National Low Carbon Fuel Standard

TECHNICAL ANALYSIS REPORT

19 JULY 2012

A Collaborative Study by

Institute of Transportation Studies
University of California, Davis

Department of Agricultural and Consumer
Economics and Energy Biosciences Institute
University of Illinois, Urbana-Champaign

Margaret Chase Smith Policy Center
and School of Economics
University of Maine

Environmental Sciences Division
Oak Ridge National Laboratory

International Food Policy Research Institute

Green Design Institute of
Carnegie Mellon University

About the National LCFS Study

The objectives of the National Low Carbon Fuel Standard (LCFS) Study were to (1) compare an LCFS with other policy instruments, including the existing Renewable Fuel Standard (RFS2) and a potential carbon tax, that have the potential to significantly reduce transportation greenhouse gas (GHG) emissions from fuel use; and (2) propose a policy structure for an LCFS that would be most effective and easy to implement. The study is a collaboration between researchers from the following institutions: Institute of Transportation Studies, University of California, Davis; Department of Agricultural and Consumer Economics / Energy Biosciences Institute, University of Illinois, Urbana-Champaign; Margaret Chase Smith Policy Center, and School of Economics, University of Maine; Environmental Sciences Division, Oak Ridge National Laboratory; International Food Policy Research Institute; and Green Design Institute of Carnegie Mellon University.

This report builds on a series of papers and reports published over the past two years, including:
- Stacking low-carbon policies on the renewable fuels standard: Economic and greenhouse gas implications
- Tradable credits system design and cost savings
- Energy security implications of a national LCFS
- Global land use change from US biofuels and finding effective mitigation strategies
- Policy options to address global land use change from biofuels
- Addressing uncertainty in life-cycle carbon intensity in a national LCFS
- Fuel electricity and plug-in electric vehicles in a national LCFS

Additional notes and discussion were also prepared on the following topics:
- Inclusion of marine bunker fuels in a national LCFS scheme
- Harmonizing low-carbon fuels policies
- Policy alternatives in reducing GHG emissions from transportation fuel uses
- Cost containment mechanism in the market-based credit markets

Individuals who contributed to the National Low Carbon Fuel Standard Study include the following (names of the principal investigators are underlined):
- Institute of Transportation Studies, University of California, Davis: Sonia Yeh, Daniel Sperling, Jamie Rhodes, Gouri Shanker Mishra, Nathan Parker, Julie Witcover, Christopher Yang, Jeff Kessler, and David Ricardo Heres
- Department of Agricultural and Consumer Economics / Energy Biosciences Institute, University of Illinois, Urbana-Champaign: Madhu Khanna, Hayri Onal, and Haixiao Hung
- Margaret Chase Smith Policy Center, and School of Economics, University of Maine: Jonathan Rubin and Maxwell Brown
- Environmental Sciences Division, Oak Ridge National Laboratory: Paul Leiby
- International Food Policy Research Institute: Siwa Msangi and Miroslav Batka
- Green Design Institute of Carnegie Mellon University: Michael Griffin, Mathew Kocoloski, Kimberly Mullins, and Aranya Venkatesh

In addition to research, the National LCFS Study also conducted extensive stakeholder outreach, including the following activities:

- Presentation of seven webinars between April and June 2011 showing preliminary research results to invited key stakeholders from industry groups, environmental NGOs, academic scholars, and policy makers. Each webinar was attended by 40 to 70+ stakeholders and was followed up with written comments from stakeholders and additional meetings between researchers and stakeholders.
- Presentation of a one-day policy workshop in Washington DC in August 2011 where key stakeholders discussed draft research results and preliminary policy recommendations.
- Co-hosting of a one-day workshop for policy makers in Washington DC in August 2011 with the International Council on Clean Transportation (ICCT). The workshop was an update of the progress of regional/state LCFS programs and a discussion forum for challenges and future collaborations.
- Publication of seven research reports and two major reports summarizing key technical analysis and policy recommendations.
- Presentation of research findings at conferences and workshops.
- Publication of journal articles and academic education on a national LCFS policy.
- Development of a National Low Carbon Fuel Standard website (http://NationalLCFSProject.ucdavis.edu) where we detail reports, journal articles, stakeholder comments, relevant literature, and a collection of state/regional LCFS policies.

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The National LCFS Study has gone through an extensive internal and external peer-review process participated in by more than a hundred stakeholders, including review of the seven research reports, seven webinars, numerous face-to-face meetings and conference calls, regional project meetings, and an one-day workshop in Washington DC discussing policy design recommendations. We greatly appreciate all the comments and feedback provided to us. Though their participation in no way represents an endorsement of the project conclusions nor the proposed policy design, we would like to acknowledge the following individuals and organizations (in no particular order):

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All the research reports have been submitted to the peer-reviewed journal *Energy Policy* to be published in a special issue, “Low Carbon Fuel Policy.” We greatly appreciate the feedback and comments provided by twenty-three anonymous academic reviewers. The special issue is expected to be available online summer 2012. We also want to thank Lorraine Anderson for her outstanding editing of the report.

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Executive Summary

Petroleum fuels make up essentially all of the transportation fuels used today. But fossil fuel use has many economic and environmental downsides, including a weakening of our energy security due to reliance on imported energy sources, air pollution that impacts health, and greenhouse gas (GHG) emissions that contribute to climate change. To reduce fossil fuel use and GHG emissions in the transportation sector and improve energy security requires a coordinated effort to reduce travel demand, improve vehicle efficiency, and switch to cleaner, lower-carbon fuels. Here we focus on switching to new fuels and examine the potential role a national low carbon fuel standard (LCFS) can play in bringing this about.

This report analyzes the costs and benefits of a national LCFS policy, together with or in place of the existing national Renewable Fuel Standard (RFS2). The companion report, *National Low Carbon Fuel Standard: Policy Design Recommendations* (PDR), suggests how best to design an LCFS. Both consider the possibility of an LCFS replacing or being adopted alongside RFS2.

RFS2, updated by the US Congress under the Energy Independence and Security Act of 2007, mandates increased production of biofuels. It codifies the concept of life-cycle emission accounting and sets GHG emission reduction thresholds for categories of biofuels, including explicit consideration of emissions from global land use conversions (often known as indirect land use change, or iLUC, emissions).

A low carbon fuel standard (LCFS) is different from biofuel mandates such as RFS2 in several ways. First, it includes all transportation fuels—electricity, natural gas, and hydrogen as well as biofuels. Second, it is a performance standard, requiring reduction of a fuel's average life-cycle GHG emissions or carbon intensity (CI)—measured in grams CO_2 equivalent per mega-joule of fuel energy (gCO_2e/MJ)—over a certain period of time. Under an LCFS, fuel providers can reduce the CI of fuels they provide by selling more low-carbon fuels; reducing the CI of fossil fuels by reducing flaring, improving refinery and oil-field efficiencies and carbon footprints, and capturing and sequestering carbon; and/or purchasing credits from other producers and fuel suppliers who are able to supply low-carbon fuels at lower prices. Third, it is more effective at stimulating innovation. Fuel suppliers are rewarded for reducing carbon emissions at every step in the energy supply chain from cultivation and extraction to fuel processing, transport, and distribution, unlike under RFS2.In summary, an LCFS is technology and fuel neutral, and is premised on stimulating innovation.

Because of these inherent attractions, the LCFS concept has been adopted in California,[1] the European Union (Fuel Quality Directive, FQD),[2] and British Columbia (Renewable and Low-

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[1] California Governor Executive Order S-01-07 (January 2007) http://www.arb.ca.gov/fuels/lcfs/eos0107.pdf

[2] http://ec.europa.eu/environment/air/transport/fuel.htm

Carbon Fuel Requirement Regulation, RLCFRR).[3] Other states and regions in the United States, including the Midwest,[4] the Northeast/Mid-Atlantic region,[5] and the states of Oregon[6] and Washington,[7] are seriously considering adopting an LCFS modeled after California's.

This report summarizes key insights from seven studies on the costs and benefits of a national LCFS in the United States, to be published in the peer-reviewed journal *Energy Policy* in a special issue, "Low Carbon Fuel Policy" from summer throughout the end of the year. Topics addressed include the economic impacts and GHG reduction potentials of the LCFS, the contributions of electricity in the LCFS, market design and credit prices, energy security impacts, mitigation options to reduce indirect land use change, and LCA uncertainties.

One important caveat regarding an LCFS is that it should not be treated as the sole transportation fuel policy. It does not directly stimulate the development of infrastructure or the purchase of vehicles needed to use the targeted alternative fuels. Other complementary policies, innovative business models, and coordinated actions among fuel and infrastructure providers are needed to overcome various start-up barriers such as the chicken-and-egg problem of rolling out new vehicles and fuels simultaneously.

Economic and GHG Impacts

The economic and GHG impacts of a national LCFS will be determined by the availability and cost of low-carbon fuels, the timeline for GHG reduction, and the design of the credit system. Based on our study (Huang et al. 2012), three key outcomes of imposing an LCFS to the existing RFS2 would be (1) reduce petroleum consumption and lower fuel prices for consumers, (2) lower crop prices due to a gradual shift from using food-based crops for biofuel production to greater reliance on cellulosic material, and (3) larger reductions in GHG emissions domestically and globally.

The LCFS carbon intensity (CI) target in our analysis gradually increases to a 15 percent reduction by 2030, while the RFS2 trajectory increases to 36 billion gallons of biofuels by the early 2030s. We find that over the 2007-2035 period, RFS2 has the potential to reduce gasoline consumption by 8% and diesel consumption by 1%. The addition of LCFS would lead to modestly larger reductions in gasoline and diesel consumption by 9% and 3% respectively (Huang et al. 2012).

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[3] http://www.em.gov.bc.ca/RET/RLCFRR/Pages/default.aspx
[4] http://shonic.net/LCFS/documents/LCFPagDoc.pdf
[5] http://www.nescaum.org/topics/clean-fuels-standard
[6] http://www.deq.state.or.us/aq/committees/lowcarbon.htm
[7] http://www.ecy.wa.gov/climatechange/fuelstandards.htm

The RFS2 and LCFS will affect the price of fuel for consumers and fuel blenders. By lowering the demand for fossil fuels these policies will lower the market price of fuel. We estimate that consumer price of gasoline and diesel would decrease by about 10% under the RFS2. The addition of an LCFS to the RFS2 would result in the price of gasoline blends being lower by 7% and the price of diesel blends by 13% since the RFS2+LCFS will enhance the production of BTL compared to the RFS2 alone.

The cost of producing fuel blends will also be affected by these policies. While the cost of producing fossil fuels will drop this will be offset by the higher cost of the alternative low-carbon fuels. However, the overall weighted costs of blended gasoline and diesel are still projected to be lower for both consumers and producers in the RFS2+LCFS scenario by 2035. As shown in Figure ES1 below the blender's cost of gasoline blends will increase by about 2% under both policy scenarios while that of diesel blends will decrease.

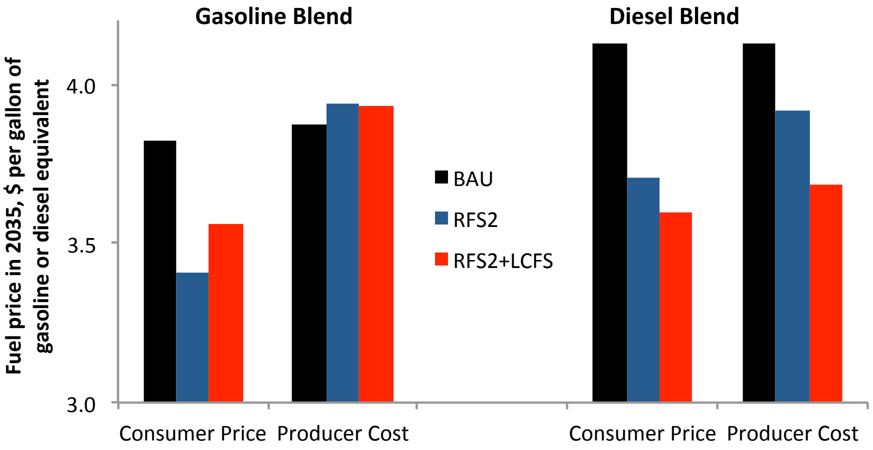

Figure ES 1. Projected price of gasoline and diesel blends for consumers and producers under different policies. Source: Based on Huang et al. 2012.

We estimate that RFS2 alone will reduce GHG emissions by about 5 percent relative to business as usual (BAU) between 2007 and 2035, but this reduction falls to 3.6 percent relative to BAU after including an international land use change (LUC) emission factor (taking into account increased emissions from diverting land to energy production). It further declines to 1.1 percent after including the global rebound effect, meaning the additional gasoline consumption around the world that results from lower US gasoline consumption slightly reducing world oil prices.

Implementing an LCFS policy alongside RFS2 would achieve an additional 3.4 percent reduction in GHG emissions after accounting for ILUC emissions and rebound effects, for a total reduction of 4.5 percent (3.4 + 1.1 percent) compared to business as usual. The projected GHG impacts are shown in Figure ES .

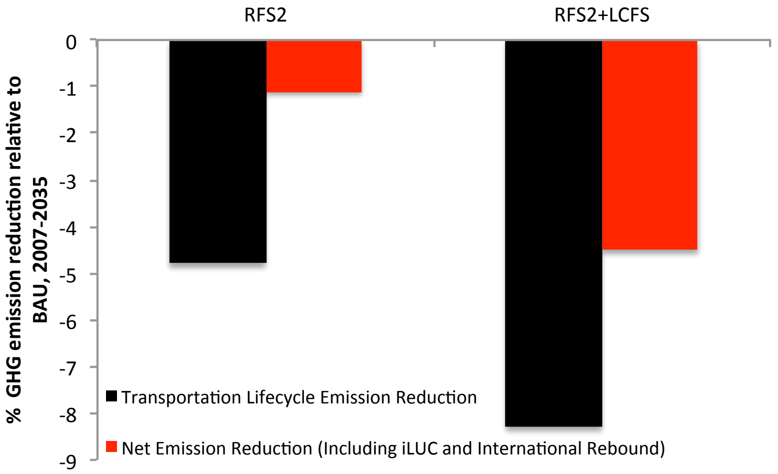

Figure ES 2. Comparison of estimated GHG cumulative emissions (2007–2035) under different policies. BAU= business as usual (assuming no RFS2 or LCFS policies). The iLUC numbers estimate GHG emissions from global land use conversions outside of the United States. Land use change emissions within the United States as a result of biofuel policies are counted within the fuel and agricultural sectors. Source: Based on Huang et al. 2012.

The forecasted fuel prices for consumers and producers are sensitive to a variety of factors, including the feedstock mix, feedstock prices, demand for gasoline and diesel fuel, demand for plug-in electric vehicles and fuel cell vehicles, and future production costs of biofuels and other alternative fuels. In the end, the cost and price impacts of achieving GHG reductions are uncertain, largely because future production costs of cellulosic biofuels and the GHG implications of their land use impacts are uncertain. A variety of scenarios were examined to quantify the uncertainty in these fuel price effects of these policies. High costs of biomass feedstocks, lower rates of growth in corn productivity and limits on land conversion for perennial crops could result in higher costs of cellulosic biofuels and higher costs of fuel for blenders and consumers. Policy mechanisms to address this uncertainty are examined in this and the Policy Design Recommendations to create a robust, economically efficient LCFS policy. These adjustments include trading and banking of LCFS credits, and imposing a price control mechanism that caps credit prices to avoid price spikes.

Electricity and Plug-in Electric Vehicles in an LCFS

The combination of electricity and plug-in electric vehicles (PEVs) presents the greatest potential to enable deep reductions in GHG emissions from light-duty transportation in the short to medium term. The actual emissions of a PEV depend greatly on the CI of the electricity that fuels it. The CI of electricity varies across regions due to differences in energy sources and how they are managed and utilized. Electricity in California, the Northwest, and the Northeast has a

CI significantly below the national average, while electricity in parts of the Midwest and the Rocky Mountains has a CI well above average.

In Figure ES 3, the life-cycle CI of electricity used as transportation fuel is estimated for various regions of the United States (based on 2005 electricity generation mixes). The CI of fuel electricity is calculated based on the CI of electricity divided by an energy efficiency ratio (EER) to account for the efficiency difference between electric and gasoline vehicles. The CIs of fuel electricity vary from a low of 24 gCO_2e/MJ in Alaska (ASCC Miscellaneous) to a high of 88 gCO_2e/MJ in Kansas (SPP North). The US average is approximately 61 gCO_2e/MJ. Given that the life-cycle CI of gasoline is estimated to be about 95 gCO_2e/MJ during the period from 2005 to 2030, our findings indicate that substituting electricity for gasoline would reduce GHG emissions per vehicle mile by 9 to 75 percent across US subregions, with the national average being a reduction of 38 percent.

These CI values for electricity, and therefore the GHG emissions of electric vehicles, are expected to decline over time. Based on the Department of Energy's *Annual Energy Outlook 2011* projection, the US average CI values for electricity are expected to decline 10 percent from 2010 to 2030 in the base case scenario. But recent shifts from coal to natural gas by many power plants suggest larger reductions are possible and even likely. If more stringent renewable energy and climate policies are adopted in the coming years or if natural gas prices stay low, electricity CI values could be reduced by 80 percent or more (Yeh 2008).

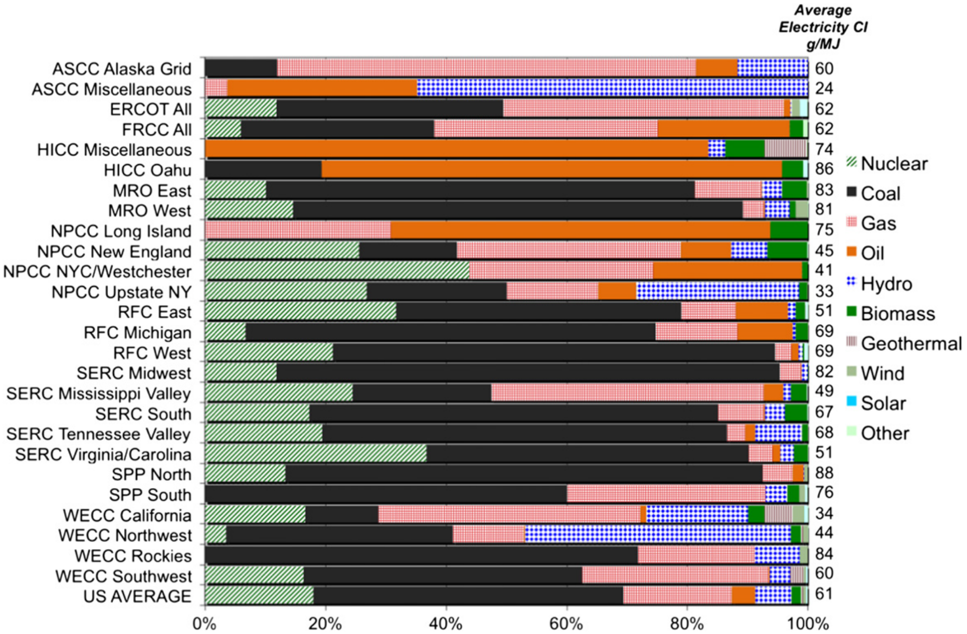

Figure ES 3. Life-cycle CI (carbon intensity) of fuel electricity by region based on the 2005 electricity generation mix. Note: The regions shown are those defined by the EPA's Emissions and Generation Resource Integrated Database (eGRID). Source: Yang 2012.

Plug-in electric vehicles (PEVs), which include both plug-in hybrids such as the Chevy Volt and pure battery electric vehicles such as the Nissan Leaf, could play an important role in the transition to low-carbon transportation. Their GHG effects are not regulated by RFS2 because that law targets only biofuels, but they are considered in an LCFS. Under an LCFS, electricity use by PEVs could generate substantial credits for purchase by oil companies striving to achieve their targets. The credit values per vehicle could be large. Assuming average travel distance and a low CO_2 credit price of $100 per tonne CO_2 LCFS credit price (which equates to $10 per tonne CO_2 price as, unlike CO2 price policies that tax all CO_2 emissions, LCFS only requires 10% of total CI reduction), we project the revenue generated from sales of CO2 credits by the electricity supplier to be $157 per electric vehicle per year, or $4,710 over the lifetime of the vehicle (somewhat less for a plug-in hybrid vehicle, such as the Chevy Volt).

Suppliers of the electricity, often regulated (or municipally owned) electric utilities, would receive these credit revenues and could use them in different ways. They could use them to subsidize the price of fuel electricity, provide financial incentives to PEV buyers, fund public or private vehicle recharging infrastructure, or upgrade electricity generation, transmission, or distribution; or they could simply retain the revenues as profit. The determination of who earned the credits—which could be not only electric utilities but also vehicle fleet operators, third-party suppliers of charging infrastructure, or others—and how the revenue was used, would be influenced and possibly dictated by local utility regulators.

Uncertainty and Variability in Life-Cycle Analysis

The measurement and analysis of life-cycle emissions is the basis of California's LCFS, the RFS2 program, and the European Union's Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). Indeed, these LCFS policies are the first major policies to incorporate life-cycle assessment (LCA) of emissions. LCA is especially important for comparing biofuels, electricity, and hydrogen, where combustion-related emissions are considered zero but life-cycle emissions can be quite high in some cases. LCA is also important as a way to acknowledge that there can be major differences in emissions from the same type of fuel produced in different places with different feedstocks and energy inputs.

During the course of any LCA, modelers must make many decisions regarding what will or will not be included in the analysis, data sources most appropriate to characterize the energy chain, and methods to estimate values for which no data are available. The larger and more complex the energy system being modeled, the greater the number of decisions to be made and the more difficult it is to arrive at one "true" value to quantify environmental impacts. Differences in GHG emission estimates across studies and models can be characterized as uncertainty. Uncertainty falls into three categories: spatial and temporal variability, data limitations, and scientific uncertainty. Understanding and addressing the magnitude of the uncertainty is essential for robust decision making. Variability and data limitations can be addressed through policy design and improved data collection and reporting. Scientific uncertainty requires more research and is more difficult to accommodate but can be addressed through creative policy mechanisms (such as those described below for land use change). Recognizing and explicitly estimating uncertainty in LCA is an important step toward making LCA a more useful tool for informing policy decisions. In this report as well as the accompanying Policy Design Recommendations, we address methods for reducing variability and scientific uncertainty.

For gasoline, the key sources of uncertainty and variability are combustion emissions, refinery emissions, and the mix of crude oils. Life-cycle emissions of gasoline produced from different sources of crude oil can differ significantly, with the CI of gasoline produced from Canadian oil sands being about 10-15 percent higher than the average life-cycle CI of gasoline made from conventional oil. The CI of gasoline from average African crude oil is nearly 7 percent higher than the US average, mostly due to the extensive flaring of natural gas found associated with this petroleum.

For biofuels, the greatest uncertainty regarding GHG emissions is related to the indirect and direct land use change (LUC) impacts of crop-based fuels such as corn, and to the N_2O emissions resulting from the application of fertilizer to grow these crops. There are also uncertainties about the performance of future conversion technologies and the land yields for new types of biofuel feedstocks (such as switchgrass).

One mechanism to reduce uncertainty related to variability and data limitations is to allow fuel producers to self-report CI values for specific activities (such as biorefinery efficiency) or for their entire energy supply chain. Fuel suppliers would use these self-reported "opt-in" values instead of the default CI values in the regulations. This opt-in mechanism is attractive because it provides an incentive for companies to innovate further to improve their GHG performance.

However, even with opt-in reporting, significant scientific uncertainty would remain, especially for fuels made from crops such as corn. Uncertainty regarding emissions from global land use conversion and N_2O emissions from fertilizer use can comprise 90 percent of the estimated variance in some cases. While these LUC and N_2O emissions can be large and uncertain, policy mechanisms can be designed to incentivize a shift to feedstocks that cause less LUC and have smaller fertilizer needs, as indicated below.

Global Land Use Change Impacts

More biofuel production almost always requires more land. The (market-induced) land use change (LUC) that results from policies such as RFS2 and an LCFS will be greater if land-intensive feedstocks such as corn are used, and lesser if high-yield dedicated cellulosic energy crops like miscanthus and switchgrass are used. There will be no LUC effect if waste materials such as crop and forestry residues and municipal solid waste are used.

RFS2 induces a greater increase in crop area (and thus GHG emissions associated with LUC) across the world than an LCFS or carbon price policies would (see Figure ES 1), because it diverts more grain crops to biofuel production, leaving less grain for export. Most of the LUC occurs in sub-Saharan Africa and Latin America. RFS2 combined with an LCFS policy would have a smaller effect on total global crop area and LUC emissions (as shown the difference between the green and blue bars in Figure ES4), reducing total LUC by about two-thirds globally. The use of an LUC emission factor in calculating life-cycle emissions, included in a performance-based LCFS, leads to relatively greater use of dedicated energy crops and waste materials, and lesser use of food-based feedstocks, resulting in a smaller decline in commodity exports, lower food prices, and less global land use change.

An LUC factor, often referred to as an iLUC factor ("i" referring to "indirect"), while not addressing all the dimensions of incentives that drive global land cover conversion and not capturing the underlying uncertainty, nevertheless serves as an effective policy tool. It has the effect of shifting the mix of biofuels away from first-generation biofuels toward cellulosic and waste biofuels, which cause less domestic and international land use conversion (Msangi et al. 2012).

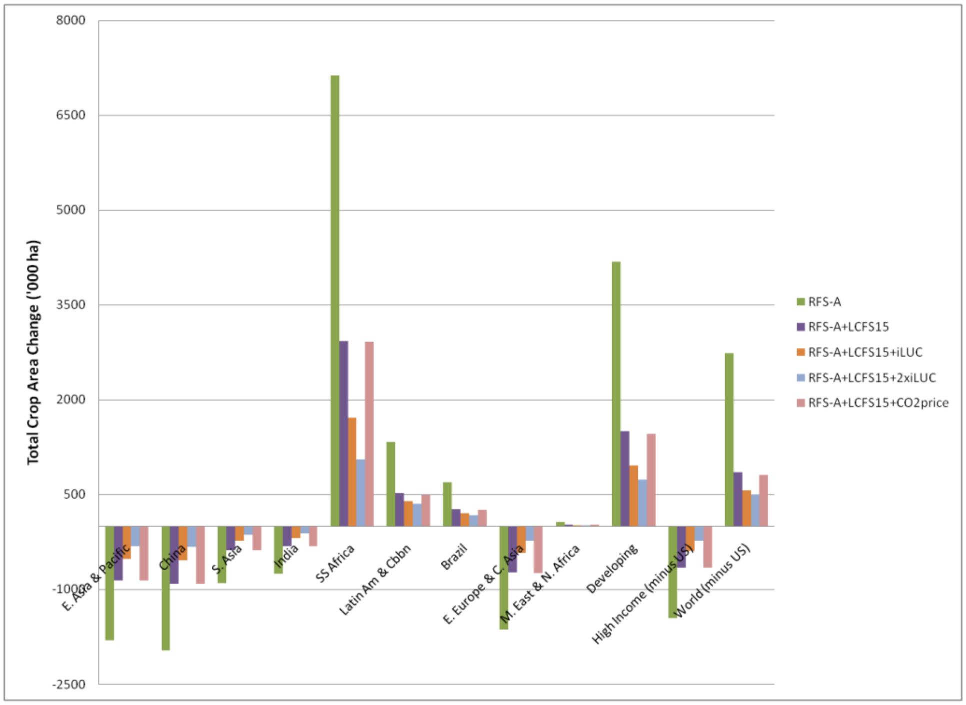

Figure ES 4. Change in total global non-US crop area from business-as-usual case, 2007–2030, under alternative US biofuel policy scenarios. Source: Msangi et al. 2012. Note: RFS-A refers to the RFS2 scenario based on the *Annual Energy Outlook 2010* projections as explained in the "Economic and GHG Impacts" section. The "2×iLUC" scenario tests the sensitivity of iLUC using a higher (more conservative) iLUC factor. The CO_2 price scenario assumed an average of \$60/ton CO_2 to all carbon emissions.

An iLUC factor is analytically determined for each feedstock and is measured as gCO_2e/MJ so as to be additive with other LCA measurements. The uncertainty surrounding the measurement of biofuel LUC, and the specification of iLUC factors, contributes to a policy challenge. Overestimating or underestimating emissions leads to real consequences and costs for society. Multiple modeling systems and other research approaches can assist in setting plausible ranges for feedstock LUC effects and in conducting sensitivity analysis throughout the ranges on expected outcomes for LUC policies. Policy makers must weigh the risks on both sides of the policy challenge to determine which emissions risks are acceptable and which policy instruments are preferred.

Despite uncertainty surrounding measurement of LUC effects, we conclude that iLUC factors are an effective mechanism for sending a clear signal to investors about LUC risk. But it is not enough, and complementary policies in both the short and long term are needed to minimize potential unintended consequences regionally and globally caused by biofuel policies. These short-term and long-term policy strategies are discussed in detail in the companion report PDR.

Impacts on Energy Security

Replacing fossil fuels with domestic supplies like ethanol, natural gas, and electricity reduces oil imports and the exposure to economic loss from oil shocks. The actual cost of energy security derives from a set of economic conditions related to fuel demand, imports, proportion of global fuel supply that is stable and competitive, risk and sensitivity to oil supply and price shocks, size and utilization of the Strategic Petroleum Reserve, and short- and long-term supply and demand flexibility. Our analysis encompasses the interplay among these key factors, with special focus on oil import costs and the economy's vulnerability to episodic shocks.

Energy security will be improved to the extent that a national LCFS decreases petroleum consumption by substituting lower-carbon alternative fuels such as biofuels, electricity, natural gas, and hydrogen.

Some argue that by restricting the carbon content of fuels, an LCFS would adversely affect energy security by preventing the use of reliable high-carbon unconventional oils, primarily from Canadian oil sands, as well as impeding domestic production of oil shale, and other unconventional heavy crudes such as Venezuelan ultra-heavy crudes. This, it is said, would lead to export of those high-carbon oils to other countries (referred to as crude shuffling and CO_2 leakage), resulting in little net reduction of global CO_2 emissions, *or* it would lead to reduced use of unconventional oils from stable, competitive sources. The result, it is argued, would be greater reliance on insecure or cartelized conventional oil and reduced energy security.

We examine the fuel substitutions that are projected to be induced by an LCFS and consider the energy security implications of displacing higher-carbon fuels, such as oil imported from

Canadian oil sands or certain imported crude oils, with lower-carbon domestic oil, biofuel, or lower-carbon oil imported from other sources.

Four responses to a national LCFS by producers of high-carbon crude are possible: (1) imports could continue with their CI reduced to levels comparable with other crudes (which Shell Oil has said is its goal for its oil sands production); (2) imports could continue with the purchase of LCFS credit offsets; (3) high-carbon crudes could be shuffled out of the United States to other markets; or (4) high-carbon crude production could decline. It should be noted that energy security is little affected by the first three options, and only the fourth option would reduce energy security—but this possibility is unlikely since production of high-carbon crude is generally profitable if the global oil price is above the range of $30 to $70 per barrel, and the profitability of oil sands production generally far exceeds the costs of the other three responses.

The first three options do not have energy security impacts. The worst-case outcome for energy security would occur if both imports of oil from Canadian oil sands to the United States and production of oil from Canadian oil sands decline together, with the imports replaced by greater US imports of crude oil from other sources.

Overall, we estimate the mean security benefits of an LCFS policy to range in 2035 from $5 per barrel if domestic alternative fuels substitute for oil from Canadian oil sands; $12 per barrel if all sources in the base US mix of petroleum are decreased proportionally; and $22 per barrel if imported crude oil demand is decreased (see Figure ES 5).

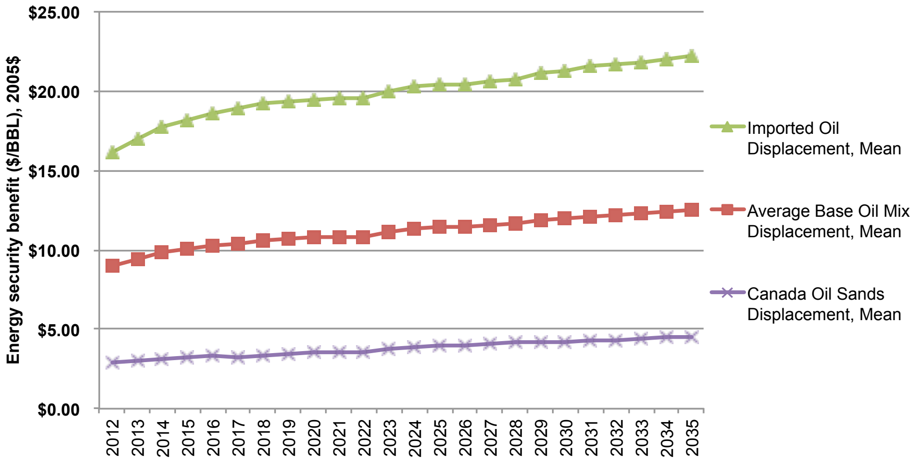

Figure ES 5. Time paths for energy security premia, various cases. Source: Leiby and Rubin 2012.

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Introduction

Petroleum fuels make up the vast majority of the transportation fuels used today. Dependence on petroleum has many adverse impacts—on climate change, energy security, health, and economic growth. Tackling all of the issues associated with petroleum dependence requires a coordinated effort to reduce vehicle use, improve vehicle efficiency, and switch to cleaner, lower-carbon fuels.

Many believe that market-based policies are best to tackle these challenges. But in the case of transportation, such policies are likely to be less effective than regulatory and performance-based approaches, at least in the near to medium term. Policy analyses by the US Environmental Protection Agency (EPA) and Department of Energy (DOE) suggest that carbon cap-and-trade programs will be ineffective in reducing transportation GHG emissions[8] unless a very stringent cap is imposed, beyond what is likely to be politically acceptable (Yeh et al. 2008).

Consider the 2007 carbon cap-and-trade program adopted by the House of Representatives in 2007. EPA found in its studies that this price increase would not likely be large enough to induce significant change in industry supply of low-GHG alternative fuels nor to induce consumers to reduce fuel use significantly or to purchase alternative fuels or vehicles (U.S. EPA 2007).[9] The contradictions lie in the "energy paradox" that has been widely recognized—that energy markets are particularly inefficient and ineffective at addressing end-use technology efficiency and demand reduction—and thus the popularity and success of regulatory-based vehicle performance standards.

The challenge in designing and adopting new policy is to understand why and how intervention is needed. The first reason for intervention is that energy markets treat climate change as an externality. But equally important are the many market failures and market conditions that riddle the energy system, resulting in consumer and business decisions that are not in the best interest of society.

Many types of policies could be used to correct these market shortcomings**.** To determine which policies are best, one must consider not only classic market failures such as inadequate R&D (Jaffe, Newell, and Stavins 2005) and pollution externalities, but also a variety of market

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[8] Analyses by the EPA and the Energy Information Administration (EIA) suggest that less than 5 percent of total emission reductions would come from the transportation sector by 2030, even though transportation accounts for almost a third of total emissions (U.S. EIA 2008; U.S. EPA 2007). If these proposed cap-and-trade policies were implemented, the transport sector would become the single largest emission source by 2050, accounting for more than half of total GHG emissions in the United States (U.S. EIA 2008; U.S. EPA 2007).

[9] The EPA estimated the GHG allowance prices under the program would be \$16 to \$87/tCO_2e from 2015 to 2050, which would raise gasoline prices by \$0.16 and \$0.81 per gallon in 2015 and 2050, respectively (U.S. EPA 2007).

conditions and barriers, some of them unique to transportation. These market conditions include the additional requirement for coordination (network effects) among fuel producers, vehicle manufacturers, and fuel distributors (Leiby and Rubin 2004; Sperling and Gordon 2009); energy security externalities related to petroleum imports (Greene and Leiby 2006; Greene et al. 2007; Leiby 2008; U.S. EPA 2011); long time horizons needed for return on investments in fuel infrastructure (NRC 2008); the lack of fuel-on-fuel competition; the diffuse nature of the biofuel industries; and the market power of oil companies and OPEC countries.

Because of these many market failings, a mix of policies is needed to reduce transportation GHG emissions. The most effective and promising policies already in place are those that target the energy efficiency of vehicles (NRC 2010; Transportation Research Board 2011). Aggressive performance-based policies for vehicle fuel economy and GHG standards have been effective and politically acceptable and are being adopted around the world. Policies addressing vehicle use and decarbonization of fuels have been less successful, partly due to the "fuel du jour" policies in the past and the lack of a robust, long-term policy framework. Here we take up the challenge of a performance-based standard aiming to decarbonize transportation fuels.

The Federal Biofuel Mandate (RFS2)

The Renewable Fuels Standard (RFS2) mandated by Congress under the Energy Independence and Security Act of 2007 and implemented by the EPA requires that 36 billion gallons of biofuels be sold annually by 2022; 21 billion gallons must be "advanced" biofuels and the other 15 billion gallons can be corn ethanol. The advanced biofuels are required to achieve at least a 50-percent reduction from baseline life-cycle GHG emissions, with a subcategory required to meet a 60-percent reduction target. These reduction targets are based on life-cycle emissions, including emissions from direct and indirect land use conversion (LUC). RFS2 directly promotes the use of clean biofuels and thus improves energy security and air quality. It also requires consideration of emissions from global land use conversion in its life-cycle analysis and requires a periodic review of the sustainability performance of biofuels. RFS2, if fully implemented, would reduce US GHG emissions by about 5 percent in 2022.

RFS2 has several shortcomings. First, it targets only biofuels—not other alternatives, including electricity and hydrogen, which arguably have even greater potential to achieve deep GHG reductions. Second, setting the threshold targets of 50- and 60-percent reductions of GHGs has the effect of forcing biofuels into a small number of fixed categories, thereby stifling innovation. The EPA calculates a priori the GHG rating of each biofuel feedstock pathway, and any fuel supplier using that biofuel feedstock automatically meets the mandate, regardless of what the actual emissions are. Fuel suppliers have no incentive to innovate to do better. Third, by treating all cellulosic biofuels the same, RFS2 does not give incentives to use feedstocks (including waste materials) that can lead to even lower GHG intensity than the threshold, nor does it encourage innovation to further reduce GHG emissions across the entire life cycle.

Low Carbon Fuel Policies

A low carbon fuel standard (LCFS) is similar to RFS2 in that both rely on life-cycle assessment. They both measure total emissions of carbon and other GHGs, expressed as carbon equivalents based on their global warming potential, per unit of fuel energy. In principle, the standard is intended to capture all GHGs emitted in the life cycle from extraction, cultivation, land use conversion, processing, transport and distribution, and fuel use. While upstream emissions of petroleum fuels represent only about 20 percent of their total life-cycle emissions, upstream emissions represent almost the total life-cycle emissions of biofuels, electricity, and hydrogen (Delucchi 2003; GREET 2010). Upstream emissions from extraction, production, and refining can also comprise a large percentage of total emissions for very heavy oils and oil sands (Brandt 2008; Brandt and Farrell 2007; Charpentier, Bergerson, and MacLean 2009).

It is important to note that not all alternative fuels have lower GHG emissions than gasoline and diesel. Fuels produced from certain feedstocks and on certain production pathways, such as electricity from coal-fired power plants, hydrogen from coal gasification (Jaramillo et al. 2009), and biofuels with significant direct and indirect land use impacts (Fargione et al. 2008; Gibbs et al. 2008), may have a higher carbon intensity. An LCFS, by employing a GHG performance standard, forces a reduction in average carbon intensity, thereby discouraging (but not banning) the use of high-carbon fuels.

LCFS policies have been adopted in California, the European Union, and British Columbia. California's LCFS requires a 10-percent reduction by 2020 in the carbon intensity (expressed as gCO_2/MJ) of all fuels supplied in California (CARB 2009a). By targeting GHG reductions throughout the entire supply chain, the life-cycle-based LCFS encourages continuous innovation in cultivation and extraction, fuel processing, transport, and distribution. The standard is technology- and fuel-neutral; regulated parties choose compliance pathways based on their own business strategies (Sperling and Yeh 2009). In principle, the standard can apply to all transport fuels, including biofuels, compressed natural gas, electricity, hydrogen, aviation fuels, and bunker.[10]

Similar to the US's RFS2, the European Union's Renewable Energy Directive (RED) also requires that 10 percent of transportation fuels in 2020 be renewable fuels. Just as RFS2 is narrower than an LCFS, the European Union also implemented Fuel Quality Directive (FQD) in addition to the fuel mandate RED requiring a reduction of 6 percent in transportation life-cycle

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[10] Not all fuels need to be regulated to reduce carbon intensity. Some fuels, such as the average electricity and natural gas, already have lower CI than petroleum fuels, will contribute to the LCFS by generating LCFS credits. Other fuel types, such as aviation and shipping, may be more difficult to regulated due to limited jurisdictions. Their role in the LCFS are discussed in more detail in the Policy Design Recommendations.

carbon intensity by 2020 (EC 2008).[11] In Canada, British Columbia's Renewable and Low-Carbon Fuel Requirement Regulation (RLCFRR) requires the same 10-percent reduction in the average life-cycle GHG intensity of transportation fuel by 2020 as California's LCFS requires.

Other states in the United States have been exploring the adoption of an LCFS policy, including states in the Midwest, northeastern and mid-Atlantic states, and the states of Oregon and Washington. Eleven northeastern and mid-Atlantic states are currently participating in the evaluation of a regional Clean Fuels Standard (CFS). A 2009 memorandum of understanding signed by the governors of the eleven states committed the states to developing a program framework and conducting an economic analysis of the potential impacts of the program. Oregon's Clean Fuels Program is proposing a two-phased approach, starting with a two-year reporting-only period to gather data and refine the program. Fuel producers and importers would gradually lower the GHG emissions of fuels by 10 percent by 2025 in the Phase two of the program, which still requires approval by the legislature. The state of Washington published an evaluation of an LCFS in 2011 that would require a 10-percent reduction in the life-cycle carbon intensity of transportation fuels from 2014 to 2023. In 2010 the Midwestern Governor's Association, representing Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin, evaluated a low carbon fuels policy based on a proposed recommendation to require 10-percent reductions in fuel carbon intensity within ten years of implementation.

Advantages of Harmonizing RFS2 and an LCFS

One possible fuels policy approach for the United States is to integrate an LCFS, or at least its key features, into the existing RFS2. Doing so would have a number of attractions. First, harmonization of the federal biofuel mandate with a performance-based LCFS would create greater flexibility and incentives to achieve GHG reduction. Each supplier would be able to strategically integrate a portfolio of low-carbon fuels with its current supplies at their geographic locations. Second, an enhanced RFS2, incorporating LCFS design attributes, would facilitate standardization of measurement protocol. It would obviate individual states creating a patchwork of LCFS regulations and thus avoid the danger of inconsistent policy designs, including varying system boundaries for fuel carbon intensity measurement, inconsistent treatment of GHG emissions from land use conversion, inconsistent treatment of crude oils with higher carbon intensity, and much more. These differences in policy design will significantly affect the stringency and effectiveness of each individual program. They will increase compliance costs and create more incentives for fuel shuffling (that is, moving fuels among different markets to meet rules in different places but without any actual emission reduction). Third, by expanding

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[11] In addition, subject to review and non-binding, it calls for an additional 2% from supply of energy for transport (road vehicle, non-road mobile machinery, agricultural/forestry tractor, or recreational craft) or use of technology to reduce carbon intensity (including carbon capture and storage), and 2% from use of Kyoto Protocol Clean Development Mechanism. Fuels must meet sustainability criteria to be eligible, including GHG savings of 35%, increasing to 50% in 2017, and 60% in 2018 (for new facilities starting production in 2017 or later).

the pool of fuels beyond biofuels, integrating an LCFS with RFS2 would make more options available to the regulated entities. More choice would mean lower overall cost, because there would be a greater chance of finding low-cost options to meet the targets or trade with other low-carbon fuel providers. Last, an enhanced RFS2-LCFS policy would make it easier to include fuels used in international transport modes, especially fuels used in jets and ships, allowing those other uses to opt into the program.

1 Policy Comparison and Economic Impact Analysis

To analyze the economic and GHG implications of a national LCFS, members of our team developed the Biofuel and Environmental Policy Analysis Model (BEPAM), a dynamic, multi-market equilibrium, nonlinear mathematical programming model. BEPAM endogenously simulates the effects of an LCFS and other policies on land allocation, fuel mix, GHG emissions, and prices of fuel, biofuel, food/feed crops, and livestock at annual time scales over the period 2007 to 2035 (Khanna, Onal, and Huang 2011; Huang et al. 2012). It also analyzes the distributional effects on consumers, producers, land use, and fuel and food prices. We tested two different scenarios, with LCFS policies having carbon intensity (CI) reduction targets of 10 percent (LCFS10) and 15 percent (LCFS15) phased in between 2015 and 2030.

BEPAM simulates market response and the impacts of the policy on spatially disaggregated crops yields, fertilizer inputs, technology efficiency, costs and deployment, and GHG emission factors at the 295 Crop Reporting Districts (CRDs) in 41 states as the spatially heterogeneous decision units and includes 15 major row crops and 8 livestock activities, and several types of first- and second-generation biofuels that can be blended with gasoline and diesel. In this model, the cost of biofuels production can decrease over time due to learning, though the feedstock and land prices tend to increase due to increased demands in the baseline and for meeting the policy targets. The LCFS policy scenario includes the quantity of electric vehicles and light trucks assumed for the moderate PEV scenario described in Yang (2012) (and Section 3 below). The BEPAM model does not attempt to estimate global land use conversion outside of the U.S. as a result of biofuel policies in the United States. Instead, the global land use effects are estimated by the global agricultural and food model described in Section 5. Here, a simple iLUC factors based on estimates by the EPA (U.S. EPA 2010a)[12] is added to the BEPAM model to estimate the policy impacts when iLUC emissions are explicitly taken into account.

We used BEPAM to analyze the economic and GHG effects of adding an LCFS alongside RFS2. We used a revised version of RFS2 based on forecasts in the US Energy Information Administration's *Annual Energy Outlook 2010* (U.S. EIA 2010a) that biofuel production volumes will likely increase somewhat more slowly than RFS2 mandates in the coming years, reaching the targeted quantities in the early 2030s instead of 2022. We combined RFS2 with the 10-percent and 15-percent CI reduction targets by 2030 and assume the target will remain flat from 2030 to 2035 to avoid end-of-year effects. The results shown here are scenarios for 15-percent CI reduction targets by 2030 (LCFS15). We also ran a scenario that combined RFS2, an LCFS15, and a carbon price (RFS2+LCFS+CO_2 price) in order to compare the effectiveness of different combination of complementary policies.

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[12] The iLUC factor for biofuel from miscanthus is assumed to be the same as that for biofuel from switchgrass due to lack of estimates specific to miscanthus. This is likely to result in an overestimate of the iLUC effect of miscanthus-derived biofuel because the yield of miscanthus per unit of land is substantially higher than that for switchgrass.

Based on our model, we find that imposing an LCFS alongside the existing RFS2 produces three main results: (1) larger reductions in GHG emissions domestically and globally; (2) lower fuel prices for consumers, and (3) lower crop prices. The lower crop prices are due to a gradual shift in feedstocks from food-based crops for biofuels production to greater reliance on cellulosic material. The other two effects are examined in detail below.

1.1 Effects of Policies on Food and Fuel Prices

Our analysis finds that the effect of RFS2 is to raise corn prices by 40 percent and soybean prices by 34 percent relative to BAU. With the addition of an LCFS, the prices of corn and soybeans are 23 percent and 14 percent lower, respectively, than under RFS2 alone, suggesting that an LCFS helps mitigate the food-versus-fuel competition by inducing a shift from corn ethanol to cellulosic biofuels.

The RFS2 and LCFS will affect the price of fuel for consumers and fuel blenders. By lowering the demand for fossil fuels these policies will lower the market price of fuel. We estimate that consumer price of gasoline and diesel would decrease by about 10% under the RFS2. The addition of an LCFS to the RFS2 would result in the price of gasoline blends being lower by 7% and the price of diesel blends by 13% since the RFS2+LCFS will enhance the production of BTL compared to the RFS2 alone.

The cost of producing fuel blends will also be affected by these policies. While the cost of producing fossil fuels will drop this will be offset by the higher cost of the alternative low-carbon fuels. However, the overall weighted costs of blended gasoline and diesel are still projected to be lower for both consumers and producers in the RFS2+LCFS scenario by 2035. As shown in Figure ES1 below the blender's cost of gasoline blends will increase by about 2% under both policy scenarios while that of diesel blends will decrease.

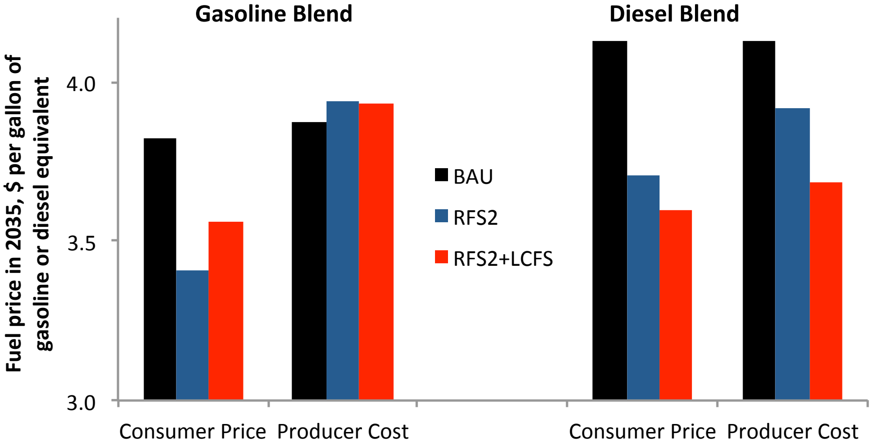

Figure 1. Projected price of gasoline and diesel blends for consumers and producers under different policies. Source: Based on Huang et al. 2012.

As shown in Figure 1, there is a gap between the producer and the consumer price of biofuels under the RFS2 and RFS2+LCFS scenarios because producers absorb some additional cost (and reduced profits) in order to incentivize the consumption of biofuels to meet the volumetric and CI reduction targets, respectively. This phenomenon implies higher costs for blenders of biofuels but lower costs for consumers. The producer price of corn ethanol is lower under the RFS2+LCFS scenario because the reduced production of corn ethanol lowers the price of corn and the cost of producing corn ethanol relative to the RFS2 scenario.

We find that over the 2007-2035 period, RFS2 has the potential to reduce gasoline consumption by 8% and diesel consumption by 1%. The addition of LCFS would lead to modestly larger reductions in gasoline and diesel consumption by 9% and 3% respectively.

1.2 Net Economic Impact of Alternative Policies

The policies considered here affects consumer and producer behavior in the agricultural and fuel sectors as well as government revenue from fuel taxes. In a large open economy such as the US, these policies also improve the terms of trade for the US, by lowering fuel (import) prices and raising agricultural (export) prices. Even without considering the environmental benefits of these policies, we find that both RFS2 and LCFS lead to small net increases in economic benefits over the 2007 to 2035 period compared to a no policy BAU scenario (Huang et al. 2012), around 1 percent. These results differ from other studies such as Holland et al which focus only on the fuel sector in a closed economy and disregard the effects of lower global fuel prices on consumers in the US and the effect of higher agricultural commodity prices on agricultural producers in the US.

1.3 Effects of Policies on GHG Emissions

We estimate that RFS2 alone will reduce GHG emissions by about 5 percent relative to business as usual (BAU) between 2007 and 2035, but this reduction falls to 3.6 percent relative to BAU after including an international land use change (LUC) emission factor (taking into account increased emissions from diverting land to energy production). It further declines to 1.1 percent after including the global rebound effect, meaning the additional gasoline consumption around the world that results from lower US gasoline consumption slightly reducing world oil prices.

Implementing an LCFS policy alongside RFS2 would achieve an additional 3.4 percent reduction in GHG emissions after accounting for ILUC emissions and rebound effects, for a total reduction of 4.5 percent (3.4 + 1.1 percent) compared to business as usual. The projected GHG impacts are shown in Figure 2.

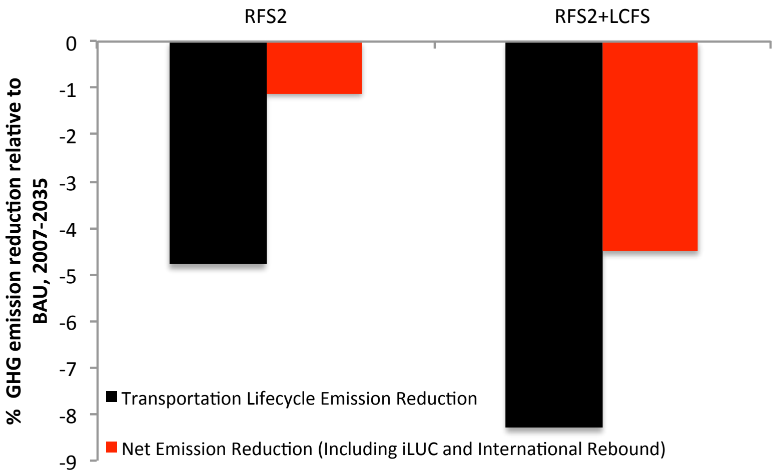

Figure 2. Comparison of estimated GHG cumulative emissions (2007–2035) under different policies. BAU= business as usual (assuming no RFS2 or LCFS policies). The iLUC numbers estimate GHG emissions from global land use conversions outside of the United States. Land use change emissions within the United States as a result of biofuel policies are counted within the fuel and agricultural sectors. Source: Based on Huang et al. 2012.

The forecasted fuel prices for consumers and producers are sensitive to a variety of factors, including the feedstock mix, feedstock prices, demand for gasoline and diesel fuel, demand for plug-in electric vehicles and fuel cell vehicles, and future production costs of biofuels and other alternative fuels. In the end, the cost and price impacts of achieving GHG reductions are uncertain, largely because future production costs of cellulosic biofuels and the GHG implications of their land use impacts are uncertain. A variety of scenarios were examined to quantify the uncertainty in these fuel price effects of these policies. High costs of biomass feedstocks, lower rates of growth in corn productivity and limits on land conversion for perennial crops could result in higher costs of cellulosic biofuels and higher costs of fuel for blenders and consumers. Policy mechanisms to address this uncertainty are examined in this and the Policy Design Recommendations to create a robust, economically efficient LCFS policy. These adjustments include trading and banking of LCFS credits, and imposing a price control mechanism that caps credit prices to avoid price spikes.

2 Market Design: The Value of Credit Trading and Banking

The impacts of an LCFS are determined by the availability of low-carbon fuels, the targets and compliance path, and the degree of flexibility in the credit system (Rubin and Leiby 2012). To compare the benefits of different market designs for trading credits under a national LCFS, members of our team developed the Transportation Regulation and Credit Trading (TRACT) Model, a dynamic nonlinear optimization model (Rubin and Leiby 2012). The model looks at the possibility of cross-fuel market trading (across gasoline and diesel fuel pools), combined with the ability to bank credits for later compliance.

The model utilizes fuel quantity and price data estimated by *Annual Energy Outlook 2010* as captured by Argonne National Laboratory's VISION model (ANL Transportation Technology R&D Center 2011). It takes the primary and final fuel quantities from VISION as supply-demand equilibrium market outcomes for each year. For each year it uses price-sensitive demand curves for final fuels based on VISION's projections of quantities and prices. The model examines various assumptions regarding biofuel supply availability and prices (from more conservative estimates by AEO/VISION to more optimistic estimates based on BEPAM), along with estimates of fuel carbon intensity (from more conservative estimates by EPA/GREET to more optimistic estimates based on BEPAM).

Our study finds that trading and banking significantly lower compliance costs (Figure 3) and lead to greater reductions in carbon emissions by reducing the number of safety-valve credits purchased. (The safety valve is a price control mechanism set in this study at a credit price of \$300/ton CO_2e—equivalent to \$30/ton CO_2e under a carbon price policy—to provide protection against extreme prices and price fluctuations.)

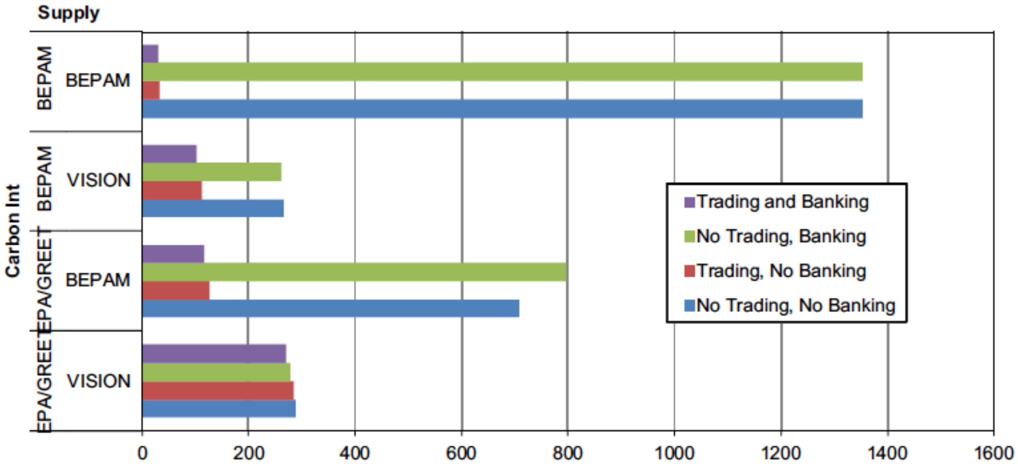

Figure 3. Impacts of trading and banking on the average costs (\$/MtCO_2e) of various carbon intensity and supply scenarios achieving a CI reduction of 10 percent. Note: \$ per Mt values can be interpreted as cost per tonne divided by 10 under a carbon price policy, since the credit prices apply only to 10 percent of the (life-cycle) carbon in the fuel. Source: Rubin and Leiby 2012.

We found that trading greatly lowers the average cost of carbon reductions. Cost reduction estimates vary from $1352 to $33 per metric ton (Mt) CO_2e depending on assumptions from different sources, as follows: $289 to $284 (EPA/AEO, representing conservative CI [EPA] and conservative supply [AEO] assumptions, respectively), $708 to $127 (EPA/BEPAM, representing EPA CI and BEPAM supply assumptions, respectively), $267 to $112 (BEPAM/AEO), and $1352 to $33 (BEPAM/BEPAM) for the respective CIs and supply estimates. The greater amount of savings from trading derived from the BEPAM supply estimates reflects the pessimism about advanced biodiesel production in the BEPAM model, versus the AEO estimates. The ability to trade credits across fuel pools significantly moderates the costs associated with the uncertainty of fuel and technology availability.

Adding banking on top of trading further lowers the average costs of carbon reduction a small amount per tonne CO2e, by $284 to $271 (EPA/AEO), $127 to $116 (EPA/BEPAM), $112 to $103 (BEPAM/AEO), and $33 to $30 (BEPAM/BEPAM) for the respective CIs and supply estimates.

3 Electricity and Plug-in Vehicles in an LCFS

The combination of electricity and plug-in electric vehicles (PEVs) presents the greatest potential to enable deep reductions in GHG emissions from light-duty transportation in the short to medium term. To decarbonize the entire transportation sector (including aviation, heavy trucks, marine, and rail), it is likely that light-duty vehicles would need to be electrified as much as possible so that biofuels are left for use by aviation and long-haul trucking, which are less suited to electrification because of weight, power, or range limitations (McCollum and Yang 2009; IEA 2010). PEVs and fuel cell electric vehicles are likely to play disproportionately large roles in the light-duty vehicle sector.

To include electricity within an LCFS, three sets of important issues need to be resolved, relating to who can earn the LCFS credits, how to calculate the CI of electricity for PEVs, and how to adjust for the higher efficiency of electric engines. This report only presents the technical analysis on the calculation of electricity carbon intensity and incentives and the value of credits from electricity use in the transportation, where as the first and the third issues are addressed in greater detail in the PDR.

3.1 Scenarios of PEV Penetration

To understand the potential role that PEVs and electricity could play in helping achieve LCFS compliance in the gasoline (light-duty vehicle) market, members of our team developed two scenarios for PEV fleet growth (Yang 2012), summarized in Table 1. The *less aggressive* scenario is based on the National Research Council's "probable" fleet trajectory, which projects 12 million PEVs in the U.S. fleet by 2030. The scenario assumes a mix of plug-in hybrid electric vehicles with electric ranges of 10 to 40 miles (with PHEV10s, PHEV40s, and BEVs making up 60 percent, 30 percent, and 10 percent of the mix, respectively)[13]. An *aggressive* scenario was built based on an analysis by the California Air Resources Board for their zero emission vehicle (ZEV) regulation (CARB 2009b). The scenario assumes that much of the country follows California's lead and adopts PEVs (30 million by 2030) such that California represents about 20 percent of the country's PEVs. PHEV10s, PHEV40s, and BEVs are assumed to make up 15 percent, 55 percent, and 30 percent of the mix, respectively.

Table 1. Summary of two PEV adoption scenarios for assessing the contribution of electricity to national LCFS compliance, resulting fleet CI reduction, and potential LCFS revenues. Source: Yang 2012.

	Less Aggressive Scenario	Aggressive Scenario
	Input Assumptions	
PEV mix (PHEV10/PHEV40/BEV)*	60%/30%/10%	15%/55%/30%
PEVs in fleet in 2030	12 miles	30 miles
Electricity CI (gCO_2e/MJ) divided by EER=3⁺	Average US mix from AEO: 62 (2010), 60 (2020) and 59 (2030)	Low CI values: 49 (2010), 45 (2020) and 45 (2030)

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[13] The number of PEVs and the mix of vehicle types (PHEV10s/PHEV40s/BEVs) will influence the proportion of electricity versus gasoline being used by light-duty vehicles.

Results		
Fleet CI reduction contributed by electricity	0.2% in 2023 and 0.7% in 2030	1.4% in 2023 and 5.9% in 2030
Average revenue per vehicle per year at $100/tonne CO_2e credit price in 2030	$64 per PEV per year	$157 per PEV per year

[*] PHEV10: PHEV with an all-electric range of 10 miles per charge. PHEV40: PHEV with an all-electric range of 40 miles per charge. BEV: an all-electric vehicle.

[+] To account for the efficiency difference between electric and gasoline vehicles. See PDR Section 6 for mode detailed discussion.

PEV contribution to LCFS compliance could vary dramatically across different regions. Using very simple assumptions about the CI of electricity—assuming average electricity CI values for the United States in the less aggressive case, and average electricity CI values of the seven regions with the lowest electricity CI in the aggressive case—leads to emission reductions for all US vehicles of 0.7 percent to 5.9 percent by 2030 (Yang 2012). This example demonstrates that PEVs have the potential to make a substantial contribution to LCFS compliance. In areas with greater PEV penetration and low electricity CI, PEVs could be responsible for larger reductions in fleet CI and a greater contribution to LCFS compliance.

3.2 The Carbon Intensity of Electricity

The actual emissions of a PEV depend greatly on the CI of the electricity that fuels it. The CI of electricity varies across regions due to differences in energy sources and how they are managed and utilized. Electricity in California, the Northwest, and the Northeast has a CI significantly below the national average, while electricity in parts of the Midwest and the Rocky Mountains has a CI well above average.

In Figure 4, the life-cycle CI of fuel electricity is estimated for various regions of the United States (based on 2005 electricity generation mixes). The CI of fuel electricity is calculated based on the CI of electricity divided by an energy efficiency ratio (EER) to account for the efficiency difference between electric and gasoline vehicles. The CIs of fuel electricity vary from a low of 24 gCO_2e/MJ in Alaska (ASCC Miscellaneous) to a high of 88 gCO_2e/MJ in Kansas (SPP North). The US average is approximately 61 gCO_2e/MJ. Given that the life-cycle CI of gasoline is estimated to be about 95 gCO_2e/MJ during the period from 2005 to 2030, our findings indicate that substituting electricity for gasoline would reduce GHG emissions per vehicle mile by 9 to 75 percent across US subregions, with the national average being a reduction of 38 percent.

These CI values for electricity, and therefore the GHG emissions of electric vehicles, are expected to decline over time. Based on the Department of Energy's *Annual Energy Outlook 2011* projection, the US average CI values for electricity are expected to decline 10 percent from 2010 to 2030 in the base case scenario. But recent shifts from coal to natural gas by many power plants suggest larger reductions are possible and even likely. If more stringent renewable energy and climate policies are adopted in the coming years or if natural gas prices stay low, electricity CI values could be reduced by 80 percent or more (Yeh 2008).

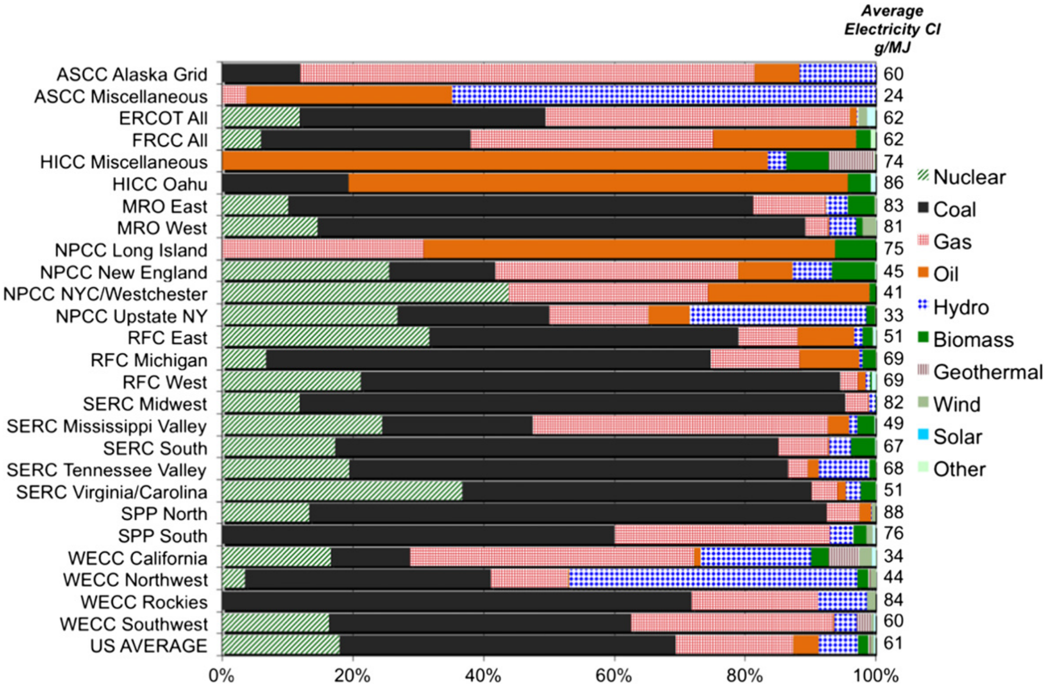

Figure 4. Life-cycle CI (carbon intensity) of fuel electricity by region based on the 2005 electricity generation mix. Note: The regions shown are those defined by the EPA's Emissions and Generation Resource Integrated Database (eGRID). Source: Yang 2012.

3.3 Incentives for Vehicles and Use of Electricity

If an LCFS is to have a significant impact on the use of electricity as fuel, it will need to influence the fleet share of PEVs. Given the high cost of PEVs (including the additional cost of home-based charging equipment), their adoption will be influenced most strongly by reductions in initial purchase price. PEVs are projected to have a higher capital cost than conventional gasoline-powered vehicles even with high-volume manufacturing. With large-scale production, PEVs could cost $3,000 to $15,000 more than a comparable gasoline vehicle, depending on the size of the vehicle battery. Additionally, the purchase and installation of home recharging equipment could add several thousand dollars to the initial investment for a PEV driver. Despite the higher efficiency of electric drive and lower cost of electricity, thus lower fuel costs per mile of travel by a factor of two to four, consumers appear to exhibit very high discount rates (i.e. shorter payback periods) when it comes to weighing the purchase price of a vehicle versus fuel cost savings for more efficient vehicles. More direct incentives will be needed to increase the penetration of electric vehicles and the use of electricity in the transportation sector.

Use of electricity as fuel is incentivized under an LCFS by the credit trading program. The revenues for electricity in an LCFS credit trading market are dependent upon the regulated CI of the fuels and the carbon trading price in $/tonne of CO_2 displaced. In a national market, there would be one fuel that would set the market-clearing credit price for the LCFS trading, which would be determined by the marginal (that is, most expensive from a CI-reduction standpoint) fuel used to satisfy the regulation. Given the expected prices for biofuels and other alternative fuels, electricity will be at the low end of the supply curve (i.e. it will cost less than other alternative fuels) but will be able to command the market-clearing price for its carbon reductions.

Thus for example, at a permit price of \$100/tonne CO_2e (the average credit price estimated from the economic analysis, Section 1, is \$85/tonne CO_2e) and assuming the US average electricity CI value (656 gCO_2e/kWh or 61 gCO_2e/MJ), LCFS revenues earned by suppliers of electricity would be around \$0.035/kWh, which would be a substantial fraction of total costs of purchased electricity or electricity generation costs. At higher permit prices and in regions with clean electricity, LCFS revenues earned by suppliers would match or exceed the cost of electricity used by vehicles.

Figure 5 shows the annual total revenue that an electricity provider could expect to generate from the sale of credits for the electricity provided to one BEV (3600 kWh/yr assuming 12,000 miles/yr at 0.3 kWh/mi) as a function of LCFS credit price and electricity carbon intensity. This figure indicates that for a LCFS credit price of \$100/t, an electricity provider that has an average electricity CI value (e.g., 656 g/kWh or 61 g/MJ) could obtain around \$125 per BEV/yr or \$75 per PHEV40/yr. A permit price of \$200/t and cleaner electricity (300 g/kWh or 28 g/MJ) could obtain around \$500 per BEV/yr or \$300 per PHEV40/yr. The values in the figure would be correspondingly lower by a factor of 60 percent for charging a PHEV40 and 20 percent for charging a PHEV10.

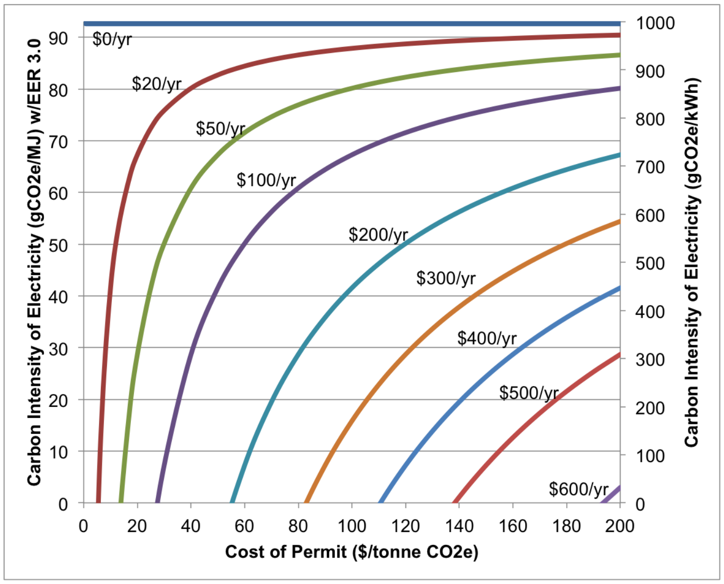

Figure 5. Annual value of LCFS credits for charging one BEV (3600 kWh/yr) as a function of LCFS credit price and electricity carbon intensity. Source: Yang 2012.

4 Accommodating Uncertainty and Variability in Life-Cycle Analysis

Life-cycle analysis (LCA) endeavors to characterize the environmental impacts of a product or service throughout its life cycle, from the extraction of raw materials through manufacturing, use, and disposal. LCA has become an important tool for environmental policy makers, playing a crucial role in the development of California's LCFS, the federal RFS2 program, and the European Union's Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). These policies promote the use of biofuels and other transportation fuels that reduce life-cycle GHG emissions relative to petroleum-based fuels.

During the course of any LCA, modelers must make many decisions regarding what will or will not be included in the analysis, data sources most appropriate to characterize the energy chain, and methods to estimate values for which no data are available. Analysts looking at the same product or service can make different decisions, resulting in different and sometimes disparate LCA measurements. The larger and more complex the energy system being modeled, the greater the number of decisions to be made and the more difficult it is to arrive at one "true" value to quantify environmental impacts.

Differences in GHG emission estimates across studies and models can be characterized as uncertainty. Uncertainty falls into three categories: spatial and temporal variability, data limitations, and scientific uncertainty. Understanding and addressing the magnitude of the uncertainty is essential for robust decision making. Variability and data limitations can be addressed through policy design and improved data collection and reporting. Scientific uncertainty requires more research and is more difficult to accommodate.

While policies and regulations can be designed to reduce variability and data limitations, and scientific research can be accelerated, uncertainty in its broader sense is and will likely remain pervasive throughout LCA or any kind of emission accounting. Recognizing and explicitly estimating uncertainty in LCA is an important step toward making LCA a more useful tool for informing policy decisions. In this report as well as the accompanying PDR, we address methods for reducing variability and scientific uncertainty and examine their effectiveness. Reducing uncertainty can in turn make it easier to accurately estimate achievable emission reductions and encourage the appropriate use of low-carbon fuels.

4.1 Uncertainty and Variability Distributions of Fossil Fuels and Biofuels

In the case of both petroleum-based fuels and biofuels, much uncertainty about life-cycle GHG emissions results from differences in input or production parameters, or between fuels produced in different regions, in different ways, at different times. Standards for reporting LCA methods, results, and data sources are important, but even with universal reporting, significant variability and uncertainty may still remain.

For gasoline, the key sources of uncertainty are combustion emissions, refinery emissions, and the mix of crude oils—factors that are largely knowable or known but not well measured to date. There is considerable regional variability in the CI of gasoline. Figure 6 shows the range of CI values for petroleum-based fuels aggregated in the five US Petroleum Administration for Defense District (PADD) regions. The median values across the different PADDs do not vary significantly, but there are significant differences in the CI values of gasoline produced from different sources of crude oil. Figure 7 shows the range of CI values for petroleum-based fuels from different international regions. Gasoline produced from Canadian oil sands has the highest CI, about 10-15 percent higher than the base scenario on average. Gasoline from African crude oil was found to have a nearly 7 percent higher CI value than the base scenario on average, likely due to extensive flaring of natural gas that is found associated with petroleum. More research is under way by others to estimate crude CI values and significantly reduce data uncertainty, especially regarding upstream extraction and flaring.

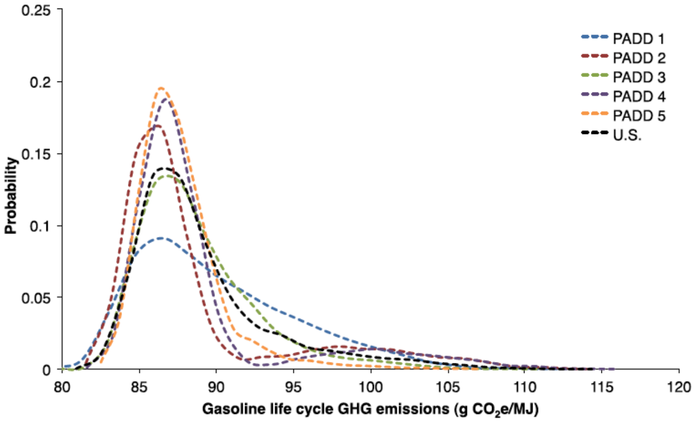

Figure 6. The probability distributions of US average and regional life-cycle GHG emissions of gasoline. PADD: Petroleum Administration for Defense District (PADD 1 = East Coast, PADD 2 = Midwest, PADD 3 = Gulf Coast, PADD 4 = Rocky Mountain, PADD 5 = West Coast). Source: Griffin et al. 2012.

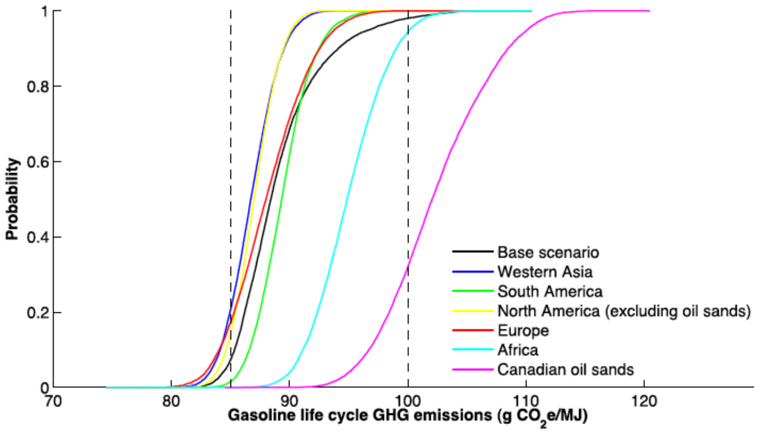

Figure 7. Comparison of probability distributions of life-cycle GHG emissions of gasoline produced from crude oil obtained from different regions (90-percent confidence interval for the U.S. average represented by dashed lines). Source: Griffin et al. 2012.

For biofuels, the greatest uncertainty regarding GHG emissions is related to the indirect and direct land use change (LUC) impacts of fuels made from crops such as corn, and to the N_2O emissions resulting from the application of fertilizer to grow these crops (Mullins, Griffin, and Matthews 2010). While these LUC and N_2O emissions can be large, policy mechanisms can respond by incentivizing a shift to feedstocks that cause less LUC and have smaller fertilizer needs.

There are also uncertainties about the performance of future conversion technologies and the land yields for new types of biofuel feedstocks (such as switchgrass). Differences can be large due to variations across biorefineries and geographic areas. For instance, corn ethanol is less carbon intensive in the Midwest and Pacific Coast regions, where corn yields are consistently high, compared to the southeastern portion of the United States. Based on simulated switchgrass yields, switchgrass ethanol from the Midwest and the Southeast is projected to have the lowest carbon intensity.

These differences are known and well understood, including variations in the amount and type of energy used at biorefineries, biorefinery efficiency, feedstock yield, amount of irrigation and pump energy source, and feedstock composition, but actually capturing the data in a regulatory context can be a challenge.

4.2 Use of an Opt-in Mechanism to Reduce Uncertainty

Uncertainties in measuring life-cycle fuel CI due to spatial and temporal variability, data limitations, and scientific uncertainty can be greatly reduced by using policy mechanisms to improve the accuracy, precision, and reliability of available data. One approach, utilized in California's LCFS policy design, is an opt-in mechanism that encourages fuel producers to self-report actual CI values to replace default CI values in the regulations.

Assigning default values to each energy path can ease the reporting requirements of energy providers. By giving fuel producers the opportunity to opt in with lower CI values for specific activities in the fuel supply chain (or entire chain), this approach provides an incentive for companies to innovate to reduce their GHG emissions. Producers who have environmentally favorable production processes can increase the value of their product by gaining a lower CI rating. This opt-in process is an effective way of reducing uncertainty due to spatial and temporal variability and data limitation.

This method, however, can lead to an "adverse selection" bias. Adverse selection occurs when fuel producers choose default values only when they perform poorly (emissions above the default value) and propose new values when they perform well (emissions lower than the default value). As a result, carbon emission reporting for the entire fuel population will systematically underestimate the actual emissions. The biases created by adverse selection can be potentially large, especially for fuel pathways with large variability or reducible uncertainty.

Adverse selection is more significant for switchgrass ethanol than for corn ethanol because there is more variability and uncertainty in the life-cycle emissions of switchgrass fuel, a less mature technology than corn ethanol production. One way to address adverse selection is to set default CI values high. As shown in Figure 8, if a default CI is set at the 50th percentile (as adopted by California's LCFS), the adverse selection biases will be 6 and 9 gCO_2e/MJ for corn and switchgrass ethanol with iLUC estimates (blue and red solid lines), respectively. The adverse selection bias can be significantly reduced if the default CI values are set at the 75th percentile or higher. For example, the selection biases for both corn and switchgrass ethanol can be reduced to less than 2 gCO_2e/MJ if the default values are set at the 80th percentile or higher. Policy options to effectively reduce the incentives for adverse selection are further discussed in the companion PDR report.

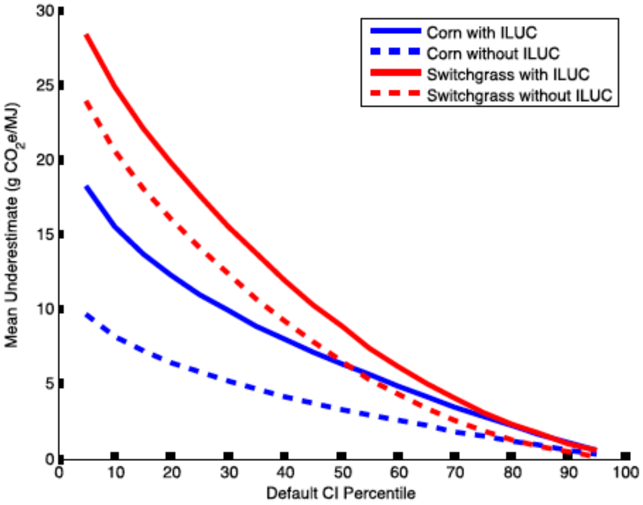

Figure 8. Mean bias introduced by adverse selection for corn and switchgrass ethanol with and without iLUC as a function of the location of the default CI value, expressed as a percentile of the overall uncertainty. Source: Griffin et al. 2012.

5 Global Land Use Change (LUC) Impacts

The use of biomass for energy can have large GHG emission benefits, but the global LUC in response to increased biofuel demand can offset some of those benefits or even contribute to a very large GHG emission "debt" that cannot be paid back within the lifetime of the biofuel program (Gibbs et al. 2008; Fargione et al. 2008). Expanded biofuel production can also cause other undesirable effects, including loss of biodiversity, air and water pollution, higher food prices, harm to indigenous peoples, and other social impacts. To ensure that the benefits of biofuel production outweigh its potential risks, the full effect of those land-based impacts needs to be considered. While biofuels made with first-generation food-crop feedstocks tend to have greater impacts than cellulosic and waste biofuels, because of their low yields and requirement for high-quality land, the risks and growing pressure on land for food and feed will continue with advanced biofuels.

LUC is greater if land-intensive feedstocks, such as corn and other agricultural crops, are used, and lesser if dedicated cellulosic energy crops like miscanthus and switchgrass are grown on degraded or abandoned land and avoid direct competition with agricultural crops. Still, while most of the land allocated to dedicated energy crops is expected or assumed to be marginal in quality, there may be some resource allocation trade-offs with cereals (corn and other food crops) or other annual crops that could have implications for their production and exports from the United States. There will be no LUC effect if waste materials such as crop and forestry residues and municipal solid waste are used.

A large quantity of biofuels is already being produced in the United States, mostly using corn as the feedstock. Much more biofuel production is likely with full implementation of RFS2, and even more with a national LCFS. Because biofuel production requires large amounts of land, adoption of fuel policies such as RFS2 and an LCFS motivate market-induced land use changes (LUC) (EC 2010; Laborde 2011; Tyner et al. 2010).

LUC is the combined effect of direct land conversions to grow biofuel feedstock, and global shifts in land cover and crop patterns in response to price changes. The total LUC effect of biofuel produced from a given feedstock is termed the "iLUC factor," measured in gCO_2e/MJ. But the magnitude of LUC and the effect on GHG emissions is uncertain, as indicated below, partly because it cannot be measured directly and partly because scientists have only begun to quantify these effects in earnest in the past five years.

5.1 Uncertainties in Global Land Use Change as a Result of Biofuel Policies

The magnitude of the biofuel LUC phenomenon and its GHG implications are uncertain. This uncertainty creates a classic policy challenge regarding which policy instruments to use and how to deal with potential risks. Ignoring emissions associated with LUC, or over- or underestimating emissions, leads to real consequences and costs for society.

Multiple modeling systems and other research approaches can be used to set plausible ranges for feedstock LUC effects and conduct sensitivity analysis throughout the ranges on expected outcomes for LUC policies. Policy makers must weigh the risks on both sides of the policy challenge to determine which emission risks are acceptable and which policy instruments are preferred under these conditions of uncertainty. As demonstrated in the previous section, models are also needed to verify the robustness of policy designs, improve the details such as regions of concerns, and identify key uncertainties and future research needs.

5.2 iLUC Factor Considered in Biofuel Policies

Both RFS2 and California's LCFS adopt an iLUC factor as part of the calculation of life-cycle carbon intensity for biofuels. Several modeling exercises have been undertaken by different study teams to estimate feedstock-specific iLUC factors for the policies. Table 2 presents point estimates and ranges from partial sensitivity analyses performed for regulatory agencies. These point estimates rely on single modeling systems and scenarios, except for the estimate for California's LCFS, which is an average of results from several scenarios.

The European Union's two biofuel policies respectively require 10 percent of transportation fuels be renewable energy by 2020 (Renewable Energy Directive, RED) and a reduction of transportation life-cycle GHG intensity by 6 percent by 2020 (Fuel Quality Directive, FQD). The calculation of life-cycle GHG emissions is coordinated between these two policies. The European Union also commissioned several studies analyzing the impacts of EU policies on global LUC, and the iLUC factors associated with each feedstock, as reviewed in Table 2. A decision is currently pending on how the European Union will address emissions from iLUC: several policy options have been proposed by the European Union: (1) defer action and monitor; (2) increase minimum GHG savings threshold requirements for biofuels; (3) add sustainability criteria to particular biofuel categories; and/or (4) apply an estimate of emission impacts (an iLUC factor). The first two options do not directly target biofuel LUC. The second two could limit biofuel LUC, depending on policy details.

Table 2. Feedstock-specific iLUC factors (gCO_2e/MJ) estimated for regulatory agencies, with partial sensitivity analysis results in parentheses.[a] Source: Witcover, Yeh, and Sperling 2012.

Feedstock	US-RFS2	CA-LCFS	EU-RED	
			IFPRI study	JRC report
Ethanol				
Corn	28 (18-42)	30 (18-44)	7 (4-9)	(9-10)
Sugarcane	5 (-4-12)	46 (32-57)	9 (5-18)	(5-14)
Sugarbeet	-	-	5 (1-9)	(2-4)
Wheat	-	-	9 (5-12)	(12-12)
Switchgrass	12 (7-20)[b]	–[c]	–	–
Biodiesel				
Soy	32 (6-63)	62 (40-70)	37 (25-49)	(34-37)
Palm Oil	-	-	36 (31-40)	(24-34)

Rapeseed (Canola) Oil	32 (9-61)	-	36 (19-54)	(34-38)
Sunflower Oil	-	-	35 (21-48)	(37-40)

[a] Parenthesized ranges represent: (1) for US-RFS2, 95% confidence interval from Monte Carlo sensitivity analysis on land cover and emissions factors; (2) for CA-LCFS, high and low scenarios generated by varying economic parameters; for EU-RED, (3) 90% confidence interval from Monte Carlo sensitivity analysis on economic supply parameters in IFPRI study; and (4) range based on minimum and maximum soil carbon in JRC report. All figures are amortized over 30 years; results for EU-RED are adjusted from 20-year amortization (using rounded figures) for comparison. Results for EU-RED are based on a no-trade-liberalization scenario. The studies allocated LUC effects to specific feedstocks: (1) for US-RFS2, by comparing LUC at the policy end date under the full policy *leaving out* the feedstock under analysis vs. under the full policy *including* the feedstock; (2) for CA-LCFS, by implementing projected feedstock volume increases one at a time; and (3) for the EU-RED studies, by increasing the analyzed feedstock marginally *above* levels projected to comply with the policy at its end date. Sources: CARB 2009a, 2010; Laborde 2011; Marelli et al. 2011; U.S. EPA 2010a, 2010b.

[b] Because the global model does not include switchgrass, international LUC is calculated based on projected changes in US agricultural exports from the domestic model.

[c] The analysis did not produce a regulatory figure for switchgrass; a provisional figure assuming no crop displacement was 18 gCO_2e/MJ.

Table above suggests three robust observations: (1) biodiesel feedstocks tend to have higher LUC emissions than ethanol feedstocks; (2) food and feed feedstocks tend to have higher LUC emissions than cellulosic materials; and (3) many feedstocks have large ranges, even within a given analysis (such as corn, soy, and canola in the US-RFS2 analysis, sugarcane and soy in the CA-LCFS analysis) and differences across modeling approaches make it difficult to rank feedstocks in terms of LUC effects and even more difficult to specify a single iLUC value for a feedstock.

These large uncertainties plague biofuel policies in the United States and abroad (including LCFS policies). There is no easy or correct response. Our analysis in the next section shows that an iLUC factor can be an effective mechanism for sending a clear signal to investors about LUC risk. But it is not enough, and complementary policies in both the short and long term are needed to minimize potential unintended consequences regionally and globally caused by biofuel policies. These short-term and long-term policy strategies are discussed in detail in the companion report PDR.

5.3 Effect of Policy Scenarios on Changes in World Crop Areas

Msangi et al. (2012) used the global agricultural multi-market equilibrium model known as IMPACT, developed at the International Food Policy Research Institute, to evaluate and compare the levels of global land use change that can be expected to occur under RFS2, a national LCFS, and other supplemental policies. The simulated LUC impacts associated with alternative policy combinations are generated by linking IMPACT with BEPAM, which projects changes in agricultural and energy market conditions that arise from the different set of incentives offered to biofuel producers and blenders as they try to meet RFS2 or LCFS targets. The changes in net exports of key agricultural commodities from the United States generated due to changes in the production of food and feed crops, such as corn and soybeans and fast-growing (cellulosic) grasses and trees, are imposed by BEPAM as an exogenous shock on IMPACT. The model then simulates the trade-driven effects that US biofuel expansion has on agricultural land use expansion in other regions of the world.

A large number of policy scenarios were tested for 2007–2030, including RFS2, RFS2+LCFS10, RFS2+LCFS15, RFS2+LCFS+CO_2 price, inclusion of iLUC factors, and doubled iLUC factors. (All RFS2 scenarios use AEO adjusted targets, whereby the 2022 targets are not reached until 2030.)

The impacts of US domestic biofuels policy scenarios can be seen as change in trade volumes and change in land use in other parts of the world as a result of trade volume change. The combination of these two effects can be measured to give the total change in cumulative agricultural crop area globally excluding United States, which leads to the indirect land use effects that we can measure from the BEPAM-driven US domestic biofuels policy scenarios (RFS2, RFS2+LCFS, and RFS2+LCFS+CO_2 price). Note that unlike most iLUC studies that examine one-at-a-time commodity shocks, the policy scenarios examined here take into account the cross-commodity effects (that is, the *combined* effect of changing feedstock mix given a policy) that are inherent in policy-driven shocks domestically and internationally. The intention of our study is not to generate feedstock-specific iLUC factors; rather, our study adopts the iLUC factors estimated in the EPA analysis of RFS2 (U.S. EPA 2010a) as given, and simulates the policy impacts of adopting an iLUC factor on cumulative globally agricultural crop area change given US domestic biofuels policy scenarios (RFS2, RFS2+LCFS, and RFS2+LCFS+CO_2 price).

Figure 9 shows the combined effect of policy scenarios on the cumulative change in agricultural crop area simulated by IMPACT, for various regions of the world. The RFS2-AEO scenario (shown as RFS_A) results in the greatest change in total non-US agricultural area from the baseline case, as would be expected given the RFS2 emphasis on food-based agricultural crop feedstocks. The biggest agricultural land use impacts outside of the United States given trade shocks from US biofuel policies are seen for developing regions like sub-Saharan Africa and Latin America, which have tended to have higher historical levels of agricultural expansion compared to other regions. Even though there are some offsetting agricultural land use decreases in Asia, Europe, and other high-income regions, the overall global effect is an increase in agricultural harvested (and physical) area. The total non-US agricultural area changes driven by RFS2 are estimated to be 2.75 million hectares between 2007 and 2030.

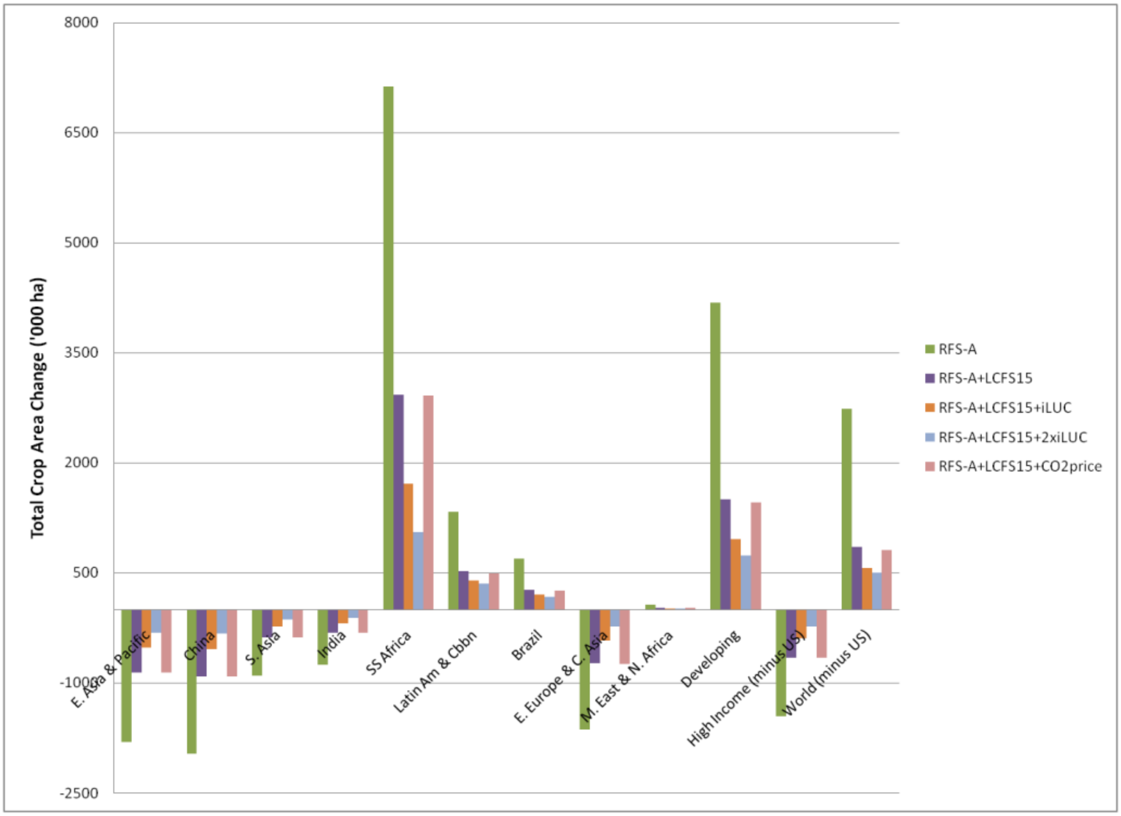

Figure 9. Change in total global non-US crop area from business-as-usual case, 2007–2030, under alternative US biofuel policy scenarios. Source: Msangi et al. 2012.

All other alternative scenarios result in lesser changes in total cumulative crop area relative to the baseline case and show variation across alternative levels of stringency of the LCFS policy and imposition of other policy measures. The total agricultural area change for sub-Saharan Africa and Latin America and Brazil decreases as the LCFS policy is combined with the RFS and as more conservative (higher) iLUC values are imposed with the LCFS policy.

Doubling the iLUC factor from the average value taken across various studies results in greater reductions of agricultural area expansion in Africa, and slightly higher expansion in Asia and Europe, resulting in an overall global decrease in cumulative agricultural area expansion. There is not much of a difference, however, between applying the average iLUC factor and applying the doubled value (2xiLUC) to represent the risk of iLUC uncertainty.

This is the first study ever conducted that shows the effectiveness of adopting an iLUC factor in policy design and implementation. Our analysis shows that, while not addressing all the dimensions of incentives that drive international LUC and land cover conversion and not capturing the underlying uncertainty, the iLUC factor nevertheless serves as an effective policy tool. It has the effect of shifting the mix of biofuels away from first-generation biofuels toward cellulosic and waste biofuels, which cause less domestic and international land use conversion

(Msangi et al. 2012).

Our analysis shows, however, that there are diminishing returns in attempting to reduce iLUC by assigning higher iLUC factors. In other words, once the policy sets the right direction in incentivizing feedstocks that use less land, adopting higher iLUC factors does not necessity lead to more reductions in global land use conversion (though some of the regional impacts can be significant, as shown for sub-Saharan Africa). More similar analyses will be critically needed in the future to test the robustness of policies and the impacts of policy design globally and on regions of concern. These modeling tools can be used to derive new insights and adjust details of policy designs accordingly.

6 Impacts on Energy Security

One of the key co-benefits of an LCFS policy, and the main objective of the RFS2 program, is to improve energy security by substituting domestic energy supplies to reduce oil imports and exposure to economic loss from oil shocks. The EPA's Regulatory Impact Analysis for the Energy Independence and Security Act of 2007 that established RFS2 projected that avoided expenditures on imported crude oil and petroleum products resulting from the RFS2-required biofuels would be roughly $41.5 billion in 2022—a 9.5-percent reduction that would save $41.5 billion that year. Taking into consideration imports of Brazilian ethanol, the total avoided expenditures on imported transportation fuels were projected to be $37.2 billion in the RFS2 control case (U.S. EPA 2010a). The energy security benefits of an LCFS would be even greater.

6.1 The Energy Security Premium of Oil Consumption

The actual cost of energy security derives from a set of economic conditions related to fuel demand, imports, proportion of global fuel supply that is stable and competitive, risk and sensitivity to oil supply and price shocks, size and utilization of the Strategic Petroleum Reserve, and short- and long-term supply and demand flexibility. Our analysis encompasses the interplay among these key factors, with special focus on oil import costs and the economy's vulnerability to episodic shocks.

We define energy security in economic terms, as the protection of the US economy against the risk of significant short- and long-term increases in energy costs and their attendant macroeconomic consequences. These concerns stem from sustained high oil import costs; the noncompetitive (cartelized and government-controlled) supply of oil; the importance of oil to the economy; and the economy's vulnerability to episodic shocks. We utilize and extend a quantitative characterization of energy security impacts derived from Leiby (2008). We apply it to the fuel use changes resulting from LCFS compliance estimated with the TRACT model described in Section 2. Within this formal energy security framework we are able to generate quantitative estimates of LCFS security impacts, accounting for fuel substitutions and potential security gains from biofuels. This includes the effects of changed crude sourcing, import levels, and the global mix of liquid fuel supply on oil price levels and the expected costs of shocks to the US economy (Leiby and Rubin 2012).

Energy security will be improved to the extent that a national LCFS decreases petroleum consumption by substituting lower-carbon alternative fuels such as biofuels, electricity, natural gas, and hydrogen. The energy security premium for oil consumption *regardless of the source of oil supply* is shown in Figure 10. There is substantial uncertainty about the level of this premium, given uncertainty about oil market conditions, market supply and demand elasticities, macroeconomic sensitivity to energy shocks, and OPEC behavior. As shown in Figure 10, the premium changes over time, reflecting changing base case market conditions such as US import levels, world price levels, and the oil intensity of the US economy. The cost premium is projected to range from $7 to $22 per barrel of oil in 2035.

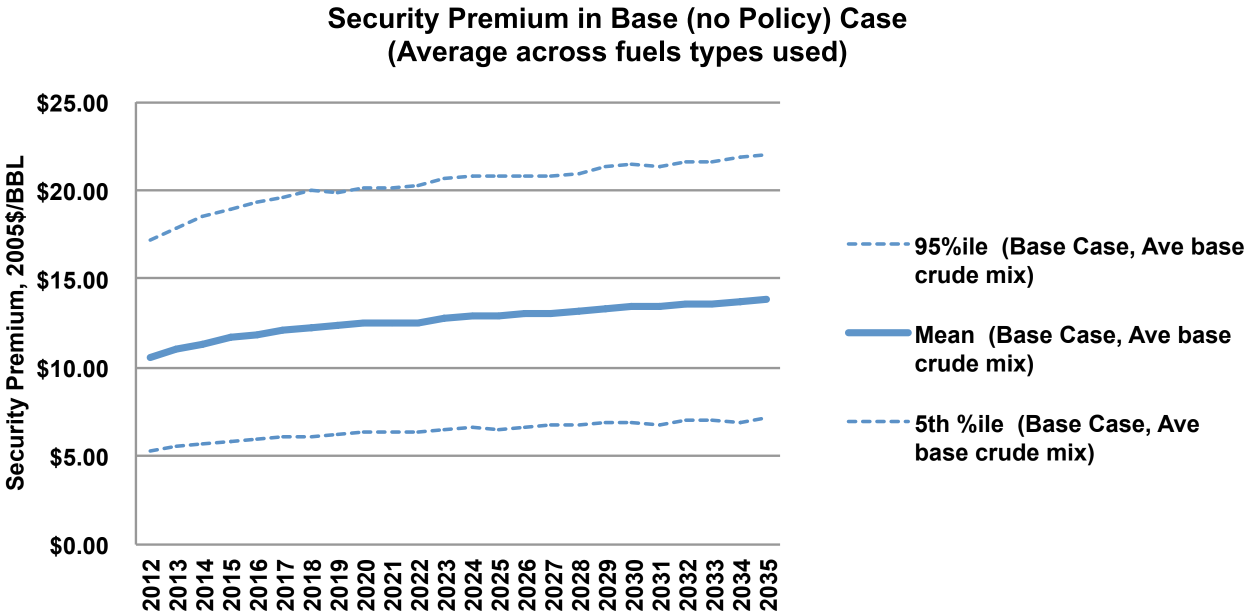

Figure 10. Estimated energy security premium of average oil consumption. Source: Leiby and Rubin 2012.

6.2 Energy Security Impacts of an LCFS Policy

The average premium shown above is only of interest if an LCFS reduces oil use proportionally, regardless of the type of fuels. However, an LCFS policy is designed to substitute lower CI fuels for higher CI fuels. The primary concern raised about an LCFS on energy security grounds is that it discourages fuel supply from some sources that are secure but higher in life-cycle carbon content. This concern is particularly acute when considering crude oil originating from Canadian oil sands (COS) since they are a substantial source of imported oil. The concern is also potentially valid for other high-carbon feedstocks from domestic shale or coal.

Some argue that by restricting the carbon content of fuels, an LCFS would adversely affect energy security by preventing the use of high-carbon unconventional oils (Canes and Murphy 2009; CNAES 2009; Kueter 2009). Petroleum fuels produced from COS represent a resource base that is very large, stable, and in close proximity to US markets. However, oil sands also have the highest well-to-wheel (WTW) GHG emissions among all crudes from different world regions, about 10-15 percent higher than the US average crude.

Four responses to a national LCFS by producers of high-carbon crude are possible: (1) imports could continue with their CI reduced to levels comparable with other crudes (which Shell Oil has said is its goal for its oil sands production); (2) imports could continue with the purchase of LCFS credit offsets; (3) high-carbon crudes could be shuffled out of the United States to other markets; or (4) high-carbon crude production could decline. It should be noted that energy security is little affected by the first three options, and only the fourth option would reduce energy security—but this possibility is unlikely since production of high-carbon crude is generally profitable if the global oil price is above the range of $30 to $70 per barrel, and the profitability of oil sands production generally far exceeds the costs of the other three responses.

The first three options do not have energy security impacts. The worst-case outcome for energy security would occur if both imports of oil from Canadian oil sands to the United States and production of oil from Canadian oil sands decline together, with the imports replaced by greater US imports of crude oil from other sources. Indeed, our study shows that the worst-case outcome for energy security would occur if both imports of oil from COS to the United States and production of oil from COS decline, with the imports replaced by greater US imports of crude oil from other sources. This scenario would result in a security cost of about $17 per barrel for each barrel of COS eliminated (in 2035), reducing the benefits just reported.

Overall, we estimate the mean security benefits of an LCFS policy to range in 2035 from $5 per barrel if domestic alternative fuels substitute for oil from Canadian oil sands; $12 per barrel if all sources in the base US mix of petroleum are decreased proportionally; and $22 per barrel if imported crude oil demand is decreased (see Figure 11).

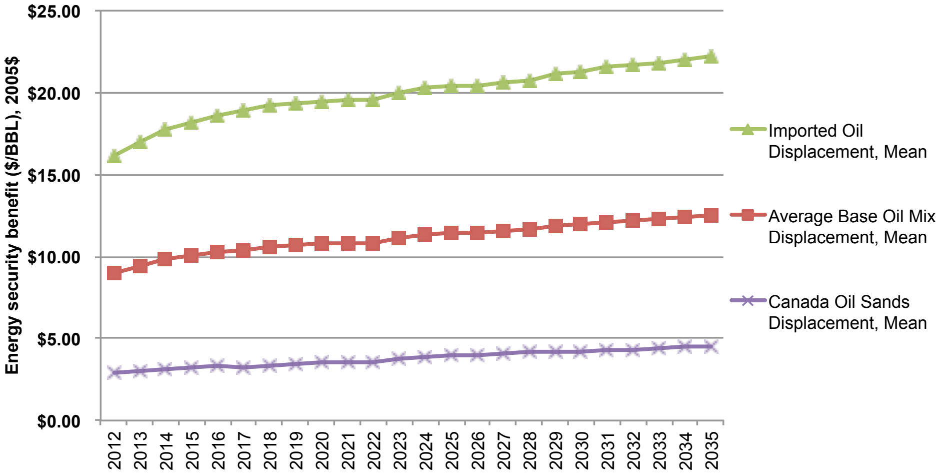

Figure 11. Time paths for energy security premiums, various cases. Source: Leiby and Rubin 2012.

A principal conclusion of this study is that by displacing petroleum fuels with more stably supplied fuels, mostly domestic biofuels, an LCFS can improve energy security. Although this outcome is dependent on specific assumptions about the availability and costs of biofuels, such a displacement of petroleum is estimated in most LCFS scenarios examined.

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