowering GHG emissions at low costs, reducing emissions by 75% or more by 2050.
3. Maximize the attainment of related objectives as much as possible, including economic growth, air quality and other environmental protection goals, affordable energy prices, environmental justice, diverse and reliable energy sources, and others.

An important policy choice is whether to address these goals through a single, economy-wide approach, as is sometimes suggested, or through a multi-sectoral approach that also covers the entire economy but does so with more targeted policies. A sectoral approach has been adopted in California (Schwarzenegger 2005; 2006). California’s multi-sectoral approach to climate policy also includes sector-specific policies in electricity, manufacturing, transportation, and others (Climate Action Team 2006). Some of these are regulatory, others may be market-based. One of these proposed policies is a Low Carbon Fuel Standard (LCFS) in which transportation fuel providers would be required to lower the global warming impact of their products.

The sectoral approach is important in part because it may better achieve all three goals described above, compared to an economy-wide approach that addresses all emissions with a single policy, such as a cap-and-trade system. Each of the goals is discussed in turn.

In an idealized case, an economy-wide approach would be efficient at achieving the first goal of reducing GHG emissions up to 2020. But because the real world entails imperfect information, transaction costs, differential taxes, different regulation (e.g. competitive industries like the oil sector, and regulated utilities like the electric power sector) and other less-than-ideal conditions, an economy-wide approach would be suboptimal. This suggests that the efficiency disadvantages of a sectoral approach might be less important than when considering a hypothetical ideal economy. However, sectoral policies should still be designed to be as economically efficient as possible.

A sectoral approach is significantly better than an economy-wide approach at achieving the second goal, technological innovation, because 1) social discount rates are much lower than private discount rates, 2) research into environmental technologies is a public good, and, 3) the sectors vary enormously in terms of industrial organization, GHG mitigation costs, capital structure, taxes, regulation, and other factors (Norberg-Bohm 1999; Taylor, Rubin et al. 2006). Each of these three reasons is briefly discussed in turn.

Private discount rates for decisions like business investments, vehicle purchases, home improvements, and so forth are often 15% or more, compared to social discount rates are often estimated to range from zero up to 7% (U.S. Environmental Protection Agency 2000; Moore, Boardman et al. 2004). Higher discount rates imply, in this case, that consumers and firms would place more weight on current costs and less on potential future benefits of innovation, compared to society's preferences. Thus, even in an idealized world, a single economy-wide approach to reducing GHG emissions would be inefficient from a social standpoint because inadequate amounts of innovation and investment in new technologies would be made.

Compare, for instance, the electricity and transportation sectors. In the former, multiple energy sources with very different (and some very low) GHG emission rates compete, including renewable and nuclear power, natural gas, and coal, as shown in Table 1. Thus, even relatively minor increases in the cost of emitting GHGs would begin to affect the operation of and investment in the electric power sector. For prices up to about $25 per metric ton (MT) of CO_2 this effect is likely to be minor; nuclear and renewable power would become relatively less expensive, but coal-fired electricity would remain cheaper still (Katzer 2007). However, at about $25 per MT-$CO_2$, carbon capture and storage (CCS) is currently projected to become less expensive than an ordinary pulverized coal power plant. Of course, predictions of environmental compliance costs have historically and almost universally been much too high, so we should imagine sequestration costs falling over time. In any case, because of these cost and GHG differences among different electricity supply options, at CO_2 prices over $25 per MT-$CO_2$ an enormous amount of innovation and change in investment is likely in electricity supply, potentially setting it up for successful decarbonization after 2020.

Table 1: Effect of a $25/MT CO_2e price on energy prices

Energy type	**Price change and percentages of retail prices**	
Electricity		
Nuclear and renewables	<$0.1/MWh	<1%
IGCC with CCS	$02.5/MWh	2%
NGCC	$12.5/MWh	11%
Pulverized coal	$20/MWh	17%
Transportation		
Gasoline	$0.21/gallon	8%
Heating		
Natural gas	$1.27/million Btu	11%

Notes: Percentages are for retail prices in California including PG&E residential electricity $0.1144/kWh, gasoline $2.50/gallon, and PG&E residential gas $1.14/therm. Electricity values calculated from (Pacca and Horvath 2002). Gasonline and Natural Gas values calculated from the Energy Information Agency's emission coefficients. See http://www.eia.doe.gov/oiaf/1605/coefficients.html

However, the other main sources of GHG emissions do not have such ready low-GHG substitutes. In transportation, essentially all fuels are based on petroleum. In an economy-wide system that induced significant change in the electric power sector, prices for gasoline might rise by less than 10%. Consumers appear to be very insensitive to changes in gasoline prices, at least in the short term (Hughes, Knittel et al. 2006). Transportation costs are a very small fraction of the cost of goods sold, so increases of this size are unlikely to reduce consumer demand for goods. Therefore, a 10% change in price might induce some changes in transportation energy supply, possibly a switch to lower GHG biofuels to lower costs, or the introduction of larger amounts of low-GHG biofuels into the fuel supply, but such increases would be too small to induce significant reductions in transportation demand, either mobility or logistics. Further evidence that 10% increases in fuel prices would spur little innovation in the transportation sector can be found in Europe. Higher prices than this have prevailed in Europe for some time, which has led to the use of smaller and more efficient vehicles (including many diesels), but not the introduction of low-carbon fuels. (Note, however, that European fuel taxes do not differentiate by carbon content.)

Further complicating issues is the fact that changes to transportation fuels involve severe coordination and investment problems between infrastructure and vehicles (Winebrake and Farrell 1997). Both experience and analysis suggest that transitions to new fuels are slow and difficult and that only one or two fuels may be significant at any time and place, in part because of cost of distribution infrastructure (Leiby and Rubin 2004; McNutt and Rodgers 2004). This effect partly explains why ethanol has gained relatively large market penetration (and biodiesel in Europe) because it can be blended in gasoline (or diesel) and at low blends requires no changes in vehicles or distribution infrastructure. Plug-in hybrid vehicles are more difficult in this sense because new vehicle technologies are needed (e.g. less expensive batteries and power electronics), but probably little in the way of new infrastructure other than appropriate meters and chargers. Hydrogen is perhaps most difficult because it requires both a new fuel distribution system and new vehicle technologies. Thus low-carbon fuels that can use existing capital seem to have a strong advantage.

The key point, however, is that the costs of reducing GHG emissions may be highest in the part of the U.S. economy that has the largest GHG emissions (transportation) and a single, economy-wide GHG policy runs the very significant risk of inducing very little technological innovation in that sector. This argues for a sectoral approach to national climate policy.

The Lawrence Berkeley National Laboratory will host a one-day international symposium on the Low Carbon Fuel Standard on May 18th, to discuss the technical and policy issues. http://www.its.berkeley.edu/sustainabilitycenter/carbonstandards.html

Conclusions

There are three types of risks in transportation fuels – strategic, economic, and environmental and it is critical in any transition to alternative fuels to understand and manage them as an integrated system. As we act to achieve one goal we unavoidably affect our prospects in dealing with the others. In terms of greenhouse gases, there is no automatic relationship between any particular fuel and GHG emissions, it depends on how that fuel is produced. Therefore, developing alternative fuels without a strong climate policy framework brings additional economic and strategic risks, as well as environmental risks.

The GHG emissions of fuels made from tar sands and coal-to-liquids could be about the same as from conventional gasoline production if CCS technologies are used, but not much better.

Therefore, the use of fossil-based alternative fuels in a way that addresses all three challenges–strategic, economic, and environmental–will require careful consideration and balancing. For instance, a requirement that all fossil-based alternative fuels use CCS and have their GHG emissions accounted for in a mandatory climate policy would encourage technological innovation and signal to other countries that the United States was taking its responsibilities in this area seriously.

There is an enormous range of potential GHG emissions from biofuels. In my view, the American agriculture and energy industries can certainly develop and market affordable, low-GHG and sustainable biofuels, but only if given the appropriate regulatory and incentive structure, including mandatory GHG emission controls. The combination of Coal-To-Liquids with both CCS and Advanced Biofuels is a relatively new concept that includes several uncommercialized technologies and its prospects are uncertain, but, in my view, it merits significant investigation.

Electricity and hydrogen offer yet further options and because these fuels can be made from a wide range of carbon-free energy sources, so they offer exciting possibilities. Unfortunatley, they are not yet economic, so research and development may be the most important approaches for these fuels. Of course, a climate policy would hasten the day that they do become economic and can start being widely used.

A prerequisite to controlling GHGs, and therefore to any mandatory climate policy, is cost-effectively measuring GHG emissions. This is likely to include imperfections and uncertainties, especially at first, but this is true for any activity and should not stand in the way of implementing climate policy. Because the environmental performance of fuels is not measured today, consumers have no information about how to buy low-GHG fuels and producers have no incentive to produce and market them. To solve this problem, a mandatory climate policy that includes measuring the global warming impact of all fuels is needed. Such a policy should not be a single, economy–wide effort, but one that focus on the transportation sector. The most important reason for a sectoral approach is to stimulate technological innovation, and is needed because 1) social discount rates are much lower than private discount rates, 2) research into environmental technologies is a public good, and, 3) the sectors vary enormously in terms of industrial organization, GHG mitigation costs, capital structure, taxes, regulation, and other factors

Understanding the relationship between agricultural practices and environmental performance is the inescapable foundation of a healthy market for low-GHG fuels. Much more research is needed to develop and refine the assessment methods by which these relationships are established and communicated. The goal should be a robust, transparent, and accessible modeling framework that will allow regulators to understand the continuous differentiation of performance and will allow producers to accurately predict, and innovate upon, the effect of practices on value production. Further, several outstanding issues remain largely unexplored, creating significant uncertainties in current assessment systems. These include biomass residues from conventional forest systems, and indirect effects caused through market interactions in food, fuel, and other commodities. These indirect effects may have significant implications for land use, so this is a particularly important area for research.

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