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National Low Carbon Fuel Standard

POLICY DESIGN RECOMMENDATIONS

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 easy to implement, cost effective, and provide maximum economic gains to the consumers and the society. 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 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; 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):
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- 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 proposed policy design, we would like to acknowledge the following individuals/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

The abundance and low cost of petroleum over the past 150 years has enabled rapid economic growth and extraordinary mobility advancements. But dependence on petroleum fuels also has large downsides, including dependence on insecure supplies, volatile prices causing high economic costs, polluted and unhealthy air, climate change, and increasing threats to local environments as production moves into more fragile areas.

The transition to low-carbon alternative transportation fuels is becoming more urgent. But their introduction is inhibited by a long list of market conditions and failures. These include sunk investments and technology lock-in by the automotive and energy industries, other forms of technological and market inertia impeding investments in deployment and R&D, cartel pricing, and the failure of markets to assign a price to greenhouse gas (GHG) emissions. Various policies might be adopted to overcome these market conditions and barriers, ranging from pure market instruments such as carbon taxes to prescriptive mandates and voluntary actions. Each has different advantages and disadvantages. Some are easier to implement administratively, some are more economically efficient, and some are more effective in accelerating investments. None is perfect.

One of the most compelling, assuming some level of urgency, is a broad, performance-based policy that targets greenhouse gas reduction—what we refer to as a low carbon fuel standard (LCFS). In this report, we integrate scientific knowledge of alternative fuels—including an assessment of economic, administrative, institutional, equity, political, and technological considerations—to aid us in proposing a policy design for an LCFS for the United States. We have aimed for a policy design that would be effective, economically efficient, and broadly acceptable.

An LCFS is a policy designed to accelerate the transition to low-carbon alternative transportation fuels by stimulating innovation and investment in new fuels and technologies. The goal is to provide a durable policy framework that will stimulate innovation and technological development. Since 2007, variations of an LCFS policy have been adopted by California,[1] the European Union (Fuel Quality Directive, FQD),[2] and British Columbia (Renewable and Low-Carbon Fuel Requirement Regulation, RLCFRR).[3] Other states in the United States have been exploring the adoption of an LCFS policy, including states in the Midwest[4] and the Northeast/Mid-Atlantic region,[5] and the states of Oregon[6] and Washington.[7]

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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
[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 design of an LCFS is premised on the use of technology-neutral performance targets and credit trading, with the intent of harnessing market forces and providing industry with flexibility. It is also premised on the use of life-cycle measurements of GHG emissions, to assure that emissions are regulated effectively and scientifically. An LCFS is a hybrid of a regulatory and market policy instrument. It does not include mandates for any particular fuel or technology and as such does not attempt to pick winners or losers. Instead, it defines an average emissions intensity standard—measured in grams CO_2 equivalent per mega-joule of fuel energy (gCO_2e/MJ)—that all energy providers must achieve across all fuels they provide. Many options exist for meeting the standard. Regulated parties are free to employ any combination of strategies that suits their particular circumstances and perspectives—including the purchase of credits from other companies.

The breadth and reach of an LCFS, and the challenge of implementing an innovative policy, means that adoption of a national LCFS will not be easy or straightforward and will require careful analysis and design. It is necessary to address the cost-effectiveness of the policy (compared with other similar GHG policies) and to analyze ease of administration, fairness, equity, market flexibility, and impacts on energy security and sustainability. We have done so in a companion report, *National Low Carbon Fuel Standard: Technical Analysis Report* (TAR). This Policy Design Recommendations (PDR) report builds on insights and findings from the TAR. Below we recommend key policy design principles that chart a path toward developing a national LCFS policy.

Summary Recommendations

Recommendation 1. Adopt complementary policies to maximize the benefits of an LCFS.

An LCFS is designed to reduce GHG emissions and accelerate the introduction of nonpetroleum transportation fuels. A wide variety of market conditions and market failures inhibit the commercialization of nonpetroleum transportation fuels. These include the failure of markets to assign a price to GHG emissions and other pollutants; sunk investments and technology lock-in by the automotive and energy industries that make alternatives look disruptive and discourage investments in new energy systems; network externalities where consumer decisions to purchase electric and fuel cell vehicles are made separately from energy infrastructure decisions; the market power of OPEC; high entry barriers in the automotive and fuels industries; R&D underinvestment due to industry diffusion (especially in agriculture), R&D spillovers where R&D findings cannot be fully captured, and learning-by-doing spillovers where societal savings are not fully captured; conservative consumer behavior in buying new types of vehicles even when they are economically superior; and volatile oil prices that create uncertainty that leads to underinvestment in alternatives.

No single policy, including a carbon tax or an LCFS policy, can overcome all these market conditions and failures. Additional, complementary policies are needed. Complementary policies can be independently developed and targeted to address key underlying issues that are difficult to address with broad policy solutions such as a carbon tax or an LCFS. Complementary policies to an LCFS might include regulations that accelerate investments in new vehicle and fuel types, basic energy and vehicle R&D, incentives for vehicles that use low-carbon fuels, policies to decarbonize electricity generation, and sustainability requirements for fuel/feedstock production. Many of these are already in place, adopted by local, state, or national governments—but many are not. The success of an LCFS (or other policies to accelerate the use of low-carbon fuels) would be aided by the adoption of complementary policies. More work is needed to carefully evaluate complementary policies that could effectively maximize the full policy benefits of an LCFS—and to identify existing policies that overlap or are not well aligned.

Recommendation 2. Modify RFS2 to incorporate elements of an LCFS, or replace it with an LCFS.

The most conspicuous example of an overlapping policy is the national Renewable Fuel Standard, most recently updated in 2007 (RFS2). RFS2 requires specified volumes of several types of biofuels, defined in terms of (life-cycle) carbon intensity thresholds. In contrast, an LCFS would apply to all transport fuels, not just biofuels, and would base the requirements on their life-cycle carbon intensity. This broader approach using a continuum of carbon intensities would provide a stronger incentive for innovation for a broader range of fuels (including electricity, natural gas, and hydrogen).

Our supporting studies conclude that implementing an LCFS alone or with RFS2 would be superior to RFS2 alone in reducing GHG emissions, improving market incentives and flexibility, and lowering domestic and international land use impacts. The impacts on energy security relative to RSF2 would likely be beneficial. If an LCFS is to be adopted, two options are possible: modify RFS2 to incorporate elements of an LCFS, or replace it with an LCFS. RFS2 and an LCFS could be complementary policies mutually reinforcing low-carbon fuel development, or an LCFS could replace RFS2, acting as a new policy framework to drive low-carbon and renewable fuel development.

Recommendation 3. Initially include within the scope of the LCFS all fuels used in on-road vehicles.

In principle, it is desirable to include more types and uses of transport fuels in a national LCFS. Including more fuels would result in greater GHG reductions and would enable more flexibility in identifying low-cost mitigation options and increasing opportunities for regulated parties to buy LCFS credits from a greater pool of options, thereby achieving LCFS targets in the most cost-effective manner. Fuels used in on-road vehicles—cars, trucks, and buses—account for 80.3

percent of total transportation fuel use in the United States; we recommend including them in an LCFS as their uses are easy to track and monitor. Electricity, hydrogen, and natural gas currently account for less than 1 percent of total transportation fuel use in the United States, but will be expanding as vehicle standards, the LCFS and other policies are implemented. These fuels should be included in an LCFS, but because they tend to have lower life-cycle GHG emissions than petroleum fuels, they would be used to generate credits for sale to petroleum fuel suppliers (depending on verification that their carbon intensity is lower than that of gasoline and diesel).

Approximately 14.7 percent of transport fuels is used for ships and aviation. Including maritime and aviation emissions within an LCFS would be challenging because ships and planes operate across national boundaries. Ideally, they should be included so as to minimize emissions leakage—whereby planes and ships evade LCFS regulations in the United States by purchasing as much fuel as possible elsewhere. As other nations adopt LCFS rules—as EU nations have already done—leakage will disappear, but the spread of carbon rules to ships and planes traveling beyond US borders will likely be slow because they are regulated by international agencies, which tend to act slowly. It may take a decade or more to establish a global policy framework to regulate shipping and aviation GHG emissions. Nonetheless, just as the EU acted unilaterally in capping aviation GHG emissions, regional and national policy initiatives could be considered in the absence of international action.

Conventional transportation fuels used for off-road vehicles and outside the transportation sector (for example, diesel fuel used for home heating) could be included in a national LCFS, but implementation could be complex. We suggest not including these initially.

Recommendation 4. Set a target of reducing the carbon intensity of gasoline and diesel by 10 to 15 percent by 2030.

We recommend a target of reducing carbon intensity (CI) by 10 to 15 percent by 2030 based on research findings of our national LCFS team. Carbon intensity is defined as life-cycle GHG emissions (converted to carbon equivalence and expressed as gCO_2e/MJ); the 10 to 15 percent reduction is with respect to gasoline and diesel, the baseline fuels. The selection of a carbon intensity reduction target calls for balancing a number of factors: the urgency of reducing GHG emissions, expected costs of future energy supplies, expected economic impacts, variation in costs and impacts across companies and regions, and the expected rate of induced innovation in supplying low-CI fuels. Because there will be a lag between the time when an LCFS policy is adopted and when investments and innovations occur, it is generally advisable to backload the compliance schedule by starting with small annual CI reduction targets and steadily increasing the size of the annual reduction percentages over time.

Recommendation 5. Regulate the parties responsible for producing, importing, or supplying fuel.

Regulated parties should generally be those parties responsible for producing or importing fuel for consumption in the US transportation sector. For petroleum fuels used in transportation (gasoline, diesel, jet fuel, bunker fuel), the regulated party should be oil refiners or importers, along with blenders when biofuels are mixed with petroleum fuels.

For transportation fuels that are also used outside the transportation sector, the initial regulated party should be the party responsible for supplying the fuel for transportation-sector applications. These could be firms supplying fuel to vehicle fueling equipment, or firms owning the vehicle fueling equipment, but not both.

Recommendation 6. Use energy efficiency ratios to adjust the carbon intensity ratings of fuels for diverse propulsion technologies.

For an LCFS to account accurately for the full life-cycle impact of different fuels, the carbon intensity (CI) ratings of fuels have to be adjusted by the differences in energy conversion efficiency of vehicle engines. This adjustment is essential to correctly reflect the actual emission reductions (in gCO_2e per mile traveled) when replacing conventional fossil fuel with alternative fuels that run on engines with much greater conversion efficiency, such as electric motors compared to internal combustion engines. Adjustments are also required for fuel cell vehicles, which are also more efficient than gasoline-powered vehicles.

These adjustment factors—energy efficiency ratios (EERs)—are best calculated by comparing the *fleet-average* efficiencies of the alternative power train with the corresponding *fleet-average* efficiencies of baseline fuel-vehicle technologies that the alternative fuel-vehicle technology will displace. The values should be updated on a regular basis to ensure they adequately reflect the evolving efficiency of vehicles on the road.

Recommendation 7. Create separate fuel pools for gasoline and diesel.

We recommend that at least two separate fuel pools be established—for gasoline and diesel—with the potential to establish additional fuel pools for jet and maritime fuels. A single fuel pool could create incorrect incentives to increase diesel fuel sales because diesel would earn a more favorable CI rating as a result of its higher EER compared to gasoline though actual displacement may not have occurred. Without separate fuel pools, a refiner would have the incentive to reduce the price of diesel fuel for sale to trucks or even foreign markets—with no long-term GHG benefits.

To implement a fuel-pooling approach, CI reduction targets and EER values will need to be established for each pool. Based on our research findings, we recommend unlimited LCFS credit trading between pools in order to provide flexibility, lower compliance costs, and acknowledge uncertainties in feedstock availability and technological progress.

Recommendation 8. Regulate fuels according to their life-cycle GHG emissions.

An LCFS is premised on measuring all GHG emissions of a fuel from the source (oil well, coal mine, farm field, and so forth) to the final point of consumption. This life-cycle approach is key to comparing the emissions of different fuels. Calculation of life-cycle GHG emissions will require modelers, and ultimately policy makers, to make decisions regarding modeling approaches, system boundaries, and data sources. When multiple jurisdictions are involved, such as nations, it will be important to harmonize the methodology used among different regulatory agencies, creating a consistent approach for defining and measuring carbon intensity in fuels. We recommend the following.

System boundaries. A national LCFS policy should adopt a standardized life-cycle assessment (LCA) method for measuring fuel CI that reflects best practices and is transparent and consistent across fuel types. Indirect emissions resulting from market-mediated effects should be evaluated for potential inclusion when they (1) substantially impact fuel life-cycle carbon intensity (CI) and (2) are closely linked to particular fuel supply chains (see Recommendation 9 for land use emissions, which are the most significant indirect effect).

Spatial boundaries. Data inputs for LCA measures should be disaggregated enough spatially to capture regional variability in supply chain emissions in ways that will incentivize greater use of low-carbon feedstock/technology. As a convenient way of operationalizing boundary definitions, we recommend using state boundaries for setting default CI values for biofuels, and load-balancing area or higher levels of aggregation for electricity CI values.

Uncertainty and variability. LCA calculations, conducted for each step of the energy supply chain, can be difficult to specify accurately. 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. 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 also be addressed through creative policy mechanisms (as indicated below for land use change effects).

We recommend that the sources of uncertainty and variability be systematically identified and carefully evaluated to determine default values (see next item) and to help design a more robust GHG reduction target given uncertainties. We recommend that variability or uncertainty due to data limitation be targeted with an opt-in reporting mechanism in the policy design to improve data availability, reduce uncertainty, and incentivize innovation. We also recommend addressing scientific uncertainty through adaptive management and targeted research.

Default values and opt-in mechanisms. Default CI values should be assigned to each energy path to ease the reporting requirements of energy providers. If energy providers (the regulated companies) can supply their fuel with lower emissions than the default values, they should be allowed to opt in with their superior value. They would do so by documenting their lower emissions. Allowing companies to opt in encourages innovation by rewarding producers for reducing emissions.

Recommendation 9. Address GHG emissions from land use change (LUC) through short-term and long-term policies.

Most of a fuel's life-cycle GHG emissions are directly measurable and within the energy supply chain. But additional emissions can be caused when large amounts of land are diverted from agriculture and other uses into energy production—which is the case with many biofuels and some fossil fuels. The impacts of these land use changes (LUC) are complex and difficult to quantify accurately—but accounting for them is important to assure that investments are directed at those feedstocks with less impact. The effects can be large for land-intensive crops such as corn but are much smaller for grass and tree feedstocks (if they are grown on marginal, degraded land and/or if they avoid direct competition with food crops) and zero for biofuels made from waste materials (crop and forestry residues and municipal solid waste). Oil sands production induces small LUCs associated with soil and forest carbon emissions from peatland conversion. We recommend adopting a flexible policy taxonomy that includes short-term and long-term policies.

Short-term policies would induce or otherwise encourage immediate action to reduce use of productive land for energy and other adverse impacts. They would encourage (1) using feedstock that does not require additional land, such as wastes and agriculture residues, or feedstock that requires less land, such as cellulosic feedstocks and algae; and (2) adopting measures that lower LUC risk from land-using feedstock by (a) enhancing carbon sequestration and storage, (b) encouraging the use of marginal, degraded, and abandoned land, and (c) prohibiting the conversion of high-carbon, high-biodiversity, and environmentally sensitive areas. Despite relatively large scientific uncertainty about LUC impacts, there are scientifically based and increasingly well-developed estimates that should be used to ensure that only those fuels that provide benefits are properly incentivized.

Long-term policy measures would combine short-term mitigation strategies with other incentive mechanisms that offer the greatest potential for mitigating LUC over the long term. These measures would encourage collaboration within and outside the biofuel supply chain to increase investments in land use productivity, environmental protection, and carbon offset schemes. The goal is to enhance economic productivity without compromising environmental or ecosystem services. The regulatory process should establish rigorous and systematic evaluation frameworks, coupled with intensified research, to assess options and implementation.

Recommendation 10. Treat all crude oils as part of the overall pool of transportation fuels.

Petroleum is not a uniform or homogenous liquid; it is a diverse mix of liquids comprised of chains of hydrogen and carbon molecules. Initially California and the European Union (EU) created a separate category of high-carbon-intensity crude oils within their LCFS and FQD. This approach does not consider the reality that the CI of crude oils varies considerably, with some conventional crudes, for instance, having higher CI values than some oil sands. It also runs the risk of legal challenge from Canada, since targeting oil sands can be construed as discriminating against a product of that country.

Instead of targeting specific high-carbon crudes, we recommend treating all crudes as part of the overall pool of transportation fuels. We recommend adopting an approach that creates an incentive to buy lower-CI crudes, invest in upstream improvements (such as carbon capture and sequestration), and modify refinery designs to favor low-CI crudes. Each refinery (that is, regulated party) would be assigned a benchmark value based on its CI in the baseline year. If it exceeded this value, it would need to offset that increase by reducing GHG emissions in other ways (or buying credits). If it reduced its crude oil CI, it could apply those reductions as credits against its LCFS obligation. Some small additional shuffling of crude supply would occur—whereby companies would send their lower-CI oil to US refineries and their higher-CI oil elsewhere—but shuffling is a normal business practice for refineries in their effort to minimize their costs. It is uncertain how much additional shuffling would occur. In any case, this shuffling would diminish when other countries, starting with the EU, adopted a similar refinery-specific approach. If the shuffling appeared to be significant, the extra transport energy consumed by crude shuffling could perhaps be calculated and included (penalized) in the life-cycle measurements for that crude.

Recommendation 11. Harness market forces using LCFS credits.

As a general principle, it is desirable to harness market forces to achieve societal goals. An LCFS does so by allowing companies to buy and sell credits. If a company prefers not to invest directly in reducing GHG emissions to achieve its carbon-intensity target, it can buy credits from other companies that can reduce emissions at less cost. The net effect is attainment of targets at less overall cost.

Trading and banking. The efficiency and effectiveness of an LCFS credit market depends on the design of the credit system, particularly the opportunities for trading and banking. Given the uncertainties in feedstock costs and availability, their CI values, and the commercial success of various biofuel refining technologies and fuel types (including "drop-in" bio-based gasoline and diesel fuel), we recommend allowing unlimited trading of LCFS credits across the gasoline and diesel fuel pools (and any others that might be created, such as jet fuels). Doing so can significantly reduce compliance costs. For the same reason, banking of credits lowers the costs of meeting the LCFS and stabilizes credit prices across compliance time periods.

Compliance and cost containment. The design of an LCFS needs to address concerns about large price swings that might result from unanticipated surges or crashes in economic growth, weather and crop prices, and low-carbon fuel availability. While banking mechanisms reduce price volatility, in extreme situations the number of banked credits available might not be sufficient to avoid a credit price spike. To avoid the possibility of low-probability but high-impact price spikes, we recommend the adoption of cost-containment mechanisms to protect regulated companies and consumers.

Carbon credits from other programs/jurisdictions. Transportation energy is produced utilizing many resources and technologies in many places across many political jurisdictions. GHG emissions in some places and from some activities are, or will soon be, regulated by other (non-LCFS) GHG programs (such as carbon caps on utilities and refiners or carbon taxes). These energy activities are already incentivized to reduce emissions through other market instruments. In these cases, when energy producers in other political jurisdictions are subject to other carbon fees or taxes, including electricity producers subject to cap-and-trade fees, we recommend that actual emission reductions along the supply chains being regulated by an LCFS be taken into account through regular updates of default CI values, reflecting changes of emission intensity aggregated over the industry, technology, or process over time.

Issues will arise, however, when obligated emission reductions in the other programs do not actually occur but are met via credits, penalties, or fees, especially when there is a large disparity between the actual or implicit carbon reduction costs or credit prices between the two programs. We recommend recognizing these traded emission credits as actual emission reductions but applying an adjustment factor to account for the price difference between programs, based on published prices of credits traded in the same compliance period. For example, if a refiner pays \$15 per tonne CO_2e of upstream emissions toward Alberta's Specified Gas Emitters Regulation (SGER) and LCFS credits are traded at \$60 per tonne CO_2e in the same compliance period, a quarter of a carbon credit (\$15/\$60) can be counted as emission reductions. This is the same approach we recommend for harmonizing a national LCFS with other LCFS jurisdictions (such as British Columbia's RLCFRR and the EU FQD), as discussed in Section 13.

Recommendation 12. Implement performance-based sustainability standards.

Aside from GHGs, there are other important nonmarket impacts associated with energy production. This group of sustainability concerns includes environmental sustainability (conservation of air, water, soil, biodiversity, and land use) and social sustainability (human and labor rights, local food security, rural development). The challenge is to determine the extent to which an LCFS should include or be linked with rules to limit adverse impacts in these other areas. Given the huge scale of energy production activities and their potentially large impacts, and because an LCFS would play an instrumental role in stimulating large energy investments, we believe that some sustainability safeguard mechanisms are needed. We recommend formulating (1) minimum sustainability requirements, including conservation (not allowing conversions of high-biodiversity and high-carbon-stock areas); and (2) reporting requirements for specified impacts or voluntary certification.

A sustainability standard that includes key environmental and social impacts should be performance based—it should not prescribe specific technology or practices but instead should focus on measurable outcomes with clear expectations regarding performance, measurement, verification, and enforcement. Effort should be made to identify incentive mechanisms that motivate innovation beyond minimum compliance thresholds established by existing laws and regulations.

Recommendation 13. Harmonize global LCFS policies.

LCFS policies adopted in other countries and regions can vary significantly in policy design, stringency levels, system boundaries, coverage of fuel types, and various other details. The goal of harmonization is to create a consistent and acceptable approach for reducing the carbon intensity of fuels to maximize the effectiveness and efficiency of the policies, while providing individual countries and regions the freedom and flexibility to tailor the policies to their local circumstances.

Harmonization can be achieved by adopting a globally consistent certification system, starting at the feedstock level. Certificate harmonization allows for robust policy frameworks and thus more room for policy and political differences, while still remaining effective. Achieving a harmonized certification system will require an improved chain-of-custody tracking system in order to provide transparent and reliable information about biofuel production across regions.

LCFS policies can be further harmonized between states and regions through credit harmonization, which requires adopting unified methods (where possible) and using credit multipliers to adjust non-unified aspects. These two methods allow credits or certificates to be valued equivalently across regions and traded efficiently to comply with regional low carbon fuel policies, even when they vary in stringency, system boundary, and fuel carbon ratings. Allowing credits to be traded across countries or regions will increase policy effectiveness and efficiency and lower the overall compliance costs. Fuel shuffling will also be reduced, hence strengthening LCFS policy.

Conclusions

This report highlights thirteen key issues that must be addressed in the design of an LCFS for the United States. The remainder of the report elaborates on these thirteen design issues, providing more analysis and detail.

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Introduction

A low carbon fuel standard (LCFS) is a technology-forcing policy designed specifically to target reduction of greenhouse gas (GHG) emissions in the transportation sector. Since 2007, variations of an LCFS policy have been adopted by California,[8] the European Union (Fuel Quality Directive, FQD),[9] and British Columbia (Renewable and Low-Carbon Fuel Requirement Regulation, RLCFRR).[10] Significant progress has also been made through state and regional LCFS initiatives in the Midwest,[11] the Northeast/Mid-Atlantic states,[12] and the states of Oregon[13] and Washington.[14]

The LCFS framework is specifically designed to advance broad climate policy objectives in the unique context of the transportation sector given the need to overcome market barriers and market inefficiency that economy-wide climate policy instruments, such as carbon taxes or cap-and-trade schemes, fail to address. The primary objectives of an LCFS are to

- provide significant reductions in GHG emissions from transportation;
- stimulate innovation, technological development, and deployment of low-emission alternatives for fueling the transport sector; and
- provide a durable framework for regulating GHG emissions in the transportation sector within a broader portfolio of climate policies.

In advancing these objectives, an LCFS is notable for its structure as a technology-neutral performance standard. It does not include mandates for any particular fuel, technology, or compliance strategy and as such does not attempt to pick winners or losers. Instead, it defines an average emissions intensity standard, measured in grams CO_2 equivalent per mega-joule of fuel energy (gCO_2e/MJ), which all regulated parties must achieve across all fuels they provide. Many options exist for meeting the standard, and regulated parties are free to employ any combination of strategies that suit their particular circumstances and perspectives.

Transportation-sector emissions abatement requires a multipronged approach, like a three-legged stool comprising increased vehicle fuel efficiency, reduced carbon intensity of fuels, and reduced vehicle miles traveled. Each of these “legs” offers potentially significant reductions in transportation-sector emissions. An LCFS strategically targets only fuel carbon intensity; vehicle fuel efficiency and vehicle use are better addressed using other policy approaches (for example, CAFE standards and mass transit initiatives, respectively). This, along with other considerations

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[8] California Governor Executive Order S-01-07 (January 2007) http://www.arb.ca.gov/fuels/lcfs/eos0107.pdf
[9] http://ec.europa.eu/environment/air/transport/fuel.htm
[10] http://www.em.gov.bc.ca/RET/RLCFRR/Pages/default.aspx
[11] http://shonic.net/LCFS/documents/LCFPagDoc.pdf
[12] http://www.nescaum.org/topics/clean-fuels-standard
[13] http://www.deq.state.or.us/aq/committees/lowcarbon.htm
[14] http://www.ecy.wa.gov/climatechange/fuelstandards.htm

noted below, reflects the notion that an LCFS is best viewed as a strategically important component within a portfolio of climate policies.

Significant progress is being made through a number of state and regional LCFS initiatives, but a national LCFS could provide important benefits through policy uniformity at the national level. Transportation fuel supply chains and the operational service areas of fuel suppliers often extend far beyond the jurisdictional boundaries of state and regional initiatives. Imposing inconsistent obligations under multiple state and regional LCFS policies could increase the complexity and costs of compliance and precipitate multiple redundant regulatory systems. The potential for differential treatment of individual fuels under multiple state and regional policies could also increase incentives for shuffling fuels between jurisdictions on the basis of their treatment under respective policies. A national LCFS policy that supersedes, integrates, or bridges emerging state and regional policies could mitigate these risks, ensure credit transportability, and provide additional opportunities for supplying low-carbon fuels through its broader coverage area, thereby reducing compliance costs and increasing efficiency. Realizing these benefits requires a national LCFS policy design that is consistent with existing and proposed state and regional initiatives.

The principal objective of this report is to integrate available information and experience gained from the earlier implementation of fuels policies and from a major set of collaborative studies conducted over the past two years. In considering the various design alternatives and developing our policy design recommendations, we followed the general principles that a policy should

- be scientifically grounded and defensible,
- be administratively easy to implement and broadly consistent with emerging state and regional initiatives,
- be cost-effective in advancing the underlying policy objectives compared with other alternatives,
- identify potential negative consequences and mitigate them as much as possible, and
- accommodate political dynamics likely to affect its implementation.

Integrating these principles was not always straightforward. Toward this end, we have attempted to integrate the combined expert judgment embodied in the research team and in the thoughtful comments and feedback provided by stakeholder participants.

As noted above, this report is released with a companion Technical Analysis Report (TAR), which summarizes the technical and policy analyses of key issues informing and underlying the recommendations presented here. In certain cases a single approach for addressing particular policy features did not clearly emerge. In such cases alternate design decisions are presented and expectations regarding their implications are summarized. This Policy Design Recommendations (PDR) report provides concluding discussion of key policy design recommendations and attempts to chart a path toward developing a national LCFS policy.

Each policy recommendation for a national LCFS policy is followed by a discussion summarizing the issues addressed by the recommendation, possible design alternatives, and the rationale for the recommended design.

1 Complementary Policy Instruments

Recommendation 1. Adopt complementary policies to maximize the benefits of an LCFS.

Key Issues

No single policy, including a carbon tax or an LCFS policy, can overcome all identifiable market conditions and failures. Additional, complementary policies are needed. Complementary policies can be independently developed and targeted to address key underlying issues that are difficult to address with broad policy solutions. The key policy design questions are (1) Why are complementary policies other than a carbon tax needed? and (2) What should the complementary policies be?

Summary and Recommendations

A wide variety of market conditions and market failures inhibit the commercialization of nonpetroleum transportation fuels. These include the failure of markets to assign a price to GHG emissions; sunk investments and technology lock-in by the automotive and energy industries that make alternatives look disruptive and discourage investments in new energy systems; network externalities where consumer decisions to purchase electric and fuel cell vehicles are made separately from energy infrastructure decisions; the market power of OPEC; high entry barriers in the auto industry; R&D underinvestment due to industry diffusion (especially in agriculture), R&D spillovers where R&D findings cannot be fully captured, and learning-by-doing spillovers where societal savings are not fully captured; conservative consumer behavior in buying new types of vehicles even when they are economically superior; and volatile oil prices that create uncertainty, which leads to underinvestment in alternatives.

No single policy, including a carbon tax or an LCFS policy, can overcome all these market conditions and failures. Additional, complementary policies are needed. Complementary policies can be independently developed and targeted to address key underlying issues that are difficult to address with broad policy solutions such as a carbon tax or an LCFS. Complementary policies to an LCFS might include mandates that jump-start investments in new vehicle and fuel types, basic energy and vehicle R&D, incentives for vehicles that use low-carbon fuels, policies to decarbonize electricity generation, and sustainability requirements for fuel/feedstock production. Many of these are already in place, adopted by local, state, or national governments—but many are not. The success of an LCFS (or other policies to accelerate the use of low-carbon fuels) would be aided by the adoption of complementary policies. More work is needed to carefully evaluate complementary policies that could effectively maximize the full policy benefits of an LCFS—and to identify existing policies that overlap or are not well aligned.

Discussion

The Kaya identity serves to define a relationship between GHG emissions and the factors that influence them, where CO_2 is a function of population, GDP, and energy:

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

In the transportation sector, the Kaya equation can be rewritten as

$$CO_2 = Population \times \frac{Miles\ traveled}{Population} \times \frac{Energy}{Miles\ traveled} \times \frac{CO_2}{Energy}$$

Instead of GDP/population measuring economic growth, miles traveled /population measures travel demand growth, or “mobility.” Energy/miles traveled measures the energy intensity of travel, and CO2/energy measures the GHG intensity of energy use.

A broad policy approach will target the left-hand side of the Kaya identity—limiting total CO_2 emissions. Most of the economic models ignore externalities associated with climate mitigation, as these costs are difficult to estimate and have rarely been quantified before. Yet these costs are real, and without specific policies to address these market barriers, economic models significantly overestimate the efficiency of the market and the potential to reduce GHG emissions without complementary policies.

Typical market failures that have not been considered in economic studies include the following:

- Failure of markets to assign a price to GHG emissions
- Sunk investments and technology lock-in by the automotive and energy industries
- The principal agent problem where operators of rental cars, truck trailers, leased vehicles, and cars for legislators/execs are not the buyers of the vehicles
- Network externalities where complementary products require large *nonrecoverable* investments and investments that cannot be made by individual consumers—such as when different vehicles or different infrastructures are needed (H2, bike paths for biking, smart paratransit, and so on)
- The market power of OPEC (cartels, oligopolies, and the like)
- High entry barriers in the auto industry
- R&D underinvestment due to industry diffusion (especially in agriculture), R&D spillovers where R&D findings cannot be fully captured, and learning-by-doing spillovers where

societal savings not fully captured
- Consumer behavior in buying new types of vehicles making decisions that underinvest in efficiency (related to lack of information and loss aversion)
- Volatile oil prices that create uncertainty, which leads to underinvestment in alternatives

In view of these failures, it will be necessary to develop targeted policies other than policies that rely on markets (including C tax and the cap=and-trade) to overcome these market barriers.

Similarly, complementary policies to an LCFS might include mandates that jump-start investments in new vehicle and fuel types, basic energy and vehicle R&D, incentives for vehicles that use low-carbon fuels, policies to decarbonize electricity generation, and sustainability requirements for fuel/feedstock production. Many of these are already in place, adopted by local, state, or national governments. For example, California has the Clean Fuels Outlet (CFO) Regulation to ensure that an appropriate number of fueling stations will dispense a designated fuel once a certain number of vehicles using that fuel are certified in California to the Low Emission Vehicle (LEV) standard. California also has the Zero Emission Vehicle (ZEV) mandates that support and accelerate the numbers of plug-in hybrids and zero emission vehicles in California. More work is needed to carefully evaluate complementary policies that could effectively maximize the full policy benefits of an LCFS. Existing policies that overlap or are not well aligned should be deleted or modified. New policies that are complementary and synergistic should be adopted, often at the local or state level.

2 RFS2 and a National LCFS

Recommendation 2. Modify RFS2 to incorporate elements of an LCFS, or replace it with an LCFS.

Key Issues

The most conspicuous example of an overlapping policy is the national Renewable Fuel Standard, most recently updated in 2007 (RFS2). An LCFS would work differently from RFS2 in that it would incentivize fuel improvement, whereas RFS2 creates a tiered system with specific GHG emission targets and volumetric requirements that fuels need to meet. Is a national LCFS necessary, given RFS2? How would an LCFS improve upon RFS2? Should RFS2 be replaced by an LCFS or should features of RFS2 be improved based on LCFS principles?

Summary and Recommendations

RFS2 requires specified volumes of several types of biofuels, defined in terms of (life-cycle) carbon intensity thresholds. In contrast, an LCFS would apply to all transport fuels, not just biofuels, and would base the requirements on their life-cycle carbon intensity. This broader approach using a continuum of carbon intensities would provide a stronger incentive for innovation for a broader range of fuels (including electricity, natural gas, and hydrogen).

Our studies conclude that implementing an LCFS alone or with RFS2 would generally be superior to RFS2 alone in reducing GHG emissions, improving market incentives and flexibility, and lowering domestic and international land use impacts. The impacts on energy security relative to RSF2 would likely be positive or small, but not negative. If an LCFS is to be adopted, two options are possible: modify the RFS to incorporate elements of an LCFS, or replace it with an LCFS. RFS2 and an LCFS could be complementary policies mutually reinforcing low-carbon fuel development, or an LCFS could replace RFS2, acting as a new policy framework to drive low-carbon and renewable fuel development.

Discussion

An LCFS policy is a diverse, multifaceted policy that is geared specifically toward pushing low-carbon fuel technology into the marketplace. While an LCFS is not a catch-all policy, it could build upon the already existing RFS2 framework to drive low-carbon fuel deployment beyond what RFS2 is already able to do.

RFS2 creates a volumetric fuel mandate and specifies carbon reduction tiers, or categories, to lump renewable fuels into and to prequalify fuels. If a fuel meets a specific category requirement, it is eligible to generate renewable identification number (RIN) credits for that fuel type that can be applied to an obligated party's regulated volume requirement.

An LCFS would define total carbon-reduction goals for regulated parties. Rather than requiring a specific volume of fuel, it would require the regulated party to meet an aggregated baseline carbon intensity (gCO_2e/MJ) with its fuels. The regulated party could achieve this either by increasing the proportion of low-carbon fuels it sells or by decreasing the carbon content of the fuels it sells (making them lower in carbon intensity). If both RFS2 and an LCFS were in place, RFS2 would provide volume-based incentives for fuels while the LCFS would provide carbon-intensity-based incentives for fuels. If the volume of fuel required by RFS2 were greater than the volume that would be achieved through low-carbon fuels required by the LCFS, RFS2 would act as an additional deployment subsidy (Huang et al. 2012).

It is notable that RFS2 does not have provisions to allow novel fuels—many of which are arguably needed to meet transportation emission reduction goals in the long term (IEA 2010; McKinsey&Company 2009)—to count toward the standard. An LCFS would create provisions for electricity, hydrogen, and novel fuels through use of an opt-in mechanism that would allow for nonconventional-fuel providers to generate LCFS credits.

Our studies conclude that implementing an LCFS alone or with RFS2 would generally be superior to RFS2 alone in reducing GHG emissions (see TAR Chapter 2), improving market incentives and flexibility (see TAR Chapter 2), and lowering domestic and international land use impacts (see TAR Chapter 5). The impacts on energy security relative to RSF2 would likely be positive or small, but not negative (see TAR Chapter 6). These results are explained in detail in the TAR.

RFS2 and an LCFS could be complementary policies mutually reinforcing low-carbon fuel development, or an LCFS could replace RFS2, acting as a new policy framework to drive low-carbon and renewable fuel development.

3 Program Coverage and Scope

Recommendation 3. Initially include within the scope of the LCFS all fuels used in on-road vehicles.

Key Issues

As an LCFS aims to reduce the average carbon intensity of transportation fuels, the program coverage and scope will affect the stringency of the standard as well as the degree of flexibility for regulated parties to meet the standard. In principle, it is desirable to include more types and uses of transport fuels in a national LCFS. Including more fuels would result in greater GHG reductions and would enable broader and more flexibility in identifying low-cost mitigation options, increase opportunities for regulated parties to buy LCFS credits from a greater pool of options, thereby achieving LCFS targets in the most cost-effective manner. On the other hand, a broadly defined coverage would impose more logistic and regulatory challenges and could increase the risk of fuel shuffling.

Summary Recommendations

Fuels used in on-road vehicles—cars, trucks, buses, freight, and rail—account for 80.3 percent of total transportation fuel use in the United States; we recommend including them in an LCFS as their uses are easy to track and monitor. Small amounts of electricity, hydrogen, and natural gas account for less than 1 percent of total transportation fuel use in the United States. These should be included in an LCFS, but because they tend to have lower life-cycle GHG emissions than petroleum fuels, they would be used to generate credits for sale to petroleum fuel suppliers (depending on verification that their carbon intensity is lower than that of gasoline and diesel).

Approximately 14.7 percent of transport fuels is used for ships and aviation. Including maritime and aviation emissions within an LCFS would be challenging because ships and planes operate across national boundaries. Ideally, they should be included so as to minimize emissions leakage—planes and ships evading LCFS regulations in the United States by purchasing as much fuel as possible elsewhere. As other nations adopt LCFS rules, leakage will disappear, but the spreading of carbon rules to ships and planes traveling beyond US borders will likely be slow because they are regulated by international agencies, which tend to act slowly. It may take a decade or more to establish a global policy/framework to regulate shipping and aviation GHG emissions. Nonetheless, just as the EU acted unilaterally in capping aviation GHG emissions, regional and national policy initiatives could be considered in the absence of international action.

Conventional transportation fuels used for off-road vehicles and outside the transportation sector (for example, diesel fuel used for home heating) could be included in a national LCFS, but implementation could be complex. We suggest not including these initially.

Discussion

A breakdown of current transportation fuel use by fuel type and segment is provided in Table 1, based on data from the US Department of Energy's *Annual Energy Outlook 2011* (U.S. EIA 2011a). Reference case projections for 2035 (not shown here) indicate similar patterns of fuel consumption but with increases in electricity, ethanol, and diesel fuel use by vehicles. These figures indicate that liquid transportation fuels (particularly motor gasoline, diesel fuel, ethanol, residual oil, and aviation fuels) account for more than 99 percent of current and expected future transportation fuel use.

Table 1. US transportation fuel consumption by fuel type and segment (trillions of Btu's)

Fuel	Light Duty Vehicles[1]	Freight trucks	Freight Rail	Rail Transport	Rec. Boating	Domestic Shipping	International Shipping	Air Transport	Military	Bus	Total	%
Motor Gasoline	16,291	354			212					25.3	16,881	63%
E85	2.63										2.63	0.0%
Distillate Fuel Oil (diesel)	449	4,029	528	26.7	51.8	154	59.3		161	232	5,691	21%
Compressed Natural Gas	11.53	7.15								9.17	27.85	0.1%
Liquefied Petroleum Gases	3	16.41								0.17	19.6	0.1%
Electricity	0.31			23.0							23.3	0.1%
Residual Oil						54.7	732		17.5		804	3%
Jet Fuel & Aviation Gasoline								2,583	586		3,169	12%
Total	16,758	4,406	528	49.7	263	208	792	2,583	764	267		
Percent	63%	17%	2.0%	0.2%	1.0%	0.8%	3.0%	9.7%	2.9%	1.0%		

[1] Includes light duty vehicles and commercial light trucks. Source: 2010 data from Table 37 in AEO 2011.

Various other transportation fuels—including electricity, hydrogen, natural gas, liquefied petroleum gases, and novel biofuels such as hydrocarbons produced from algae—currently make only modest contributions to the transportation fuel mix; however, their use as transportation fuels may increase considerably in certain scenarios. Such increases may be accelerated by an effective national LCFS policy due to their potentially lower carbon intensity than petroleum. However, recent evidence also suggests that not all alternative fuels are inherently low carbon, and significant variations exist depending on their sources, production methods, and uses (Burnham et al. 2011; Howarth, Santoro, and Ingraffea 2011; Samaras and Meisterling 2008). Therefore, a consistent performance standard should also be applied to these alternative fuels that are likely to play increasingly important roles in future transportation. Within this context, parties supplying these fuels for transportation should be allowed to opt in to an LCFS policy for the purpose of generating LCFS credits.

Notwithstanding these general points regarding *fuel types* covered by a national LCFS, several *segments* of the transportation sector listed in Table 1 warrant special consideration.

Shipping. International maritime vessels can shift refueling patterns in response to even modest price signals (Michaelis 1997; Mishra and Yeh 2011).[15] The shipping industry is likely to witness

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[15] The bunker fuel industry is highly cost competitive and ship operators choose their bunker source on the basis of small price differentials. An often-quoted example is that of the introduction and subsequent repealing of a sales tax on bunkers sold at the Port of Los Angeles / Long Beach in California (Michaelis 1997). Before the introduction of the tax in 1992, the LA/LB bunker market had a monthly turnover of around 4.5 million barrels. After introduction of an 8.5-percent sales tax, bunker sales dropped below 1 million barrels and shifted largely to Panama, which is en-route for many ships calling the ports of LA/LB. As a result, the tax was rescinded within one year. None of the major bunker markets—Houston, Singapore, Rotterdam, and LA/LB—impose any taxes on bunkers sold to international shipping.

significant change in fuel use and increases in operating costs as a result of MARPOL Annex VI regulation of sulphur emissions. The regulation will force the industry to transition from inexpensive but dirty residual oil–dominated bunker fuels to cleaner, low sulphur distillate–dominated bunker fuel by 2020/2025. Even in the absence of GHG regulation, fuel costs are likely to increase sharply in the future and provide strong incentives to reduce fuel consumption (Mishra and Yeh 2011). The structure of the bunker industry precludes the potential to regulate the refinery or bunker supplier due to the high risk of leakage and thus adverse economic impacts. Incentive-based policy, however, has the potential to work best for this particular industry to take advantage of climate finance under market-based instruments (IMF 2011). Our rough estimates suggest that if an LCFS were applied to the shipping industry and assuming no leakage, which is very unlikely, it could contribute to a roughly 19-million-tonne GHG reduction at US\$33–330/tonne CO_2e (total abatement costs will be US\$0.7–4 billion to reduce the well-to-wheel CO_2e intensity of bunkers sold in the US by 10 percent) (Mishra and Yeh 2011).

Aviation. Including fuels used in *international* aviation, even on an opt-in basis, may be complicated by commitments agreed upon under the 1944 Convention on International Civil Aviation (CICA) that such fuel "be exempt from customs duty, inspection fees or similar national or local duties and charges" [16] The CICA's implications for a national LCFS are not clear, however, because an LCFS is a performance standard, rather than a duty, fee, or charge. Legal analysis is required before firm conclusions can be drawn in this respect. The aviation industry has been particularly active in exploring potential low-carbon bio-jet fuels under the renewable biofuel programs in the United States and the European Union.[17] Including aviation fuels under a national LCFS could further strengthen these incentives (IMF 2011).

Military. Fuel used in tactical military applications should be exempt from a national LCFS on the basis of national security interests. The US military has, however, taken a leadership role in reducing the carbon intensity of its fuel supplies—reflected in key provisions in the Energy Independence and Security Act of 2007 and the Great Green Fleet initiative.

Rail. Fuel used in rail transportation should also be allowed to opt in to an LCFS program to generate credits. This would provide additional incentives for more efficient and low-carbon transportation modes, such as freight hauling (Greene, Baker, and Plotkin 2011; U.S. DOT 2010), to compete with diesel-fueled trucks on a more level playing field. Careful analysis will be needed in the future to determine the basis for comparison (for example, to arrive at appropriate adjustment factors to account for the different efficiencies of the modes).

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[16] Convention on International Civil Aviation, Dec. 7, 1944, *61 Stat. 1180*, *15 U.N.T.S. 295*

[17] The European Council recently adopted a directive (document 3657/08) that includes aviation activities in the EU GHG emission allowance trading system (ETS). As of 1 January 2012, all flights arriving at or departing from an EU airport will be included in the scheme. The directive is being challenged by industry trade groups in the European Court of Justice (ECJ).

Nontransport. Certain nontransport applications of transportation fuels —such as home heating with distillate (diesel) fuel and biofuels—have been considered for inclusion in regional LCFS efforts, such as home heating oil (No. 2 distillate) in the Northeast/Mid-Atlantic LCFS. The considerations are that (1) it will present significant challenges to separate out fuel oil used for space heating vs. for transportation, with the proportion roughly 50/50 in the region; (2) including nontransport applications will incentivize additional GHG emission reductions;[18] (3) including nontransport applications will reduce the possibility of fuel shuffling, in which high-CI fuels are diverted to stationary applications in exchange for equivalent fuels with lower CI. In this particular case, the inclusion of heating oil could offer the additional benefit of simplifying fuel accounting by focusing attention on transportation fuels supplied rather than on final use, and allowing greater consistency with the RFS2 policy, which qualifies renewable fuels used for home heating. Situations like this could be considered on a regional basis, as the goals of a national LCFS should be broadly consistent with state or regional initiatives and should support credit trading and potential policy integration (Kessler, Yeh, and Sperling 2012).

4 Baseline and Targets

Recommendation 4. Set a target of reducing the carbon intensity of gasoline and diesel by 10 to 15 percent by 2030.

Key Issues

The policy baseline is the initial carbon intensity value from which reduction targets are measured under an LCFS. Several factors influence the stringency of an LCFS: the baseline carbon intensity, the target reduction, and the phasedown schedule (rate of reduction from the baseline carbon intensity to the target). These factors affect not only the level of policy stringency but also the cost-effectiveness and the economic impacts of an LCFS policy.

Summary Recommendations

We recommend a target of reducing carbon intensity (CI) by 10 to 15 percent by 2030 based on research findings of the national LCFS team. Carbon intensity is defined as life-cycle GHG emissions (converted to carbon equivalence and expressed as gCO_2e/MJ); the 10-to-15-percent reduction is with respect to gasoline and diesel, the baseline fuels. The selection of a carbon intensity reduction target calls for balancing a number of factors: the urgency of reducing GHG emissions, expected costs of future energy supplies, expected economic impacts, variation in costs and impacts across companies and regions, and the expected rate of induced innovation in

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[18] http://www.ct.gov/dep/lib/dep/air/climatechange/lcfs_mou_govs_12-30-09.pdf

supplying low-CI fuels. Because there will be a lag between the time when an LCFS policy is adopted and when investments and innovations occur, it is generally advisable to backload the compliance schedule by starting with small annual CI reduction targets and steadily increasing the size of the annual reduction percentages over time.

Discussion

The carbon intensity (CI) of petroleum fuels has been increasing over time because heavier and more unconventional crude sources are being used (U.S. EIA 2010b), which require more energy for extraction and processing (Brandt 2008, 2011). As the share of unconventional crude oil from oil sands rises from 9.4 percent of US domestic petroleum consumption in 2010 to 18.1 percent in 2020, the CIs of gasoline and diesel are expected to increase from 93.1 to 96.3 gCO_2e/MJ for gasoline and from 92.0 to 97.1 gCO_2e/MJ for diesel over the period 2005–2035 (Figure 1) (Rubin and Leiby 2012). On the other hand, the average CI of the transportation fuel mix will remain relatively flat or decrease gradually, due to the mandated mix of biofuels under RFS2 (Huang et al. 2012; Rubin and Leiby 2012; Yeh and Sperling 2010).

As a result, the stringency of an LCFS policy will vary depending on the baseline selected, ranging from the least stringent (that is, highest CI baseline if using the actual 2012 petro-gasoline and petro-diesel fuel CIs) to the most stringent (that is, lowest CI baseline if using the actual 2005 gasoline and diesel fuel CIs) (Rubin and Leiby 2012). We recommend using a baseline CI of regulated transportation fuels for the most recent year for which there is data, such as the CI of 2011 fuel mix for the gasoline and diesel fuel pool). This translates to a medium-level stringency reflecting the actual baseline CI of the regulated fuel pool(s).

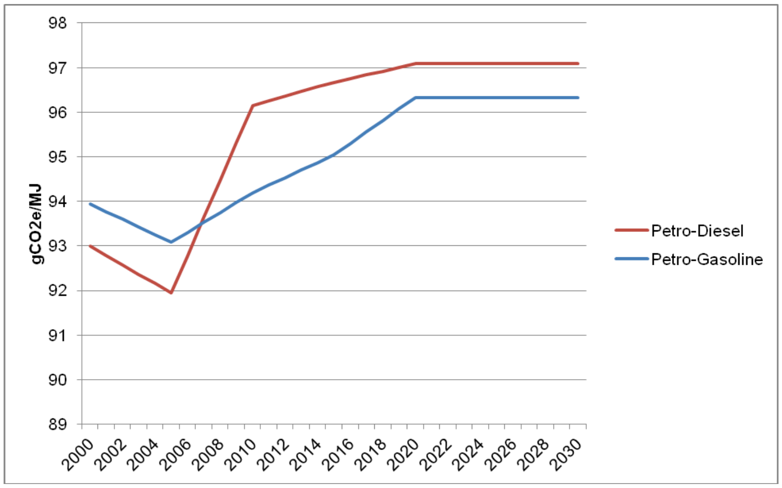

Figure 1. Actual (2000–2009) and projected (2010–2030) changes in the carbon intensity of petroleum-based fuels. Source: Rubin and Leiby 2012.

LCFS targets define the CI reductions to be achieved within a certain time frame, such as a 10-percent reduction by 2030. The national LCFS analysis examined a wide range of policy options at varying CI baseline and target levels. These options used a range of assumptions, varying (1) feedstock costs, availability, and CI values including the values of indirect land use change (iLUC); and (2) policy options in treating high-carbon crude and the existence of other complementary/contradictory policies as discussed in detail in our technical analysis papers (Huang et al. 2012; Rubin and Leiby 2012).

As summarized in the TAR, our studies found that when an LCFS and RFS2 are combined, the success of the LCFS policy depends on whether that policy can further incentivize low-carbon feedstocks beyond those required by RFS2 at reasonable costs. The impacts of a national LCFS are fundamentally determined by (1) the availability of low-carbon fuels, (2) the compliance path, (3) the reference level CI of the fuel baseline, and (4) the degree of flexibility in the credit system. Setting a 15-percent reduction target below a historical level such as that of 2005 can be an achievable target provided there is a flexible credit trading and banking design (Huang et al. 2012; Rubin and Leiby 2012).

The phasedown schedule—that is, the amount of CI reduction annually within the policy time frame—also affects the stringency of the policy. For example, LCFS policies in California and British Columbia have both adopted a "technology-forcing" CI trajectory, in which modest reductions in early years are followed by more substantial reductions later on (Table 2). This backloading of CI reductions is intended to provide sufficient lag time to develop new low-carbon fuel supplies, including R&D, construction of biorefineries, development of feedstock supplies and infrastructure, and system integration (NRC 2011). Some stakeholders have suggested that this approach may create additional challenges to financing low-carbon fuel development, as modest initial reduction targets yield relatively low LCFS credit prices early in the program. Our credit analysis study demonstrates that uncertainty in mitigation costs, feedstock and technology availability, and credit prices can largely be mitigated via credit trading and banking (Rubin and Leiby 2012).

Table 2. Summary comparison of policy baselines and CI targets

Policy design feature	CA LCFS	BC LCFS	OR LCFS[1]	WA LCFS[1]	NEMA LCFS[1]
Gasoline baseline CI (gCO_2e/MJ)	95.85	82.40	90.38	92.2	
Baseline basis	2010[2]	2010[2]	2010[3]	2007	2010
Reduction target	10%	10%	10%	10%	10%
Target year for achieving target	2020	2020	2022	2023	2023
Phasedown	Tech-forcing	Tech-forcing	Tech-forcing	Tech-forcing	

Notes: 1. LCFS policy initiatives for Oregon, Washington, and the Northeast/Mid-Atlantic (NEMA) region are in various stages of development. The information presented here reflects the authors' current understandings of

likely policy designs based on publicly available information sources. This information may not reflect final policy designs, if and when they are developed.
2. Baselines for California and British Columbia, and recommended baselines for WA were defined by projecting a 2010 CI with 2007 data.
3. The recommended baseline for Oregon was defined by projecting a 2010 CI using data from 2007 and 2009.

5 Point of Regulation and Regulated Parties

Recommendation 5. Regulate the parties responsible for producing, importing, or supplying fuel.

Key Issues

Identifying the point of regulation and the regulated parties determines who will be allowed to generate and sell credits. How far upstream should the point of regulation be so as to maximize administrative efficiency? Should alternative fuel providers other than oil companies, such as biofuel producers, be regulated parties and allowed to generate credits? Should providers of nonconventional transportation fuels such as electricity, natural gas, and hydrogen be regulated parties, given that transportation application is only a small portion of the total energy these energy companies provide?

Summary Recommendations

Regulated parties should generally be those parties responsible for producing or importing fuel for consumption in the US transportation sector. For petroleum fuels used in transportation (gasoline, diesel, jet fuel, bunker fuel), the regulated party should be oil refiners or importers, along with blenders when biofuels are mixed with petroleum fuels.

For transportation fuels that are also used outside the transportation sector, the initial regulated party should be the party responsible for supplying the fuel for transportation-sector applications. These could be firms supplying fuel to vehicle fueling equipment, or firms owning the vehicle fueling equipment, but not both.

Discussion

An LCFS and relevant fuel policies (including RFS2 and the EU's biofuel policy RED and LCFS-like policy FQD) are technology-forcing policies (as opposed to demand-pull policies that focus on creating demands directly). Thus fuel suppliers and importers are natural regulated parties as they have sufficient control over fuels and/or feedstock sourcing and processing to enable implementation of carbon-intensity-reduction strategies. They also have sufficient knowledge of life-cycle emissions to fulfill compliance obligations and are sufficiently few in number to enable effective administration and enforcement. In addition, fuel suppliers and importers are in the position of making long-term commercial and R&D investments in increasing the supply of low-carbon transportation fuels and have sufficient resources to manage the trade of carbon credits.

For petroleum fuels used in transportation (gasoline, diesel, jet fuel, bunker fuel), the regulated party should be oil refiners or importers, along with blenders when biofuels are mixed with petroleum fuels.

Gasoline and diesel fuel producers can choose among five methods to meet LCFS targets:

1. Reduce the carbon intensity (CI) of gasoline and diesel.
2. Increase their use of alternative fuel blends in gasoline and diesel.
3. Substitute lower-CI for higher-CI biofuels in blends (for example, substitute low-carbon ethanol for corn ethanol).
4. Sell more alternative fuels (for example, E85, B100, and CNG).
5. Purchase credits from other regulated parties or use credits banked in previous years.

The initial regulated party for those fuels currently used mostly for nontransportation purposes (for example, natural gas, electricity, hydrogen) should be the party responsible for dedicating the fuel to transportation-sector applications. This could be either the party supplying fuel to vehicle fueling equipment or the owner of the vehicle fueling equipment, depending on the circumstances. For fuels that are predominantly used outside the transportation sector, producers and other upstream supply chain participants may have only limited influence over and interests in the fuel used in transportation as it represents a very small market share of total use. In this regard, incentives that focus on “demand-pull” may be more effective in incentivizing the introduction of low-carbon fuels into the transport sector.

In the case of electricity used in transportation, the owners of vehicle-charging equipment could potentially be allowed to act as regulated parties either directly or in some type of pooled capacity without being regulated as an electric utility. This would provide greater flexibility in increasing the supply of electricity to transportation, which is currently limited by the vehicle fleet and charging infrastructure rather than by the supply of low-carbon electricity.

For example, Yang (2012) examined ways to allocate credits along the electric pathway in order to maximize incentives to contribute electricity to lower transportation carbon intensity. From a policy maker’s perspective, one approach to deciding who can claim LCFS credits is to consider who is likely to use the proceeds from the sale of credits in a manner that will enhance the goals of the LCFS—that is, lowering the fuel CI and increasing the amount of alternative fuel being consumed. Increased infrastructure deployment can increase the amount of electricity used to lower transportation CI by spurring additional plug-in electric vehicle (PEV) sales and increasing charging opportunities for existing PEV drivers. Some have argued that smaller third-party providers may influence the PEV market more than utilities would, because third-party charging providers would receive LCFS credits only if they deployed charging infrastructure that is used by PEV drivers, whereas utilities could obtain LCFS credits simply by virtue of having customers who purchase PEVs. Utilities could also participate by installing charging equipment and putting rules in place to prevent unfair competition. Allowing the infrastructure provider to obtain the LCFS credit, rather than simply defaulting to the electric utility, especially for infrastructure outside homes, would potentially increase the level of investment that results in useful infrastructure or direct subsidy to PEV purchasers (Yang 2012).

6 Energy Efficiency Ratios for Diverse Propulsion Technologies

Recommendation 6. Use energy efficiency ratios to adjust the carbon intensity ratings of fuels for diverse propulsion technologies.

Key Issues

Some advanced fuel-engine combinations have superior efficiency and thus deliver more vehicle miles traveled for the same amount of energy compared with gasoline internal combustion engine (ICE) vehicles, resulting in lower carbon emissions on per mile basis (gCO_2e/VMT). The differences in efficiency are particularly large for all-electric drive trains and fuel cell vehicles. To appropriately recognize actual emissions displaced by low-carbon fuels, fuel carbon intensity (CI) should be adjusted to account for the superior efficiencies of advanced vehicular propulsion systems. Proposed/adopted state, regional, and European LCFS policy programs have adjusted the effective CI of fuels using energy efficiency ratios (EERs). However, the efficiencies of gasoline/diesel vehicles are expected to increase substantially in response to increasingly stringent efficiency standards (U.S. EPA 2011a, 2011b). As a result, the efficiency differences between advanced vehicles and gasoline/diesel vehicles will change over time. Therefore the key issues are how to calculate EERs (including issues of accounting for varying efficiencies across fleet and time) and how often to update them.

Summary Recommendations

For an LCFS to account accurately for the full life-cycle impact of different fuels, the carbon intensity (CI) ratings of fuels have to be adjusted by the differences in energy conversion efficiency of vehicle engines. This adjustment is essential to correctly reflect the actual emission reductions (in gCO_2e per mile traveled) when replacing conventional fossil fuel with alternative fuels that run on engines with much greater conversion efficiency such as electric motors compared to internal combustion engines. Adjustments are also required for fuel cell vehicles, which are also more efficient than gasoline-powered vehicles.

These adjustment factors—energy efficiency ratios (EERs)—are best calculated by comparing the *fleet-average* efficiencies of the alternative power train with the corresponding *fleet-average* efficiencies of baseline fuel-vehicle technologies that the alternative fuel-vehicle technology will displace. The values should be updated on a regular basis to ensure they adequately reflect the evolving efficiency of vehicles on the road.

Discussion

An LCFS targets the fuel side of the fuel-vehicle system to reduce GHG emissions. However, the tight coupling of fuel-vehicle systems has important implications for GHG emissions when vehicles switch to new propulsion technologies. These differences must be addressed to ensure that LCFS incentives accurately reflect the actual emission reductions achieved by fuel switching. This issue of propulsion technology shifts is relevant to many alternative fuels, but electricity provides the most dramatic example. Electric motors use substantially less energy per vehicle mile than combustion engines. As a result, substituting electricity for conventional transportation fuels can provide substantial emissions benefits even if the CI of electricity is higher per MJ of fuel delivered to the vehicle.

This issue of energy efficiency ratios was explored in recommendations developed for California's LCFS by Farrell and Sperling (2007), and the concept of EERs has been widely adopted by state and regional LCFS initiatives, including the two policies that have been implemented: EU's FQD, and British Columbia's RLCFRR. A couple of different approaches to calculate EERs are possible, including the direct drive-train comparison and weighted average approaches, both of which are discussed below. While the discussion and examples here focus on electricity, EER values should be assigned to all fuels used in different drive trains with significant differences in efficiency.

EER—direct drive-train comparison approach. In the direct drive-train comparison approach to EERs, an EER is defined as the fuel consumption of a vehicle using an alternative fuel divided by the fuel consumption of a vehicle using a conventional fuel (gasoline or diesel) for the same amount of service delivered (miles traveled). Fuel consumption differences due to the fuel/drive-train system are isolated from other factors by using fuel consumption data for vehicles with different fuel/drive-train systems that are otherwise comparable in terms of vehicle class, capacity, performance, and equipment. Table 3 shows the EER values used in California's LCFS, which were developed using this approach.

Table 3. EER values used in California's LCFS

Light/medium-duty applications (fuels used as gasoline replacement)		Heavy-duty/off-road applications (fuels used as diesel replacement)	
Fuel-vehicle combination	EER values relative to	Fuel-vehicle combination	EER values relative

	gasoline		to diesel
Gasoline and gasoline-ethanol blends	1.0	Diesel and diesel-renewable-/bio-diesel blends	1.0
CNG–ICEV	1.0	CNG or LNG (spark-ignition engines) CNG or LNG (compression-ignition engines)	0.9 1.0
Electricity–BEV or PHEV	3.4	Electricity–BEV or PHEV	
H2–FCV	2.5	H2–FCV	

Source: CARB 2011. Appendix A. Proposed regulation order. BEV: battery electric vehicle; PHEV: plug-in hybrid electric vehicle; CNG: compressed natural gas; ICEV: international combustion electric vehicle; H2 FCV: hydrogen fuel cell vehicle.

EER—weighted average approach. One way of adjusting the EER baseline for gasoline is to compute fuel-specific EERs as averages across drive trains, weighted by the proportion of vehicles with each drive train. This approach is illustrated for two time periods in Table 4 using one particular set of estimates for drive-train efficiencies calculated for 2008 and projected for 2035 (Bandivadekar et al. 2008).[19] The same method is used for adjusting the average EER of new drive-train technologies as they are commercialized more broadly. For instance, the mix of different fuel cell and battery electric vehicles would be used to update EERs for those technologies (relative to gasoline vehicles).

Table 4. Illustrative drive-train weighted average EERs for electricity as a gasoline replacement

Time period	Subject fuel	Baseline fuel / drive train	Proportion of vehicles	Drive-train-specific EER	Weighted average EER
1	Electricity	Gasoline (ICE)	99.996%	4.00	4.00
		Gasoline (HEV)	0.005%	2.81	
2	Electricity	Gasoline (ICE)	85%	3.28	3.06
		Gasoline (HEV)	15%	1.83	

Notes: Subject fuel is the alternative fuel for which the EER is being calculated. Baseline fuel / drive train reflects the baseline fuel / drive train system being displaced by the subject fuel. Proportion of vehicles reflects the fraction of vehicles using each baseline fuel / drive-train system being displaced by the subject fuel. Time period 1 estimates are provided for illustration purposes from values provided in Table 46 (U.S. EIA 2010a). Drive-train-specific EER represents the EER computed as the ratio of fuel efficiencies for each combination of displaced fuel / drive-train systems. Values based on tank-to-wheel energy use estimates from Table 7 (Bandivadekar et al. 2008), except Period 1 value for electricity as a substitute for gasoline ICE, which is based on the Oregon LCFS analysis. Weighted average EER represents the mean of drive-train-specific EERs weighted by the proportion of vehicles.

How often to update EER values. There are at least two options for updating EER values: (1) EER values could be analyzed and revised on an ongoing basis; or (2) EER values could be defined according to fleet fuel economy forecasts that cover relatively longer time periods. In the latter case, EER values could define a schedule that mirrors expected changes in fleet fuel economies. The first approach is used by California, the second by Oregon. Defining EER values

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[19] Computed as the ratios of fuel efficiency estimates provided in Table 7 of the referenced report: 1.77 / 0.54 = 1.8 for gasoline hybrid electric vehicles (HEVs); and 0.99 / 0.54 = 3.3 for gasoline internal-combustion engines (ICEs).

for extended time horizons in principle provides greater certainty to fuel suppliers regarding LCFS credit and deficit generation, though the changes in credits due to EER adjustments are likely to be small and predictable. However, the uncertainty inherent in technology forecasts suggests that periodic updating—perhaps every three or four years—may provide a more technically sound basis for regulation.

EER values are expected to change over time because fuel-specific drive-train efficiencies are expected to evolve at different rates. For example, gasoline engine systems are expected to continue to improve over time as direct injection, continuously variable transmissions, and hybrid-electric technologies (including stop-start) are improved and adopted. Likewise, battery electric drivelines are also likely to improve significantly as battery management systems, electric motors, and other control technologies are improved (Figure 2 and Figure 3). The impact of new technologies will be moderated by the relatively slow turnover of the vehicle fleet; however, the evolving nature of EERs needs to be captured in the policy design.

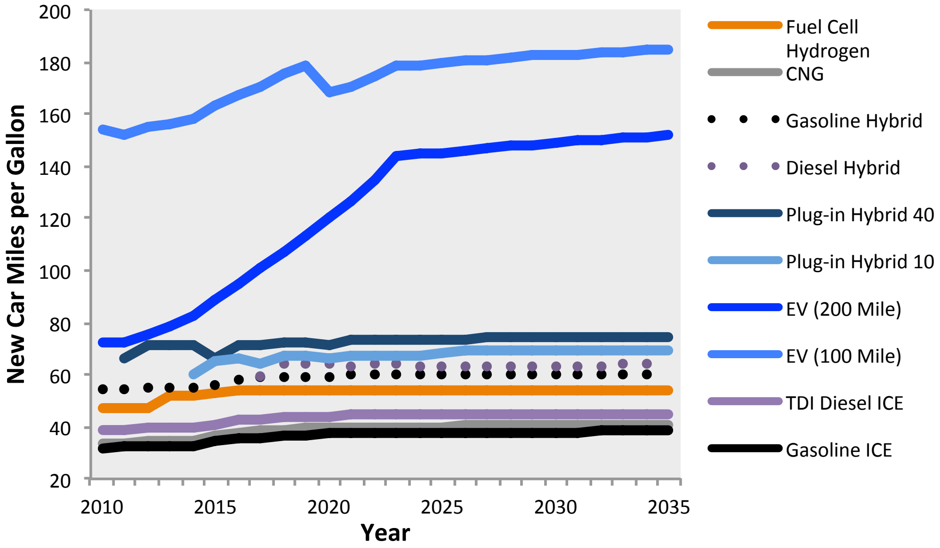

Figure 2. Projected new car fuel consumption (miles per gallon) by technology type. Source: U.S. EIA 2012.

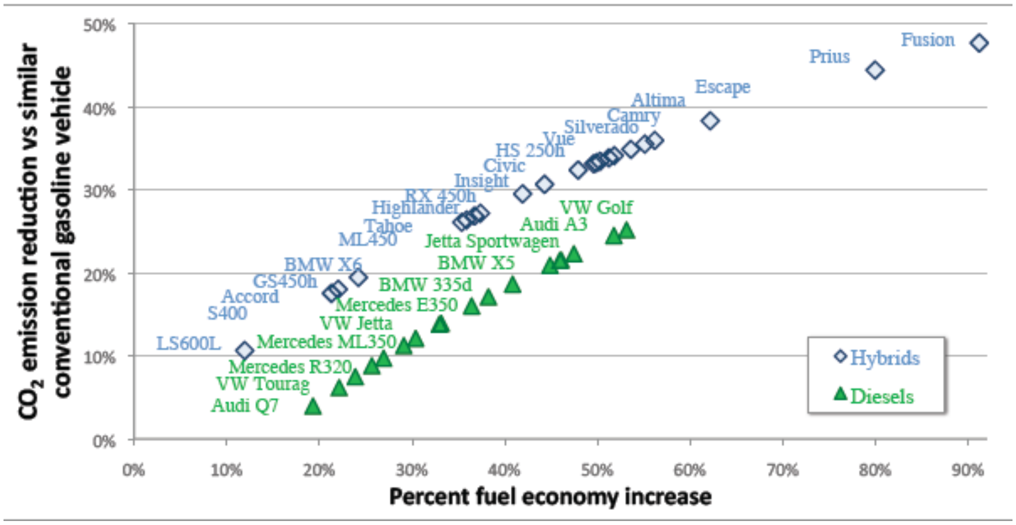

Figure 3. Fuel economy improvement and CO_2 emission reduction from hybrid and diesel vehicles, compared directly with the most similar conventional gasoline models made by the same automaker. Source: Lutsey 2010.

EER updating is especially important because of the increasing diversity of drive-train technologies in the vehicle fleet. In particular, EER values for vehicles burning gasoline in internal combustion engines will need to reflect the increasing penetration of hybrid-electric and direct-injection technologies. As gasoline engine systems become more efficient, EER values will be smaller for battery electric and fuel cell systems.

7 Separate fuel pools for gasoline and diesel

Recommendation 7. Create separate fuel pools for gasoline and diesel.

Key Issues

States and regions that have adopted LCFS policies generally divide the regulation into two distinct fuel pools based on the petroleum product they displace—gasoline or diesel. The intention is to minimize the potential for adverse incentives that encourage increased sale of diesel fuel, which has a slightly lower CI value than gasoline, without actual investments in low-carbon fuels, such as cellulosic biofuels, hydrogen, and so on. Should a national LCFS adopt the same diesel vs. gasoline fuel pools approach? Should a single fuel pool be adopted to emphasize regulatory simplicity and consistency across all fuels? Should more fuel pools be adopted for each category of fuels and fuel substitutes, such as adding a jet fuel pool for jet fuel substitutes?

Summary Recommendations

We recommend that at least two separate fuel pools be established—for gasoline and diesel—with the potential to establish additional fuel pools for jet and maritime fuels. A single fuel pool could create incorrect incentives to increase diesel fuel sales if diesel earned a more favorable CI rating as a result of its EER value against gasoline. Without separate fuel pools, a refiner would have the incentive to reduce the price of diesel fuel for sale to trucks or even foreign markets—with no long-term GHG benefits.

To implement a fuel-pooling approach, target CI reductions and EER values will need to be established for each pool. Based on our research findings, we recommend unlimited LCFS credit trading between pools in order to provide flexibility, lower compliance costs, and acknowledge uncertainties in feedstock availability and technological progress.

Discussion

As discussed in Section 6, EER values are an important means of ensuring that LCFS credits and deficits accurately reflect the emission intensities of fuels as they are used in vehicle propulsion systems. EER values are only meaningful, however, when they are defined with respect to fuels used as direct substitutes. Applying EER values for fuels that do not directly substitute for baseline fuel use can result in inappropriate incentives and unintended consequences.

One fuel pool. The drawbacks of a single fuel pool have been discussed particularly in the context of diesel fuel. In principle, EER values for diesel fuel used in vehicles should reflect the efficiency advantage of shifting from spark-ignition gasoline engines to compression-ignition diesel engines. Switching from gasoline to diesel fuel would appear to reduce emissions (per mile traveled) by 11 to 18 percent based on the EER values adopted under California's LCFS, though this efficiency advantage exists only for diesel used as a *substitute* for gasoline in light- and medium-duty vehicles. Diesel in light- and medium-duty vehicles currently accounts for less than 3 percent of diesel consumption in transportation (AEO 2011, Table 37). As a result, defining EER values for the whole diesel fuel pool based on the efficiency advantage of compression-ignition engines would mischaracterize the emissions reduction of diesel consumption and create inappropriate LCFS incentives for fuel suppliers.

There are two possible ways to more accurately implement this concept of displacement:

1. Regulate fuel pools separately (dual or multi-fuel pools), requiring regulated parties to track fuel used in each fuel pool.
2. Regulate transportation fuels as a single pool using single EER values for each fuel, defined as the average of pool-specific EER values weighted by the proportion of the fuel used in each pool, similar to the example in Table 5.

A number of concerns have been raised in discussions regarding the appropriate EER value for diesel fuel, including (1) the potential for an LCFS to subsidize diesel consumption in heavy-duty vehicles at the expense of light- and medium-duty vehicles; (2) impacts of increased diesel fuel usage on air quality and environmental justice; (3) technical and equity issues for refiners related to increasing diesel supplies to US markets; and (4) the ability of diesel fuel to advance the LCFS policy objective of driving innovation in low-carbon fuels. These concerns were explored in the California LCFS policy design document (Farrell and Sperling 2007).

Two fuel pools. The California LCFS responded to these concerns in its LCFS policy by defining and regulating CI reductions in separate fuel pools for diesel, gasoline, and their respective substitutes. Other state and regional CFS policy initiatives appear to be following suit. British Columbia's RLCFRR took exception and first adopted a one-fuel-pool design but soon found problems with refiners tying retail contracts to increase diesel sales. It is our understanding that BC is working to revise its standard toward a two-fuel-pool system.

Under the two-fuel-pool system, fuel suppliers are required to meet the CI targets for each pool separately. Selling more diesel fuels in the market by itself does not affect the carbon intensity of diesel and gasoline pools unless there is actual emission displacement from more efficient diesel vehicles in the gasoline fuel pool. This effectively prevents an LCFS from motivating increased diesel fuel sales and alleviates related concerns. Concerns regarding uncertainties in technology costs, maturity for commercialization, and feedstock availability of diesel substitutes can be alleviated by unlimited LCFS credit trading between pools, which is expected to effectively prevent costs from escalating (Huang et al. 2012; Rubin and Leiby 2012).

EER values for each fuel depend on its fuel pool—whether it is associated with a shift away from gasoline or diesel engines. The impact of fuel pool designation on LCFS credit generation can be significant. This is illustrated in Table 5. The example highlights the importance of identifying regulated parties[20] and improved chain-of custody to accurately track fuel delivery to end uses.

Table 5. An example of credit generation rates for CNG under California's LCFS

Fuel pool	Gasoline displacement	Diesel displacement
CI value for CNG (gCO_2e/MJ)	67.7	67.7
Pool-specific EER value	1.0	0.9
Target CI values (gCO_2e/MJ)		
2011	95.61	94.47

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[20] As discussed in Section 5, in order to incentivize infrastructure development and vehicle deployment, the initial regulated party can be the party responsible for supplying the fuel for transportation-sector applications.

2020	86.27	85.24
Credit generation rates (gCO$_2$e/MJ)		
2011	27.9	19.2
2020	18.6	10.0

Notes: The CI value for CNG is the value associated with fuel Pathway Identifier CNG001, as specified in the California LCFS Look-Up Tables. EER values and target CI values for each fuel pool are as specified in the regulation order for the California LCFS. The numbers of credits generated are computed according to the formula provided in the regulation order.

Multiple fuel pools. Fuels used in multiple transport modes and vehicle segments face similar challenges regarding appropriate EER values. For example, electricity is used in both on-road vehicles and rail transport; the efficiency advantages of electric motors may be substantially different in these different modes. Moreover, EER values for jet fuel that reflect the relative efficiencies of aircraft turbines and on-road vehicle engines would be completely meaningless. Some means of addressing these issues is necessary to ensure that LCFS incentives are meaningful, reflect the emissions intensity of fuels as they are used in vehicle propulsion systems, and motivate changes in the fuel mix that efficiently advance underlying policy objectives. To ensure technology neutrality, an LCFS policy should address these issues in a way that is consistent across all fuels.

As a practical matter, the challenges associated with assigning alternative fuels to specific fuel pools may not be overwhelming. This is due to their relatively modest contributions to transportation fuel supply, the ownership structure of their distribution infrastructure, and the composition of associated vehicle fleets. These challenges may increase over time, however, particularly if increasing use of alternative fuels is associated with increasing diversification across fuel distributors and vehicle segments.

An alternative approach—one fuel pool based on weighted average. If a dual-pool approach is considered to be too complex and difficult to track and verify, there is an alternative: the transportation sector could be viewed as an aggregation of multiple fuel pools but regulated as one. Multiple fuel pools would be used to develop multiple EER values for each fuel. Pool-specific EER values would be aggregated into a single average value for each fuel that would be weighted by the proportion of fuel used in each fuel pool. This approach would ensure that EER values accurately reflect the dynamics of fuel substitution over time, which motivated the dual-pool approach, and would remove the need for each unit of fuel to be assigned to a particular fuel pool.

This approach is illustrated in Table 6 for a simplified example of EER value for diesel fuel under the single-pool approach. Two time periods are shown to illustrate the calculation of diesel EER in the base year and future adjustments for changes in both fuel usage patterns (reflected in the proportion of fuel used in each vehicle segment) and efficiency of vehicle propulsion systems (reflected in EER values for each segment). Note that this approach could be applied to the dual-pool case California has adopted for regulating fuels used in on-road vehicles, or it could be generalized to accommodate many potential fuel pools, depending on the coverage and scope of the policy.

Table 6. Simplified illustration of multi-pool EER calculation for diesel fuel

Year	2011		2020	
Fuel pool	Light-duty	Heavy-duty	Light-duty	Heavy-duty
Proportion of fuel use	3%	97%	10%	90%
Pool-specific EER	1.2	1	1.16	1
Fuel average EER	1.006		1.016	
Averaging formula	(3% * 1.2 + 97% * 1)		(10% * 1.16 + 90% * 1)	

Notes: Pool-average EER is computed as the ratio of fuel consumption by vehicle propulsion systems in each fuel pool. Fuel consumption data is from tank-to-wheel energy use estimates from the literature (Bandivadekar et al. 2008). Values for the proportion of fuel use within each pool are hypothetical and consider fuel use only in these two vehicle segment fuel pools.

Implementing this approach would add some complexity for administering agencies, which would be required to develop EER values for all fuels and monitor fuel allocation across all fuel types over time. For example, each transportation mode (aviation, rail, on-road, and so on), segment of the vehicle fleet (for instance, heavy-duty and on-road vehicles), and use of transportation fuels (diesel use for home heating, for example) would need to be clearly defined and tracked. Each fuel would then be evaluated to determine a fuel-specific EER value based on technology mix and corresponding efficiency changes, as illustrated in Table 6. Fuel suppliers would then adopt a single EER value for each fuel type and a single CI target each year defined by the policy. This approach, however, has the downside of the incentives being too indirect and too weak to motivate direct technology/vehicle substitution by fuel providers or third parties (see Recommendation 5).

8 Life-Cycle Carbon Intensity as Regulatory Metric

Recommendation 8. Regulate fuels according to their life-cycle GHG emissions.

Key Issues

An LCFS is premised on measuring all GHG emissions of a fuel from the source (oil well, coal mine, farm field, and so forth) to the final point of consumption. This life-cycle approach is key to comparing the emissions of different fuels. GHGs are emitted from various sources within transportation fuel supply chains. Life-cycle analysis (LCA) captures emissions sources from the source to the end use of each fuel's supply chain. But the results are subject to significant uncertainty and variability—due to level of disaggregation, boundary definitions, scientific uncertainty, and various assumptions and methods. How can regulations be designed to improve precision and accuracy, taking into account the challenges of data availability, administration, and enforcement, and the goal of stimulating innovation?

Summary Recommendations

Calculation of life-cycle GHG emissions will require modelers, and ultimately policy makers, to make decisions regarding modeling approaches, system boundaries, and data sources. When multiple jurisdictions are involved, such as nations, it will be important to harmonize the methodology used among different regulatory agencies, creating a consistent approach for defining and measuring carbon intensity in fuels. We recommend the following.

System boundaries. A national LCFS policy should adopt a standardized life-cycle assessment (LCA) method for measuring fuel CI that reflects best practices and is transparent and consistent across fuel types. Indirect emissions resulting from market-mediated effects should be evaluated for potential inclusion when they (1) substantially impact fuel life-cycle carbon intensity (CI) and (2) are closely linked to particular fuel supply chains (see Recommendation 9 for land use emissions, which are the most significant indirect effect).

Spatial boundaries. Data inputs for LCA measures should be disaggregated enough spatially to capture regional variability in supply chain emissions in ways that will incentivize greater use of low-carbon feedstock/technology. As a convenient way of operationalizing boundary definitions, we recommend using state boundaries for setting default CI values for biofuels, and load-balancing area or higher levels of aggregation for electricity CI values.

Uncertainty and variability. LCA results throughout the supply chain, which an LCFS will rely on to estimate emission benefits compared to baseline fossil fuels, are subject to significant uncertainty and variability over space and time. We recommend that the sources of uncertainty and variability be systematically identified and carefully evaluated to determine default values (see next item) and to help design a more robust GHG reduction target given uncertainties. We recommend that variability or uncertainty due to data limitation be targeted with an opt-in reporting mechanism in the policy design to improve data availability, reduce uncertainty, and incentivize innovation. We also recommend addressing scientific uncertainty through adaptive management and targeted research. Uncertainty and variability distributions should be updated regularly to reflect changes in science and technological progress.

Default values and opt-in mechanisms. Default values should be assigned to each energy path to ease the reporting requirements of energy providers. If energy providers (the regulated companies) can supply their fuel with lower emissions than the default values, they should be allowed to opt in with their superior measurement value. They would do so by documenting their lower emissions. Allowing companies to opt in encourages innovation by rewarding producers for reducing emissions.

The use of default values leads to an “adverse selection” bias, which occurs when only fuels with CI values lower than the default opt in with their lower values while fuels with CI values higher than the default choose the default values. This results in systematic underestimation of actual emission reductions by the LCFS (and less stimulation of innovation).

To minimize adverse selection bias, the downside of using default values and opt-in mechanisms, we recommend (1) disaggregating fuels according to production method and other parameters that have high impacts on GHG emissions; (2) minimizing the adverse selection bias by periodically updating the distribution of fuels to eliminate fuels that have already been using lower CI opt-in values; and (3) placing the default CI value at the high end of the distribution, such as the 70th percentile and above, thereby incentivizing more reduction.

Discussion

GHGs are emitted from various sources within transportation fuel supply chains. The relative contribution of sources varies considerably across different fuel types. For example, vehicle tailpipe emissions account for roughly 80 percent of life-cycle GHG emissions from conventional gasoline but effectively 0 percent of emissions from biofuels or fuel electricity.[21] As a result, CI measurements based on tailpipe emissions alone would overstate the potential benefits of biofuels and electricity. To ensure that GHG policies correctly incentivize fuels that are truly low carbon, fuel CI measurements should capture emissions within the fuel’s entire life cycle. A standardized and transparent life-cycle analysis model should be developed and adopted for use within a national LCFS policy. Stakeholders should be engaged in reviewing and revising the methodology, and the model should be regularly updated based on the best available science.

8.1 System boundaries

To calculate fuel GHG emissions over a life cycle, it is important to define the boundaries around each energy pathway and system. To estimate the CI of biofuels for RFS2, the US Environmental Protection Agency (EPA) used a number of models and tools, including the Argonne National Laboratory’s GREET model, Texas A&M’s Forestry and Agricultural Sector Optimization Model (FASOM), and Iowa State University’s Food and Agricultural Policy Research Institute’s (FAPRI) international agricultural models, as well as the Winrock International database. The California Air Resources Board (CARB) adapted the GREET model for California to calculate the life-cycle CI of all fuel pathways, and used the Global Trade

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[21] CO_2 emissions from the combustion of biofuels, particularly from crop-based feedstock, have been considered carbon neutral since the same carbon has recently been removed from the atmosphere during biomass production and so is generally assumed to have zero net global warming potential (GWP). Biofuels produced from wood-based feedstock cannot be considered as carbon neutral due to the long lag time of resequestering the emitted carbon, and therefore they require separate consideration. GHGs emitted from fuel electricity are emitted from the power plant, not the vehicle.

Analysis Project (GTAP) model coordinated by Purdue University for land use emissions for biofuel pathways. The European Union developed rules and formulations for the calculation of life-cycle CI in the 2009 EU RED. British Columbia uses GHGenius, an LCA model for Canada that is analogous to the GREET model, to support its RLCFRR. These different major biofuel programs rely on different models and input assumptions, and they draw different system boundaries for the calculation of GHGs for different biofuel and fossil fuel pathways (Table 7).

Table 7. Life-cycle GHG emission categories and models used for electricity, fossil fuel, and biofuel under the US (EPA) RFS2, California (CARB) LCFS, EU RED, and British Columbia (BC) RLCFRR

Electricity	**Fossil Fuel**	**Biofuel**	EPA	CARB	EU	BC
		Domestic Farm Inputs and Fertilizer N2O	FASOM			
	Domestic Land Use Change	Domestic Land Use Change	FASOM	GTAP		
		Domestic Rice Methane	FASOM			
		Domestic Livestock	FASOM			
Changes in generation mix	International Land Use Change	International Land Use Change	FAPRI	GTAP		
Changes in grid capacity expansion		International Farm Inputs and Fertilizer N2O	FAPRI			
Other indirect effects? (rebound, leakage)	*Other indirect effects? (rebound, leakage)*	International Rice Methane	FAPRI			
		International Livestock	FAPRI	GTAP		
Fuel and Feedstock Transport	Fuel and Feedstock Transport	Fuel and Feedstock Transport	GREET	GREET	RED	GHGenius
Fuel Production	Fuel Production	Fuel Production	GREET	GREET	RED	GHGenius
Tailpipe	Tailpipe	Tailpipe	MOVES	GREET	RED	GHGenius

Note: Table includes emissions from within the supply chain (solid box) and outside the supply chain (dash box); the latter are often called indirect or market-mediated effects. Only highlighted areas have been considered in the regulatory LCA analyses so far.

System boundaries—especially with respect to co-products, by-products, and indirect effects—need to be carefully defined because different definitions of boundaries can result in quite different emission calculations for some products (Wang, Huo, and Arora 2011). The production process for corn ethanol, for example, not only produces ethanol but also large quantities of valuable co-products used for animal feed, and the method used to allocate "credits" for the co-products can result in very different GHG emission ratings (Wang, Huo, and Arora 2011). In addition, the consideration of emission impacts outside of direct supply chains, often called market-mediated response or indirect emissions (see Section 9), has been highly controversial in the past few years, in the case of biofuels (Melillo et al. 2009; Searchinger et al. 2008b), fossil fuel (Drabik and Gorter 2011), and electricity (McCarthy and Yang 2010).

Variability in system boundaries of fuel pathways should be minimized. Policy makers should define the system boundary through a transparent process, propose a method to quantify significant emissions that occur outside the supply chain due to market-mediated effects (often referred to as indirect emissions), engage stakeholders in reviewing/revising the methods, and regularly update the information based on the best available science. To avoid unintended consequences and send correct policy signals regarding the true GHG impacts of fuels, we recommend that indirect emissions resulting from market-mediated effects be carefully evaluated for potential inclusion in fuel CI when they (1) substantially impact fuel CI and (2) are closely linked to particular fuel supply chains as a result of fuel policy.

The existence of inconsistent system boundaries between policies creates the danger of ignoring potentially significant emission sources, leading to confusion and to incorrect and conflicting incentives for GHG emission reductions. It can also lead to leakage and shuffling of fuels and credits. Minimizing shuffling and confusion and assuring compatible and consistent models, assumptions, and outputs will require collaboration between responsible governments. Multilevel stakeholder discussion will also be critical to ensure a collaborative and science-based approach that leads to effective outcomes.

Overly expanded system boundaries can cause double counting, as the same emissions may already be regulated in other regulations or carbon markets. If credits are allowed to be generated from emission reductions within the expanded system boundary, double crediting can also occur. This issue is further discussed in Section 11. The second challenge is that the characterization of indirect effects often requires large-scale modeling and predictions, and therefore significantly increases uncertainties as well as the resources and time required to update CI values associated with indirect effects.

8.2 Spatial boundaries

Improving the spatial resolution of some parameters can significantly reduce known variations in measurements. Perhaps the most blatant example is electricity production—where in some regions much of the electricity is produced with hydropower, nuclear, solar, and wind, and in others mostly with coal. But variations in biomass production emissions can also be large, because of climate, soil conditions, irrigation, farming practices, carbon footprint of local electricity, and electricity offsets generated from some refining facilities. Greater resolution and disaggregation of spatial boundaries will increase the accuracy of fuel CI values and provide incentives motivating efficient use of available resources (Elvidge et al. 2009). We recommend that spatial boundaries reflect geographic units that capture meaningful variability and have sufficient data available. The level of regional specificity may be different for different types of data inputs and different fuel types.

Uncertainties in calculating biofuel CIs are dominated by uncertainties regarding land use emission factors, N_2O emissions from fertilizer application, land yields, and sources of production energy. Biomass yields tend to be region specific, depending on local/regional climate conditions such as temperature, rainfall, humidity, and soil type (Figure 4), resulting in fuel CI values varying by a factor of 2 to 3 across the United States (Figure 5). Setting spatial boundaries at the state level for calculating biofuel default CI values is desirable because it (1) makes use of reliable public data that is collected annually, (2) effectively minimizes uncertainty, and (3) incentivizes more efficient use of available resources.

One issue with regional disaggregation of fuel CI values stems from the commerce clause of the US Constitution. A lawsuit against California's LCFS that is currently under appeal questions whether the assignment of CI values to midwestern corn ethanol represents an impermissible interference with and discrimination against interstate commerce. The solution might be to use more generic labels for GHG performance criteria, rather than labels based on geographic regions.

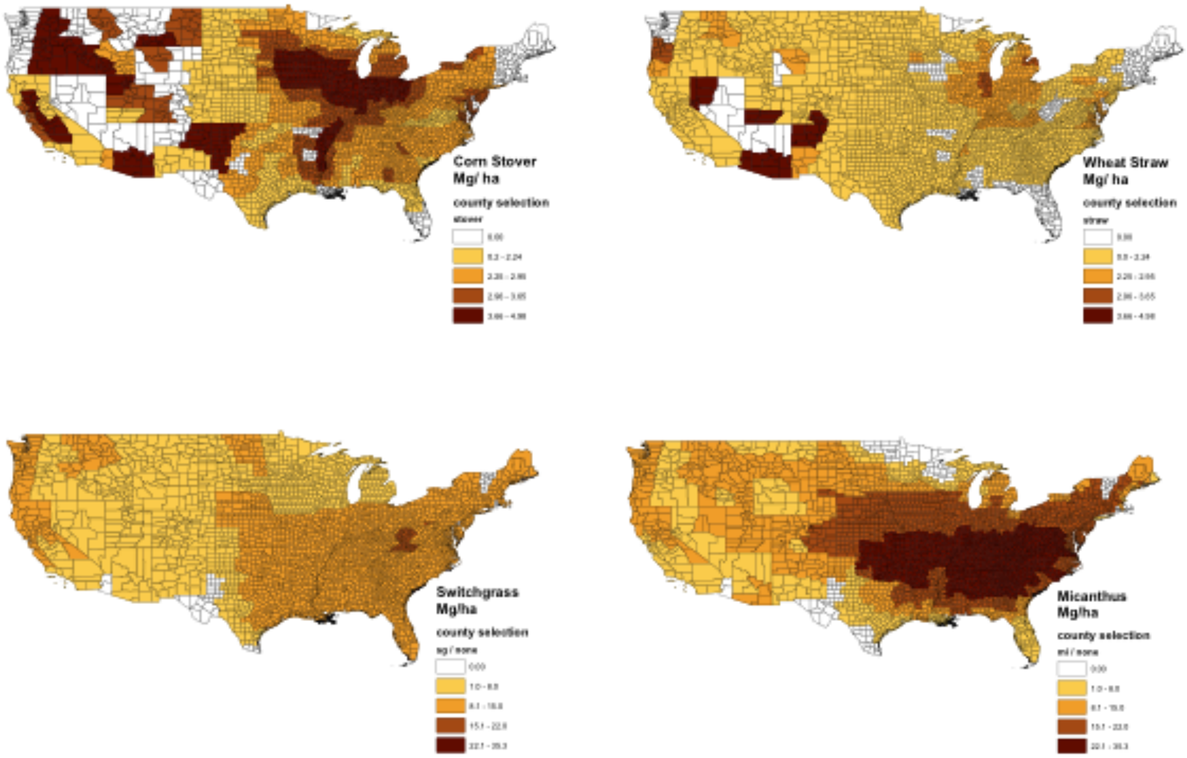


Figure 4**.** Delivered biomass yields in the United States by region (ton dry mass/ha). Source: Khanna, Onal, and Huang 2011.

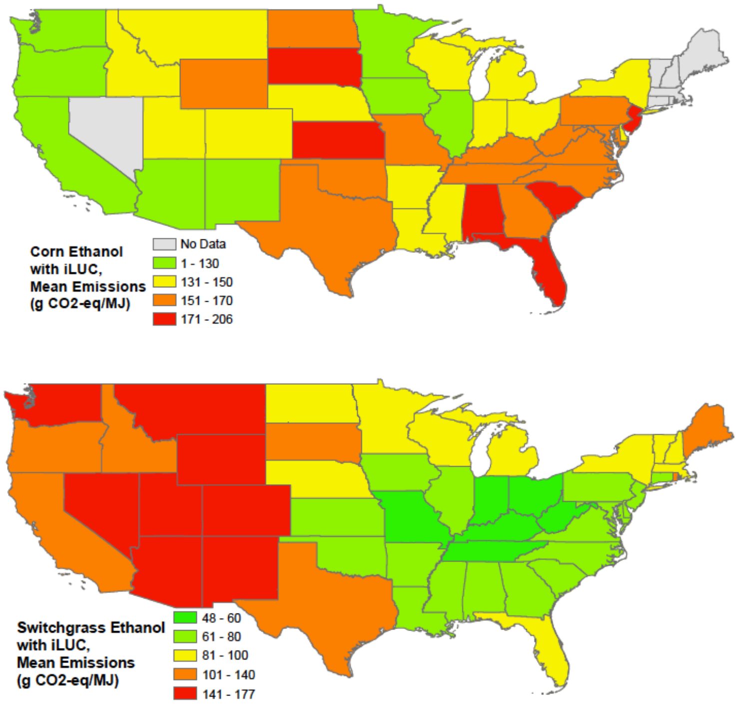


Figure 5. Regional variability in mean GHG emissions for corn (top) and switchgrass (bottom) ethanol. Source: Khanna, Onal, and Huang 2011.

Electricity—both for use as transportation fuel (powering electric vehicles) and as an input for producing other fuels—presents several unique challenges with regard to establishing CI values. These challenges stem from (1) the fact that electricity systems in the United States and associated CI values are extremely heterogeneous and regionally specific; (2) the complex nature of electricity supply that varies hourly and seasonally; (3) interconnections between regional power grids; and (4) the lack of a system for tracking cross-boundary electricity flow.

Moving to larger regions of aggregation for determining electricity CI reduces the variability in CI between regions. There is significantly greater spread in average CI when we look at the 112 eGRID power control areas (PCA) compared to the 10 NERC regions or the US average (a single value) (Figure 6). The choice of spatial boundary for electricity allocation purposes can have implications for the electricity CI value and the incentives that will result. Assigning every electricity provider the same average CI value (for example, by defining one national region with equal CI) would provide a uniform incentive to all electricity providers to provide electricity as a transportation fuel, despite whether its actual CI values exceed the CI of gasoline. Using smaller spatial boundaries would lead to greater variability in electricity CI and differential incentives based on actual CI values. The distribution of electricity CI values becomes fairly robust at the level of EGRID subregions and finer resolution, as shown in Figure 6.

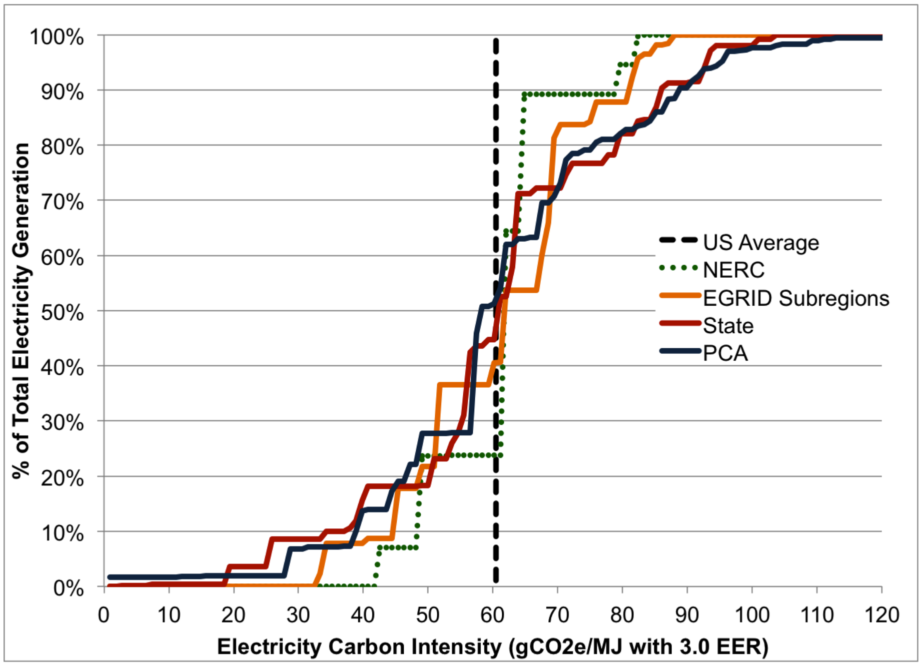


Figure 6. Cumulative distribution of life-cycle carbon intensity of electricity for different levels of regional disaggregation. NERC: North American Electricity Reliability Corporation; U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID) has 26 subregions and 112 Power Control Area (PCA). Source: Yang 2012.

We recommend establishing CI values at the load-balancing area or higher level of aggregation (encompassing dozens or more investor-owned and municipal utilities) based on the historical average generating mix. This would give sufficient flexibility to choose the level of aggregation depending on data availability and ease of administration. LCFS credits, electricity providers should be required to provide detailed data on charging load, timing and location by a verifiable, utility-grade meter. This information will be used for grid planning and CI calculations and also ensure that PEV charging does not cause or exacerbate grid issues

8.3 Uncertainty and variability

LCA calculations, conducted for each step of the energy supply chain, can be difficult to specify accurately. Differences in GHG emission estimates across studies and models can be characterized as uncertainty. Uncertainty falls into three categories: spatial and temporal variability, data and model limitations, and scientific uncertainty. Variability and data limitations can be addressed through policy design and improved data collection and reporting. Scientific uncertainty requires more research and better models; it is more difficult to accommodate but can also be addressed through creative policy mechanisms (as indicated below for land use change effects).

One issue that cuts across virtually all the questions regarding life-cycle CI is the difference between variation and uncertainty. In the case of uncertainty, parameters cannot be measured because more scientific knowledge is needed or because data is difficult or impossible to collect. In the case of variability, economic activities and technology usage vary dramatically—for instance, in electricity generation—resulting in dramatically different emission characteristics over space and across energy systems. In principle, virtually all variation can be eliminated by increasing the resolution of regulations (for example, by specifying exactly where and how the fuel is produced). But in practice, such fine resolution comes at a high cost and places a large burden on regulators and the regulated parties. The challenge is to acknowledge and address uncertainty, and for regulatory design to identify the optimal location on the spectrum from fine disaggregation to high-level aggregation.

Different types of variability and uncertainty can be addressed and managed effectively according to their sources. We recommend that *variability or uncertainty due to data limitation that can be reduced through data reporting* be targeted with an opt-in reporting mechanism in the policy design to improve data availability, reduce uncertainty, and incentivize innovation (see discussion in Section 8.4).

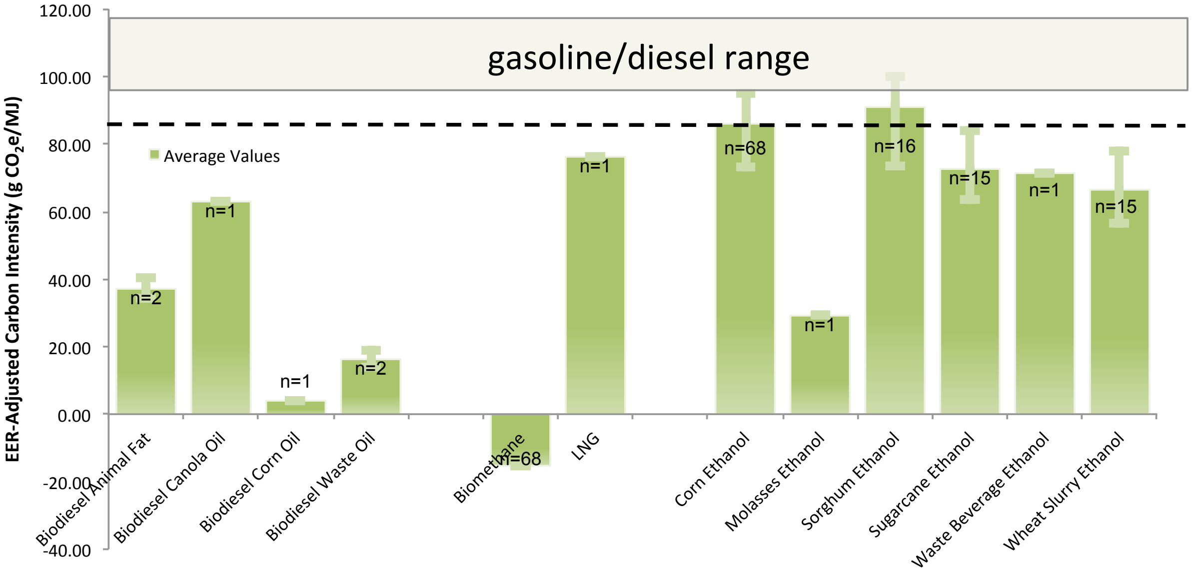
Scientific uncertainty can be addressed through adaptive management and targeted research. Scientific uncertainty that results from an incomplete understanding of particular factors (such as nitrogen volatilization rate or the global warming potential of non-GHG gases) or relationships between factors (potential impacts of factors outside of historical ranges) can be reduced gradually as our understanding of the underlying factors and relationships evolves. Targeted research initiatives should be established to accelerate reductions in scientific uncertainty regarding factors that have large impacts on fuel CI. Adaptive management strategies should be used to systematically incorporate new information into fuel CI measures. This can be accomplished through periodic updating of fuel CI values to incorporate the most current scientific information available, including information from targeted research initiatives.

Model uncertainty can be treated with a differentiated approach, including a transparent and principled analysis of the effect of changes in market responses or the effect of changes in market structure grounded in the policy objectives. Model uncertainty can be traced to several root causes, including the idealized nature of mathematical models (for example, a computable general equilibrium model vs. a partial equilibrium model), numerical approximation of relationships, subjective or normative decisions inherent in LCA (for example, different methods of allocating co-products), scientific uncertainty about the relations being modeled, and scenario uncertainty. Model uncertainty can be differentiated according to these various causes and an appropriate treatment can be developed to establish bounds for quantitative model results.

8.4 Default values and opt-in mechanisms

One means of increasing flexibility for regulated companies, reducing the regulatory burden, and providing an incentive for technological innovation is to create default values for parameters and an opt-in procedure for companies with innovative low-carbon products. Without default values, the regulator would have to develop specific CI ratings for every activity in every energy pathway, which would require substantial data collection, analysis, reporting, and collection for each batch of fuel delivered. That is not feasible. Establishing default CI values representative of fuel pathways, as has been done in most existing LCFS policies, can reduce data and analysis requirements for the majority of fuel producers.

An opt-in mechanism allows fuel producers to generate CI values tailored to their fuels by modeling and validating their own fuel production pathways. The opt-in mechanism implemented in California's LCFS allows fuel producers to (1) propose verifiable input values within the existing pathways; or (2) request new, customized fuel pathways for their fuels. Approved pathways are published with associated CI values and added to the list of default values. Proprietary information can be redacted from fuel pathway descriptions to ensure confidentiality. This approach appears to be effective: as many as 124 new CI values and pathways had been approved as part of California's LCFS as of today (Figure 7). Many of these lower-than-default-CI fuels have enjoyed higher market prices than those using default values.[22] We recommend a similar approach for a national LCFS.



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[22] According to Pacific Ethanol's Third Quarter 2011 Financial Report, the company's corn ethanol CI rating is on average 18 gCO_2e/MJ lower than the default value and has an approximately 2 to 4 cent per gallon premium compared with other corn ethanol (http://www.pacificethanol.net/site/_documents/investors/PEIXQ311ConfCallPresentationFinal.pdf). Such a price advantage translates to approximately $15–30/tonne CO_2e avoided.

Figure 7. Opt-in CI values (average and minimum and maximum ranges) and number of applications by feedstock pathway for California's LCFS as of July 2012. The dash line represents the 2020 gasoline and diesel 10% CI reduction targets.

The danger of adverse selection. A well-designed system of default values and opt-in reporting mechanisms can effectively address the data and analytic requirements of LCA but can also create a risk of adverse selection. 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 calculations for the entire fuel population will systematically underestimate the actual emissions from fuel production. The biases created by adverse selection can be potentially large, especially for fuel pathways with large variability or reducible uncertainty.

To reduce adverse selection, default values could be

- Established for a much expanded set of fuel pathways so as to address variation. Well-differentiated fuel pathways can reduce the magnitude of CI variations among fuels within each fuel pathway and thereby reduce the magnitude of potential adverse selection impacts, as discussed in the TAR. An improved chain of custody compared with the existing system is needed ensure the measurability and verifiability of these opt-in CI values.
- Reviewed and updated periodically (every three to five years) to ensure that they accurately reflect the CI of fuels using the default values. In particular, default CI values may need to be adjusted upward to exclude opt-in reporting of fuels with relatively low CI values.
- Set conservatively, such that 70 percent or more of fuels within each fuel pathway are expected to have CI values below the default value. As discussed in the TAR and underlying reports, this approach can effectively reduce the magnitude of adverse selection impacts by more than 50 percent if using the average value.

Carbon capture and sequestration technology. Carbon sequestration technology may provide important contributions to reducing fuel CI. It is the subject of considerable research and development activity, which is expected to yield important innovations for advancing LCFS policy objectives.[23] The diversity of technological approaches, the limited experience to date, and the various concerns expressed regarding carbon sequestration suggest some special

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[23] The term *carbon sequestration* is used here to refer broadly to systems that secure carbon that would otherwise be emitted as CO_2 away from the atmosphere for timescales relevant to climate policy objectives. This includes a diverse set of technological approaches, including CO_2 capture from industrial waste streams (for example, power plant and refinery emissions) or from the atmosphere for sequestration in geologic formations; CO_2 sequestration in mineral deposits, for example via enhanced weathering processes; biological accumulation of soil carbon from changes in agricultural practices; sequestration of bio-char in agricultural soils; and remote burial of biomass carbon in ocean basins or alluvial sediments.

consideration may be warranted. Guidelines should be established to ensure that LCFS credits are granted only in cases where concerns are addressed regarding the measurability, verifiability, additionality, permanence, and security of sequestered carbon.

9 Land Use Change GHG Emissions

Recommendation 9. Address GHG emissions from land use change (LUC) through short-term and long-term policies.

Key Issues

Most of a fuel's life-cycle GHG emissions are directly measurable and within the energy supply chain. But additional emissions can be caused when large amounts of land are diverted from other uses (such as agriculture) into energy production—which is the case with many biofuels and some fossil fuels. Accounting for these land use changes (LUC) is necessary to develop more accurate life-cycle CI values and to assure that the LCFS sends correct signals to fuel suppliers. Given evolving scientific knowledge about land use change effects, what is the best policy mechanism for addressing these land use changes?

Summary Recommendations

The impacts of these land use changes (LUC) are complex and difficult to quantify accurately—but accounting for them is important to assure that investments are directed at those feedstocks with less impact. The effects can be large for land-intensive crops such as corn but are much smaller for grass and tree feedstocks (if they are grown on marginal, degraded land and/or if they avoid direct competition with food crops) and zero for biofuels made from waste materials (crop and forestry residues and municipal solid waste). Oil sands production induces small LUCs associated with soil and forest carbon emissions from peatland conversion. We recommend adopting a flexible policy taxonomy that includes short-term and long-term policies.

Short-term policies would induce or otherwise encourage immediate action to reduce use of productive land and other adverse impacts. They would encourage (1) using feedstock that does not require additional land, such as wastes and agriculture residues, or feedstock that requires less land, such as cellulosic feedstocks and algae; and (2) adopting measures that lower LUC risk from land-using feedstock by (a) enhancing carbon sequestration and storage, (b) encouraging the use of marginal, degraded, and abandoned land, and (c) prohibiting the conversion of high-carbon, high-biodiversity, and environmentally sensitive areas. Despite relatively large scientific uncertainty about LUC impacts, we recommend using iLUC factors selected from science-based ranges so that LUC policy has a transparent basis in emissions and integrates easily with existing policies.

Long-term policy measures would combine short-term mitigation strategies with other incentive mechanisms that offer the greatest potential for mitigating LUC over the long term. These measures would encourage collaboration within and outside the biofuel supply chain to increase investments in land use productivity, environmental protection, and carbon offset schemes. The goal is to enhance economic productivity without compromising environmental or ecosystem services. The regulatory process should establish rigorous and systematic evaluation frameworks, coupled with intensified research, to assess options and implementation.

Discussion

The term *land use change* (LUC) refers to changes in the way land is used to support human activities. The most dramatic examples are deforestation and land clearing to support agricultural production. LUC contributes to approximately 17 percent of global GHG emissions (Metz et al. 2007). When land is cleared, carbon stored in the natural vegetation and soils is released to the atmosphere, primarily as CO_2.

Biofuel production can cause LUC GHG impacts through three distinct mechanisms: (1) clearing land to produce biofuel feedstock can cause emissions from above- and below-ground carbon — called direct land use change emissions; (2) changes in the amount of carbon stored in agricultural soils caused by changes in farming practices—generally included in direct land use change emission accounting; and (3) clearing land to meet the demand for conventional agricultural products expansion where agricultural lands are displaced by biofuel feedstock production domestically or in other countries—called indirect land use change (iLUC) emissions.

LUC is inherent to all farming activities, including production of biofuel feedstock. Emissions from clearing land for biofuel production, especially in high-carbon areas such as forests and peatlands, have been shown to offset the carbon savings of displacing fossil fuels with bioenergy, and the payback period[24] can be longer than decades (Fargione et al. 2008; Gibbs et al. 2008). LUC raises a number of concerns beyond increased GHG emissions, including higher or more volatile food prices, which affect the poor in greater proportion and magnitude (FAO 2008a; FAO et al. 2011); conversion of high-biodiversity areas; overuse or degradation of local water or land resources; damage to important ecosystem services (Donner and Kucharik 2008; Koh and Wilcove 2008; Welch et al. 2010); and disruption of local land ownership or other social patterns (Toulmin 2009). Depending on location and management practices, however, LUC from biofuel production can also improve resource productivity, sequester carbon, or provide an additional

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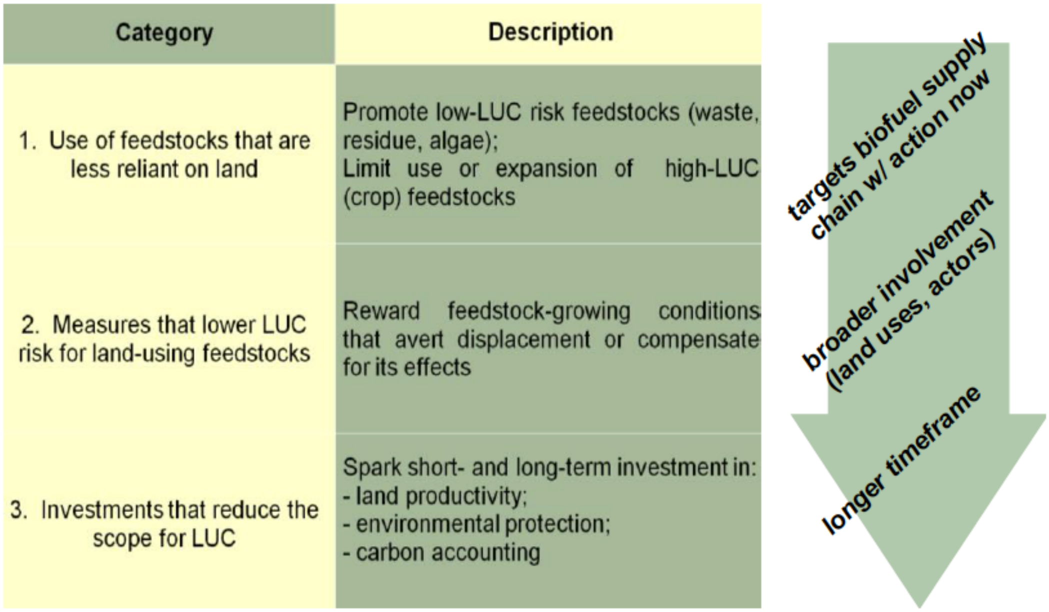
[24] *Payback period* is defined in Fargione et al. (2008) as “how many years it takes for the biofuel carbon savings from avoided fossil fuel combustion to offset the losses in ecosystem carbon from clearing land to grow new feedstocks.”

income source for rural populations (Berndes, Bird, and Cowie 2010; Lapola et al. 2010; Tilman et al. 2009).

RFS2 requires “renewable biomass” crops and crop residues to come from agricultural land (cropland, pastureland, Conservation Reserve Program land, and possibly rangeland) cleared or cultivated before the law was enacted (U.S. EPA 2010). Thus, theoretically direct LUC should not occur within the direct biofuel production system, though this ironically increases the likelihood of iLUC. Due to the complexities of LUC, no single policy is likely to adequately address biofuel LUC.

Mitigation strategies to address unwanted biofuel LUC effects fall into three categories: (1) use feedstocks that require less land, (2) adopt measures that lower LUC risk for land-using feedstocks, and (3) invest in productivity gains, environmental protection, and carbon accounting methods that reduce the scope for biofuel (and other) LUC. In general, moving down the list, policy targets broaden—from within to beyond the biofuel supply chain—and involve more investment and coordination and a longer time to come to fruition. These three strategies are summarized in Figure 8.



Category	Description
1. Use of feedstocks that are less reliant on land	Promote low-LUC risk feedstocks (waste, residue, algae); Limit use or expansion of high-LUC (crop) feedstocks
2. Measures that lower LUC risk for land-using feedstocks	Reward feedstock-growing conditions that avert displacement or compensate for its effects
3. Investments that reduce the scope for LUC	Spark short- and long-term investment in: - land productivity; - environmental protection; - carbon accounting

Figure 8. General strategies for addressing biofuel LUC. Source: Witcover, Yeh, and Sperling, 2012.

Theoretically, if GHG emissions from all LUC activities were covered globally and priced accordingly, iLUC would still exist but iLUC emissions would be accounted for within the global policy. However, recognizing (1) the difficulty of reaching an international consensus to address LUC within a reasonable time frame, (2) the need to mitigate the potential unintended consequences of increased biofuel production before the problem becomes irreversible, and (3) the need to encourage the production of feedstock that has low risk of LUC, we make the following short- and long-term policy recommendations, broken down by the three categories listed above.

Short-term policy recommendations:

1. Use feedstocks that require less land. Encourage feedstocks that come from wastes or agricultural residues, or that require less land, such as cellulosic feedstock and algae. Current US policies already contain some of these incentives such as setting volumetric requirements and providing tax incentives and subsidies for cellulosic ethanol.

2. Adopt measures that lower LUC risk for land-using feedstocks.

   a. Soil carbon accumulation from switching to energy crops or adopting low-till farming practices can reduce life-cycle GHG emissions and therefore should be included in the life-cycle CI rating through an opt-in mechanism. Carbon accumulated in soils due to changes in crops or farming practices can be re-emitted to the atmosphere if farmers revert to previous crops and practices. The treatment of soil carbon accumulation in biofuel CI measures must balance this risk of re-emission against the potential importance of soil carbon emissions effects. Uncertainty about the magnitude of soil carbon effects should be treated consistently with other sources of LCA uncertainty (see the discussion in 8.3, Uncertainty and Variability).

   b. Although RFS2 disallows crops and crop residues to come from agricultural land, broadly defined, cleared or cultivated before the law was enacted, the conversion of marginal/degraded/abandoned land should be allowed and encouraged, provided that adequate definitions are adopted through transparent policy discussion.

   c. The conversion of high-carbon, high-biodiversity, and environmentally sensitive areas and wetlands should be prohibited.

   d. Employing an iLUC factor provides a relatively straightforward, plausible approach that can contribute to addressing biofuel LUC in a way that explicitly recognizes emission effects. Choosing a single number from a science-based range for use as an iLUC factor is defensible for policy purposes if the assigned factor sends unambiguous signals to investors encouraging use of less land-intensive feedstocks in a way that reflects (transparent) policy decisions regarding acceptable risk. Issues associated with the use of an iLUC factor, including uncertainty about its magnitude, are not unique to LUC emissions. Any policy that considers feedstock LUC emissions will face this same challenge. To address the issue of uncertainty, we recommend selecting a "risk-based" value from a distribution of LUC emissions, such as the methodology demonstrated in Griffin et al. (2012). The report uses probability distributions to match acceptable risk for meeting a policy target (for example, 75 percent certainty of success in achieving a

10-percent threshold of GHG savings) to a particular iLUC factor value within the distribution. The probability distribution of the iLUC factor can be updated regularly to reflect scientific improvements in capturing the true uncertainty distribution.

Long-term policy recommendations:

3. Invest in productivity gains, environmental protection, and carbon accounting methods that reduce the scope for biofuel (and other) LUC. The largest potentials for reducing global LUC lie outside of the biofuel sector. Incentivizing producers to take concrete steps to lower the LUC risk for land-using feedstocks, or to invest in technology/management that lowers LUC, within and outside of the biofuel supply chain, provides the greatest potential for reducing LUC. However, stringent evaluation criteria must be developed to ensure that these policies are implementable (that is, effective, efficient, robust, and fair to all players) and feasible (available, practical, integratable with other policies, and transparent) (Witcover, Yeh and Sperling 2012). The challenge of guaranteeing additionality (reductions would not have occurred anyway), no leakage (reductions in the project area will not shift elsewhere), and permanence (conserved carbon will not be released in the future) are shared across all project-level certification schemes discussed below. These processes will take time, thus we recommend that long-term biofuel LUC policies consider the following:

a. Encourage project-level yield increase, efficient use of co-products, and/or system integration to reduce losses within biofuel supply chains. Measuring how much production is truly additional, however, is complicated given many field-level sources of output variation such as weather, prices, and local policies. Output from similar local production systems or from project land in the past can help set benchmarks for normal production levels.

b. Allow carbon offsets, up to the value of the default LUC factor, through established international programs dealing with LUC such as the initiative on Reducing Emissions from Deforestation and Degradation (REDD), which offers compensation for preventing emissions from tropical forest conversion; or the Kyoto Protocol's clean development mechanism (CDM), limited to projects related to LUC, which allows developing countries to earn carbon credits that can be sold to industrialized nations, then used to meet their treaty obligations.

c. Engage in broad-based LUC policy initiatives that encourage investments in productivity, environmental protection, and carbon accounting or sequestration measures involving all sectors beyond bioenergy. Reaching international agreements about land use policy could take decades, as coordinated action involves extraordinary technical and political challenges. Msangi et al. (2012) demonstrate that modest productivity gains for staple crops in sub-Saharan Africa, or environmental protection around the Amazon, could reduce or even completely offset a biofuel iLUC factor determined by the EPA. Forging

> an alliance between bioenergy and other land-using sectors, and moving toward common land-use policies for all sectors, is critical for meeting twenty-first-century needs without compromising environmental or ecosystem services. A balance must be struck between achieving a scale for coordinated efforts to have meaningful effects and avoiding new layers of bureaucracy that introduce unnecessary inefficiencies.

One last policy issue: the inclusion of market-mediated LUC effects in biofuel LCA raises additional questions such as how biofuel policy should treat other potentially significant market-mediated emissions like those from agricultural management changes due to LUC (included in RFS2 but not in California's LCFS) or rebound effects in fossil fuel markets. Examples of attempts by other market-based carbon policy proposals to incorporate indirect effects include adjusting for leakage at borders for carbon tax and cap-and-trade policies, or within carbon accounting programs like REDD (Murray 2008). LCFS might need amending to include previously ignored indirect effects.

10 GHG Emissions from Crude Oils with Higher Carbon Intensity

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Recommendation 10. Treat all crude oils as part of the overall pool of transportation fuels.

Key Issues

Given the depletion of conventional fossil resources, there is increasing reliance on domestic and imported unconventional oil resources that take more energy to extract, process, and transport. Under an LCFS, any significant GHG benefits and debits associated with the use of transportation fuels should be accounted for and treated equally, as discussed in Sections 8 and 9. Fuels from certain petroleum resources—including Canadian oil sands, oil shales, and other heavy crudes, together identified as high-carbon-intensity crude oils—can generate substantially greater GHG emissions than most, but not all, conventional crude oils, potentially negating any benefits achieved through the introduction of low-carbon fuels.

Some argue that in restricting the carbon content of fuels, a national LCFS would adversely affect energy security by preventing the use of reliable high-carbon unconventional oils. This, it is said, would encourage US reliance on less secure oil imports. It would then either lead to export of those oil sands to other countries, resulting in little net reduction in global CO_2 (crude shuffling CO2 leakage); or it would lead to reduced global use of unconventional oils from stable, competitive sources, hence greater global reliance on insecure or cartelized conventional oil sources.

Summary Recommendations

Petroleum is not a uniform or homogenous liquid; it is a diverse mix of liquids comprised of chains of hydrogen and carbon molecules. Initially California and the European Union (EU) created a separate category of high-carbon-intensity crude oils within their LCFS and FQD. The EU has persisted with a unique category for oil sands with a distinct set of regulations and targets. This approach does not consider the reality that the CI of crude oils varies considerably, with some conventional crudes, for instance, having higher CI values than some oil sands. It also runs the risk of legal challenge from Canada, since targeting oil sands can be construed as discriminating against a product of that country.

Instead of targeting specific high-carbon crudes, we recommend treating all crudes as part of the overall pool of transportation fuels. We recommend adopting an approach that creates an incentive to buy lower-CI crudes, invest in upstream improvements (such as carbon capture and sequestration), and modify refinery designs to favor low-CI crudes. Each refinery (that is, regulated party) would be assigned a benchmark value based on its CI in the baseline year. If it exceeded this value, it would need to offset that increase by reducing GHG emissions in other ways (or buying credits). If it reduced its crude oil CI, it could apply those reductions as credits against its LCFS obligation. Some small additional shuffling of crude supply would occur—whereby companies would send their lower-CI oil to US refineries and their higher-CI oil elsewhere—but shuffling is a normal business practice for refineries in their effort to minimize their costs. It is uncertain how much additional shuffling would occur. In any case, this shuffling would diminish when other countries, starting with the EU, adopted a similar refinery-specific approach. If the shuffling appeared to be significant, the extra transport energy consumed by crude shuffling could perhaps be calculated and included (penalized) in the life-cycle measurements for that crude (though constructing a counterfactual baseline might be onerous and even impossible).

Discussion

Given the depletion of conventional fossil resources, there is increasing reliance on domestic and imported unconventional oil resources that take more energy to extract, process, and transport.[25] These additional emissions should be captured and reduced. However, the fuel CIs of crudes from different sources tend to overlap, as do those of conventional crudes and unconventional sources such as oil sands from Canada (Figure 9). Flaring practices in particular, which emit

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[25] The U.S. EIA estimates production of unconventional crude oils (primary from Canada's oil sands and Venezuela's Orinoco belt) will reach 4 million barrels per day higher in 2035 than in 2008 and will represent 5.6 percent of the global liquid fuels supply in 2035. US production of oil shale is projected to reach 0.4 million barrels per day in 2035 in the reference case. The EIA also projects that relatively high prices will encourage growth in global coal-to-liquid (CTL), gas-to-liquid (GTL), and biofuel production, from a combined total of 1.8 million barrels per day in 2008 to 8.4 million barrels per day in 2035, or 8 percent of total liquids supplied (U.S. EIA 2010a).

large quantities of methane gas into the atmosphere from countries including Russia, Nigeria, Iran, Iraq, and Algeria (Elvidge et al. 2009), also result in conventional crude with high carbon intensity. As a result, the crude mix by region (Griffin et al. 2012) may not be significantly differentiated (Figure 10).

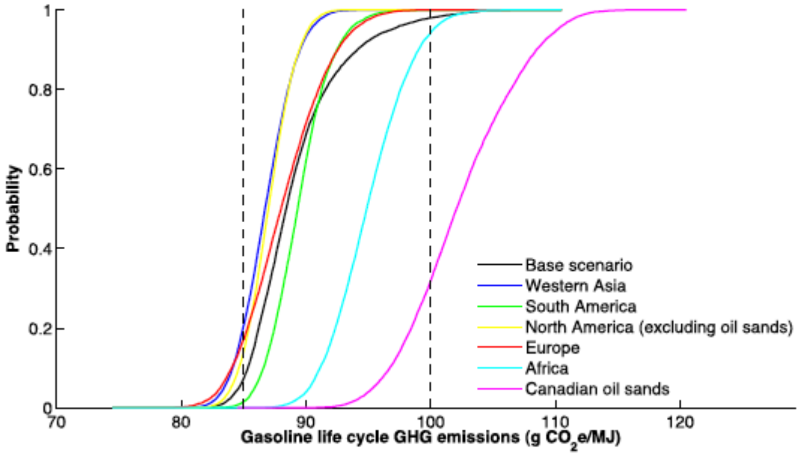

Figure 9. Comparison of probability distributions of life-cycle GHG emissions of gasoline produced from crude oil obtained from different regions (90-percent confidence interval for the U.S. average represented by dashed lines). Source: Griffin et al. 2012.

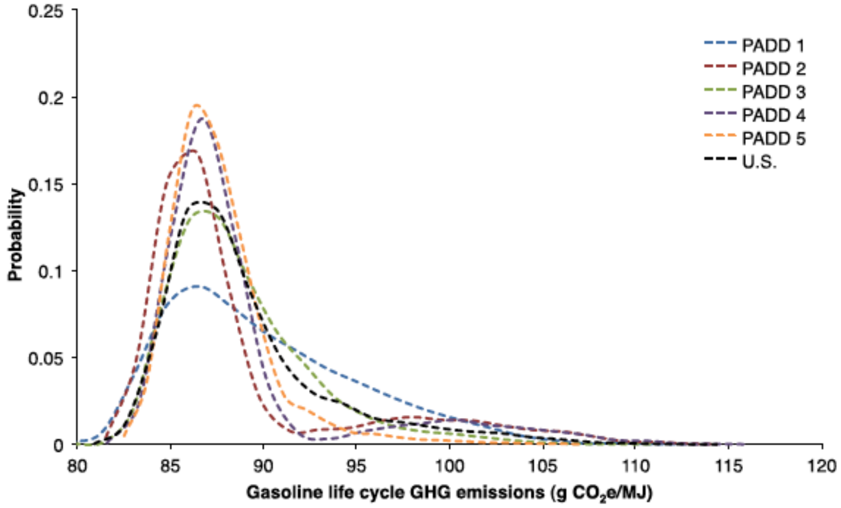

Figure 10. The probability distributions of US average and regional life-cycle GHG emissions of gasoline. PADD: Petroleum Administration for Defense District (PADD 1 = East Coast, PADD 2 = Midwest, PADD 3 = Gulf Coast, PADD 4 = Rocky Mountain, PADD 5 = West Coast). Source: Griffin et al. 2012.

Individual refineries, however, are typically designed to take a particular slate of crudes, and their emissions vary depending on the level of complexity and type of refined products produced. We recommend treating all crudes as part of the overall pool of transportation fuels instead of targeting specific high-carbon crudes. Each refinery would be assigned a benchmark based on its CI rating in the baseline year. Each year, records of the volumes and crude marketing names (also known as "marketable crude oil name") for all crudes delivered to the US market by regulated parties would be used to calculate refinery-specific crude CI values. If a refinery exceeded this value, it would need to offset that increase by reducing GHG emissions in other ways (or buying credits). If it reduced its crude oil CI, it could apply those reductions as credits against its LCFS obligation. This approach might result in small amounts of additional shuffling of crude supply, if companies sent their lower-CI oil to US refineries and their higher-CI oil elsewhere. This shuffling would be reduced if other countries, starting with the EU, adopted a similar refinery-specific approach. If the shuffling appeared to be significant, the extra transport energy consumed by crude shuffling could be calculated and included (penalized) in the life-cycle measurements for that crude (though constructing a counterfactual baseline might be onerous and even impossible). By setting individual refinery-specific targets, this approach provides the greatest incentive to innovate and to reduce the carbon intensity of crudes.

This recommended approach for handling high-carbon-intensity crude oils has the following benefits:

- Preserves program benefits of accounting for all GHG emissions and debits associated with the use of transportation fuel uses of each regulated party equally across all fuel types
- Ensures consistent treatment of all crudes regardless of their origins
- Improves accounting of GHG emissions from production and transport of crude oil
- Promotes innovation by allowing companies to earn credits using innovative methods to reduce crude carbon intensity or to shift to low-carbon fuel

Producers could reduce the CI of upstream operations—that is, of extraction, upgrading, and refining. This could be done by improvements in the energy efficiency of technology and systems or by carbon capture and sequestration. There is limited published information on the costs to reduce the CI of high-carbon crude, specifically Canadian oil sands. The technologies and costs are uncertain and not proven at commercial scale. A review of limited data in the literature suggests that 0 to 7 percent of oil sands' life-cycle CI (up to 35 percent of production GHG emissions) could be reduced at less than \$0.25 per barrel of oil (/BBL), and a maximum reduction of 8 percent of life-cycle CI (40 percent of production GHG emissions) could be achieved for a cost of \$9/BBL. These figures translate into a carbon cost of between \$28 and \$87 per metric ton (MT) of CO_2 (Leiby and Rubin 2012).

There may be other innovative CI reduction strategies that can reduce a sizable percentage of crude production emissions economically, such as carbon capture, utilization, and storage (injecting captured CO_2 into depleted oil wells to recover untapped oil; CO_2-enhanced oil recovery), and flaring and venting reduction. As with other emission reduction credits discussed in Sections 7 and 8, evaluation criteria need to be developed to ensure measurability, verifiability, additionality, permanence, and security of these carbon reduction strategies.

Some raise concerns that a refinery-specific approach has the potential downside of shuffling high-carbon crudes to countries that do not have climate policies and disproportionally affecting the import of Canadian oil sands, which may have significant energy security implications. The concern about carbon leakage and impacts on domestic economy is shared across all climate/environmental policies, though the energy security concern deserves additional attention and analysis. A study by Leiby and Rubin (2012) on the energy security impacts of an LCFS concludes that policies that discourage high-carbon-intensity crude oil (HCICO) will lower the average CI of crude consumption in the United States, resulting in lower compliance obligation, lower credit prices, and overall positive *net* energy security benefits. This occurs due to either (1) shuffling (sending Canadian oil sands elsewhere instead of exporting them to the United States, which is likely to occur regardless of LCFS policy (U.S. EIA 2011b), and/or changing the crude mix that U.S. companies purchase), (2) reduced oil sands production, (3) investments in technologies that reduce upstream GHG emissions during extraction and production of HCICO, or (4) companies purchasing national LCFS credits and continuing to import Canadian oil sands to the United States. Detailed discussion of these scenarios and the costs and benefits calculation can be found in Leiby and Rubin (2012).

11 LCFS Credits

Recommendation 11. Harness market forces using LCFS credits.

Key Issues

As a general principle, it is desirable to harness market forces. An LCFS does so by allowing companies to buy and sell credits. If a company prefers not to invest directly in reducing GHG emissions to achieve its carbon-intensity target, it can buy credits from other companies that can reduce emissions at less cost. The net effect is attainment of targets at less overall cost. Key questions regarding structuring and supporting credit trading in a national LCFS include: Should regulated parties be allowed to trade credits across fuel pools? Should banking be allowed? Is a cost containment mechanism such as a safety-valve price for credits necessary to insure against the outcome that future compliance is more expensive than anticipated or otherwise technologically infeasible? Should regulated parties be able to use LCFS credits in other carbon programs and vice versa?

Summary Recommendations

Trading and banking. The efficiency and effectiveness of an LCFS credit market depends on the design of the credit system, particularly the opportunities for trading and banking. Given the uncertainties in feedstock costs and availability, their CI values, and the commercial success of various biofuel refining technologies and fuel types (including "drop-in" bio-based gasoline and diesel fuel), we recommend allowing unlimited trading of LCFS credits across the gasoline and diesel fuel pools (and any others that might be created, such as jet fuels). Doing so can significantly reduce compliance costs. For the same reason, banking of credits lowers the costs of meeting the LCFS and stabilizes credit prices across compliance time periods.

Compliance and cost containment. The design of an LCFS needs to address concerns about large price swings that might result from unanticipated surges or crashes in economic growth, weather and crop prices, and low-carbon fuel availability. While banking mechanisms reduce price volatility, in extreme situations the number of banked credits available might not be sufficient to avoid a credit price spike. To avoid the possibility of low-probability but high-impact price spikes, we recommend the adoption of cost-containment mechanisms to protect regulated companies. Such mechanisms would reduce uncertainty and accelerate capital formation for low-carbon fuel production and deployment.

Carbon credits from other programs/jurisdictions. Transportation energy is produced utilizing many resources and technologies in many places across many political jurisdictions. GHG emissions in some places and from some activities are, or will soon be, regulated by other (non-LCFS) GHG programs (such as carbon caps on utilities or carbon taxes). These energy activities are already incentivized to reduce emissions through other market instruments. In these cases, when energy producers in other political jurisdictions are subject to other carbon fees or taxes, including electricity producers subject to cap-and-trade fees, we recommend that actual emission reductions along the supply chains being regulated by an LCFS be taken into account through regular updates of default CI values reflecting changes of emission intensity aggregated over the industry, technology, or process over time.

Issues will arise, however, when obligated emission reductions in the other programs do not actually occur but are met via credits, penalties, or fees, especially when there is a large disparity between the actual or implicit carbon reduction costs or credit prices between the two programs. In principle, policy should try to avoid imposing "double penalties" on regulated parties for the same unit of emissions. We recommend recognizing these traded emission credits as actual emission reductions but applying an adjustment factor accounting for the price difference between programs based on published prices of credits traded in the same compliance period. For example, if a refiner pays \$15 per tonne CO_2e of upstream emissions toward Alberta's Specified Gas Emitters Regulation (SGER) and LCFS credits are traded at \$60 per tonne CO_2e in the same compliance period, a quarter of a carbon credit (\$15/\$60) can be counted as emission reductions. This is the same approach we recommend for harmonizing a national LCFS with other LCFS jurisdictions (such as British Columbia's RLCFRR and the EU FQD), as discussed in Section 13.

Discussion

11.1 Trading and banking

LCFS credits are generated when regulated parties supply fuel with CI values lower than the regulatory standard. Credits can be sold to regulated parties for whom credit purchasing represents the least costly compliance option. In this way LCFS credit trading enables least-cost reductions across all transportation fuel suppliers.

Credit trading between fuel pools allows regulated parties to apply LCFS credits generated in one fuel pool to compliance obligations in any other fuel pool. It is applicable only in the context of a policy design that disaggregates transportation fuels across multiple fuel pools (for example, gasoline, diesel, and their respective substitutes), as discussed in Section 7. Because significant uncertainty exists regarding projected technological advancements in producing cellulosic biofuels as diesel or gasoline substitutes (Huang et al. 2012; Rubin and Leiby 2012), it could be significantly more expensive to meet national LCFS requirements for *equally stringent phasedown paths* if each market were required to meet its target separately. The ability to trade credits across gasoline and diesel markets provides a straightforward mechanism to solve this fundamental underlying uncertainty about future advances in biofuel technology.

Credit banking serves a similar function. It allows regulated parties to reserve or "bank" LCFS credits generated in one period to satisfy compliance obligations in a future period. It represents a type of intertemporal credit trading within firm, which can be used to hedge against risks of higher future compliance costs. Our study results indicate that allowing banking of credits would lower the costs of meeting an LCFS and stabilize credit prices (Rubin and Leiby 2012). Banking provides additional temporal flexibility for regulated parties to meet increasingly stringent CI standards (per the phasedown schedule). This is because regulators do not know the most cost-effective time path for reducing fuel CI. Were they clairvoyant, an optimal phasedown path could be specified and banking would be redundant. Trading across time, as banking allows, is particularly suited to a carbon-mitigation system like an LCFS. This is because the environmental impacts of CO_2 emissions result from cumulative emissions across time, and earlier reductions can only reduce the total effect.

11.2 Compliance and cost containment

The trading price for LCFS credits represents an important signal to fuel suppliers and prospective low-carbon fuel developers. In particular, the credit price provides a signal to market participants regarding the relative cost-effectiveness of available compliance options. Parties capable of reducing fuel CI at costs lower than the credit price will generally invest in achieving those reductions, while parties that cannot generate CI reductions at such costs will generally comply by purchasing credits. The policy design should provide a clear and coherent price signal to the market. Absent a clear signal, investment decisions will be based on more abstract and uncertain notions of LCFS credit value, which will generally yield inefficient investment decisions and increase compliance costs.

In addition to enabling efficient investment decisions, the credit price signal can facilitate efficient access to capital markets. The high capital requirements of developing fuel supplies in general, and low-carbon fuel supplies in particular, have the potential to create a bottleneck for scaling up production capacity. Efficient access to capital markets can therefore accelerate deployment to some extent. A clear LCFS credit price signal should help low-carbon fuel developers demonstrate conformance with financing criteria by establishing the value of supplying low-CI fuels.

The design of an LCFS, however, also needs to address concerns about large price swings that could potentially result from unanticipated developments in availability of low-carbon fuels, economic growth, and weather and crop prices. While a banking mechanism does reduce price volatility, the number of banked allowances available at any given time may limit their efficacy. To improve the structure and integrity of an LCFS program, mechanisms need to be developed to address potentially severe spikes in prices due to low-probability but high-impact scenarios. Such mechanisms will reduce perceived uncertainty and accelerate capital formation for low-carbon fuel production and deployment, and improve support for the program overall.

The need for allowance price containment mechanisms is highlighted by the experience with southern California's REgional CLean Air Incentives Market (RECLAIM), a cap-and-trade program aimed at reducing NOx and SOx emissions from industry and electricity utilities. In 2000, unanticipated regulatory-driven disruptions in the electricity sector and a weather-driven fall in hydroelectricity generation led to a spike in demand for electricity from fossil-fuel generators and consequently a spike in allowance prices. In the absence of any price containment mechanisms, the price of NOx allowances traded in 2000 exceeded $45,000 per ton NOx, compared to the average price of $4,284 per ton traded in 1999 (Burtraw et al. 2006).

One potential price containment mechanism is a price ceiling (also called a safety valve), where support is triggered when allowance prices reach a predefined level. At this stage, participants can purchase unlimited allowances from the regulator at the ceiling price. Trigger prices usually increase over time—for example, the ceiling price in New Zealand's Emissions Trading Scheme (ETS) will increase by NZ$5 per annum (http://www.climatechange.govt.nz/emissions-trading-scheme/) while the ceiling prices in California's cap-and-trade program will increase annually by 5 percent plus inflation measured by the consumer price index (CPI) (Enion 2012).

When unlimited allowances can be introduced at the trigger price, quantity uncertainty replaces price uncertainty and risks the entire environmental integrity of an LCFS program. This is the reason cited for not allowing a price ceiling in the EU ETS program (Moslener and Sturm 2008). For example, participants may undermine emission goals by buying allowances at current low safety-valve prices, and banking and using them sometime in the future when caps as well as ceilings are more stringent (Murray, Newell, and Pizer 2008). This can be addressed by what is known as a soft price ceiling or allowance reserve (Fankhauser and Hepburn 2010; Murray, Newell, and Pizer 2008). With a soft price ceiling, a small percentage of allowances are saved in the reserve and can be used at a trigger price level (Fell et al. 2011). Most recent legislative proposals in the United States for GHG reduction programs—such as the Waxman-Markey and Kerry-Boxer bills, as well as California's cap-and-trade program, which went live in 2012—have adopted the allowance reserve option to reduce price volatility.

Careful selection of a ceiling price is necessary to ensure the overall integrity of an LCFS program. A low price ceiling will mean the mechanism is triggered more frequently and, in extreme cases, may convert an LCFS program into a carbon tax regime, as was observed in the Danish ETS program between 2000 and 2003 (Jacoby and Ellerman 2004). A very high trigger price, on the other hand, will reduce price volatility to a smaller extent and only safeguard participants against more extreme spikes. The trigger price also depends upon the size of the reserve—a smaller reserve will necessarily warrant a higher price ceiling.

Since the reserve is created by taking away allowances allocated in any given period and thus reducing the allowance budget, this increases the stringency of the program and hence the potential for higher allowance prices. In the California cap-and-trade program, this situation is addressed by increasing the allowable number of offsets by an equal amount. More careful study is needed to implement a price containment mechanism for a national LCFS. Table reviews price containment mechanisms in market-based regulations.

Table 8. Overview of price containment mechanisms in market-based regulations

Cap-and-trade program	Price containment mechanism	Details
CA RECLAIM (year 2000 version)	No price floors or ceilings	
EU ETS	No price ceiling. Penalties of €40/ton and €100/ton are imposed in Phases I and II respectively.	Paying penalties does not release participants from the obligation to reduce emissions—excess emissions must also be offset in the following compliance period (Fankhauser and Hepburn 2010).
Danish ETS (2000–2003)	Hard price ceiling. Ceiling fixed at a level sufficiently below the marginal cost.	Due to the low ceiling and stringent nature of the cap (emission caps were 30% below average annual emissions in 1994–1998), the system operated as a "tax with tradable exemptions" (Jacoby and Ellerman 2004).
CA cap-and-trade	Soft price ceiling. Around	Three levels of price supports. For 2013, those price triggers will

	4% of the allowances will be stowed away into a reserve every quarter.	be \$40, \$45, and \$50. Correspondingly, the reserve is divided equally into three tiers.
NZ ETS	Hard price ceiling initially at low levels but rising rapidly	Hard price ceiling at NZ\$12.50 (US\$10) per metric ton currently. After December 2012, the ceiling will double to NZ\$25 (US\$20) per metric ton of GHG. Subsequently, the NZ ETS Review Panel (2011) recommends increasing the ceiling by NZ\$5 per annum to reach NZ\$50 in 2017.
Regional Greenhouse Gas Initiative	No price ceiling	However, reaching some predefined CO_2 allowance price thresholds will trigger expanded use of offsets—from a default 3.3% of a power plant's total compliance obligation to 5% and even 10%.

The RFS2 program allows the EPA to sell cellulosic biofuel credits when it determines that quantities of available cellulosic biofuels are below levels required in the Energy Independence and Security Act of 2007. For 2011 the EPA has set the price at \$1.13 per credit (75 FR 76790) (Rubin and Leiby 2012). Rubin and Leiby (2012) set the safety-valve credit price in their study at \$300/$MtCO_2e$, which is equivalent to a \$30/$MtCO_2e$ carbon tax, or about a \$0.38/gallon ceiling on the cost of reducing gasoline CI by 10 percent (Rubin and Leiby 2012). We recommend that a national LCFS include provision for substantial flexibility and trading of credits, with a credit safety-valve price and at least limited banking. While these mechanisms can entail trade-offs between managing the uncertain cost of compliance and assuring regulatory effectiveness, they seem essential for the workability of a national LCFS in a global motor fuel market. Further examination of the implications of alternative safety-valve levels and alternative banking systems is merited.

11.3 Carbon credits from other programs/jurisdictions

The production, transport and delivery of transportation energy utilize a wide range of resources and technologies across the entire life-cycles, which take place in many places across many political jurisdictions. Energy producers in other political jurisdictions can be, or maybe soon, subject to other carbon caps or taxes. If upstream energy activities subject to an LCFS are already required to reduce emissions elsewhere, we recommend that actual emission reductions along the supply chain be recognized through regular updates of default CI values using industry averages.

When emission reductions, trading, and fees are covered under separate market mechanisms, it is appropriate to recognize these emission reductions and regularly update the average emissions factor to reflect changes of emission intensity aggregated over the industry, technology, or process over time. As any additional emission reductions (or debts) by individual companies beyond policy requirements are appropriately rewarded in the other regulated markets, adopting an industry, technology, or process average also avoids any potential issue associated with double counting/crediting/penalizing. This approach also appropriately recognizes the trade and jurisdictional authority of emission sources regulated under other jurisdictions.

Issues will arise, however, when obligated emission reductions in the other programs do not actually occur but are met via credits, penalties, or fees, especially when there is a large disparity between the actual or implicit carbon reduction costs or credit prices between the two programs. In principle, policy should try to avoid imposing “double penalties” on regulated parties for the same unit of emissions. We recommend recognizing these traded emission credits as actual emission reductions but applying an adjustment factor accounting for the price difference between programs based on published prices of credits traded in the same compliance period. For example, if a refiner pays $15 per tonne CO_2e of upstream emissions toward Alberta’s Specified Gas Emitters Regulation (SGER)(Table 9) and LCFS credits are traded at $60 per tonne CO_2e in the same compliance period, a quarter of a carbon credit ($15/$60) can be counted as emission reductions. This is the same approach we recommend for harmonizing a national LCFS with other LCFS jurisdictions (such as British Columbia’s RLCFRR and the EU FQD), as discussed in Section 13.

Table 9. Alberta’s three principal greenhouse gas policies

Name of policy	Main sectors covered / Likely emission reduction	Description
Specified Gas Emitters Regulation (SGER)	Industrial facilities (electricity, oil and gas, other) Likely reduction in annual emissions in 2020 relative to no policy: 1.5–5 Mt CO_2e	This regulation, which took effect in July 2007, sets GHG intensity (emissions per unit of production) targets for all facilities emitting more than 0.1 Mt CO_2e per year. The target for a facility beginning operation before 1999 is 12% below the average intensity for 2003–05. Newer facilities are exempt for their first three years of operation and then face targets that gradually increase to reach, in the ninth year of operation, 12% below the intensity measured in the third year. Facilities with emissions higher than their targets can comply by making payments of $15 per tonne CO_2e into the Climate Change and Emissions Management Fund (see below) and by purchasing offset credits from projects in Alberta.
CCS Major Initiatives	Industrial facilities (electricity, oil and gas, other) Likely reduction in annual emissions in 2020 relative to no policy: 1.5–5 Mt CO_2e	In 2009 the Alberta government selected four large-scale CCS projects to receive grants totaling $2 billion over 15 years. The projects—a coal-fired power plant retrofit, an oil sands upgrader, an underground coal gasification project, and a CO_2 pipeline—are expected to start up by 2015. However, it is not yet certain that all four projects will be constructed.
Climate Change and Emissions Management Fund (CCEMF)	Industrial facilities (electricity, oil and gas, other) Likely reduction in annual emissions in 2020 relative to no policy: 0.5–1.5 Mt CO_2e	The $15 per tonne payments into the CCEMF, made under the SGER, are reinvested in a wide range of emission reduction projects. In 2007–10, $256 million were paid into the CCEMF; to date $126 million has been committed to approved projects.

Source: Bramley et al. 2011

12 Performance-Based Sustainability Standards

Recommendation 12. Implement performance-based sustainability standards.

Key Issues

Aside from GHGs, there are other important nonmarket impacts associated with energy production. This group of sustainability concerns includes environmental sustainability (conservation of air, water, soil, biodiversity, and land use) and social sustainability (human and labor rights, local food security, rural development). The challenge is to determine the extent to which an LCFS should include or be linked with rules to limit adverse impacts in these other areas.

Summary Recommendations

Given the huge scale of energy production activities and their potentially large impacts, and because an LCFS would play an instrumental role in stimulating large energy investments, we believe that some sustainability safeguard mechanisms are needed. We recommend formulating (1) minimum sustainability requirements, including conservation (not allowing conversions of high-biodiversity and high-carbon-stock areas); and (2) reporting requirements for specified impacts or voluntary certification.

A sustainability standard that includes key environmental and social impacts should be performance based—it should not prescribe specific technology or practices but instead should focus on measurable outcomes with clear expectations regarding performance, measurement, verification, and enforcement. Effort should be made to identify incentive mechanisms that motive innovation beyond minimum compliance thresholds established by existing laws and regulations.

Discussion

As biofuel production increased in the early 2000s, new studies began to link this increased production to increased risk of adverse environmental impacts (Donner and Kucharik 2008; Miller, Landis, and Theis 2007; Robertson et al. 2008) and of social and economic impacts (FAO 2008b; Rajagopal et al. 2007; Tenenbaum 2008), casting doubt on the real GHG benefits of some biofuels (Fargione et al. 2008; Gibbs et al. 2008; Searchinger et al. 2008a). Even though there are vastly different views on the nature and magnitude of causal relationships between biofuel policies and diverse environmental impacts, land use changes, and global food prices, there have been increasing efforts to adopt sustainability requirements to minimize potential social and environmental damage and unintended consequences. These efforts are intended to provide environmental and social safeguards for biofuels directly or indirectly via biofuel subsidies, tax credits, demand mandates, and other mechanisms.

In the past few years, sustainability requirements for biofuel production have been adopted/implemented by the Netherlands (Cramer et al. 2006, 2007; NEN 2009), the United Kingdom (RFA 2009), Germany (German government 2007; WWF 2006), the European Union (EC 2008), and California (CEC 2008). International organizations, including the United Nations Food and Agriculture Organization (FAO), the UN Environment Programme (UNEP), and the G8's Global Bioenergy Partnership (GBEP), have encouraged and supported the research, modeling, and negotiation efforts among stakeholders at the country level. There are also more private and public efforts in promoting certifications, facilitating information sharing, and developing guidelines for sustainability best management practices (BMP). Many new, especially commodity-based, biofuel-targeted certifications have recently been or are being established, such as the Roundtable on Sustainable Palm Oil (RSPO), the Roundtable on Responsible Soy (RTRS), the Better Sugarcane Initiative (BSI), the Council on Sustainable Biomass Production (CSBP, focusing on second-generation feedstock), and the Roundtable on Sustainable Biofuels (RSB, focusing on creating internationally consistent sustainability criteria and certification schemes). A more detailed review of these recent activities can be found elsewhere (Endres 2010; Lewandowski and Faaij 2006; van Dam et al. 2008; Winrock International 2009).

Due to the importance and complexity of sustainability issues, many of which are irreversible, we recommend a hybrid of a minimum standard plus self-reporting approach: (1) require independent verification or voluntary certification of meeting two mandatory minimum requirements: no newly converted land in high-biodiversity areas, and no newly converted land in high-carbon-stock areas; and (2) encourage/require self-evaluation and reporting against sustainability principles and criteria,[26] plus verification; or alternatively, voluntary certification.[27]

Self-reporting and verification. The self-reporting requirement would encourage regulated parties to develop self-evaluations against sustainability principles and criteria agreed to via a stakeholder process and to report these evaluations. The self-evaluation would not be required to demonstrate meeting all of the sustainability principles and criteria, but its data accuracy would need to be verified by an independent auditor. Independent verification would also be required to ensure that the two mandatory minimum requirements were fully met. The intention would be to

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[26] The list of principles and criteria should ideally cover environmental, social, and economic criteria developed by environmental agencies in consultation with the public.

[27] Establishing mechanisms for dispute will be a critical component of certification schemes.

take a first step toward creating an easy means of reporting sustainability performance, encouraging innovation by regulated parties in developing metrics for evaluating sustainability performance, and collecting verifiable data. Annual evaluation and periodic review of the program would need to be conducted to determine whether further adjustments or an alternative system were needed in the future.

Demonstration of compliance. To demonstrate compliance, the following requirements should be met:

- submit information on biofuels' compliance with the two mandatory minimum requirements as specified as (1) above and self-evaluation and reporting or voluntary certification against other principles and criteria as specified as (2) above, and
- arrange for an adequate standard of independent auditing.

Challenging issues that require significant progress toward the implementation of sustainability standard include improvement in chain-of-custody (CoC) from fuel-to-field level; and potential WTO challenges to some of the sustainability standards.

CoC in the current biofuel carbon accounting schemes, including RFS2 and California's LCFS, does not track feedstock to the field level, only to refinery gates. Establishing sustainability requirements would require tracking CoC to the field level. Extending CoC tracking to the field level would incentivize fuel providers to report agricultural practices that have large carbon-reduction benefits such as no-till, reduced fertilizer use, and yield improvement that cannot be acknowledged under the current carbon accounting CoC system.

The CoC tracking system that's best for the United States need not to be the same as the one required in the European Union's RED sustainability requirement: the mass balance CoC. The mass balance CoC requires that certified/verified feedstock not be separated from the feedstock/biofuel and that it stays with the finished products along the supply chain. A mass balance CoC system would be challenging to establish in the United States for two reasons: (1) in an LCFS, carbon credits may be separated from fuels in the future, as in RFS2 where RIN credits can be sold separately from fuels, allowing for more flexible trading of credits; (2) food commodities such as soybeans have very complex supply chains; in this case, soybean oil is only a by-product and thus its CoC is hard to establish. For these reasons, a more flexible CoC system such as book-and-claim might be more desirable, especially in the early years of compliance. In a book-and-claim system, end users (in this case, the fuel suppliers/importers) submit certificates that guarantee the production of a certain quantity of sustainable biomass, but the certified products can be delivered anywhere.

The WTO might challenge mandatory sustainability standards and even carbon intensity standards (for example, the recent WTO dispute in the European Union regarding the calculation of carbon intensity for biofuels and Canadian oil sands). There is a chance that the recommendations proposed here would largely avoid WTO challenges since (1) the mandatory minimum requirements propose here regarding no newly converted land in high-biodiversity and high-carbon-stock areas are consistent with the EU-RED requirement and have the least likelihood of provoking WTO challenges, and (2) mandatory reporting and voluntary compliance with the broader sustainability principles and criteria was considered to have the least likelihood of violating WTO rules.[28]

13 Global LCFS Policies

Recommendation 13. Harmonize global LCFS policies.

Key Issues

LCFS policies adopted in other countries and regions can vary significantly in policy design, stringency levels, system boundaries, coverage of fuel types, and various other details. The goal of harmonization is to create a consistent and acceptable approach to reducing the carbon intensity of fuels to maximize the effectiveness and efficiency of the policies, while providing individual countries and regions the freedom and flexibility to tailor the policies to their local circumstances.

Summary Recommendations

Harmonization can be achieved by adopting a globally consistent certification system, starting at the feedstock level. Certificate harmonization allows for robust policy frameworks and thus more room for policy/political differences while still remaining effective. Achieving a harmonized certification system will require an improved chain-of-custody tracking system in order to provide transparent and reliable information about biofuel production across regions.

LCFS policies can be further harmonized between states and regions through credit harmonization, which requires adopting unified methods (where possible) and using credit multipliers to adjust non-unified aspects. These two methods allow credits or certificates to be valued equivalently across regions and traded efficiently to comply with regional low carbon fuel policies, even when they vary in stringency, system boundary, and fuel carbon ratings. Allowing credits to be traded across countries or regions will increase policy effectiveness and efficiency and lower the overall compliance costs. Fuel shuffling will also be reduced, hence strengthening LCFS policy.

Discussion

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[28] See review and more discussion in Lendle and Schaus 2010; Yeh et al. 2009.

The goal of harmonization is to create a consistent and acceptable approach to reducing fuel CI while allowing individual regions the freedom to incorporate a policy that makes the most sense in that region. Presently, each governing body has its own interpretation of how an LCFS should be structured and implemented. Because LCFS policies are aimed at reducing CO_2 emissions from the transportation sector within regional boundaries as part of global reduction goals, harmonization is necessary if LCFS programs are to be effective at the aggregate level at reducing global GHG emissions. As with any policy, two key areas determine policy success: policy effectiveness and policy cost. Any harmonization strategy thus must serve to improve policy effectiveness (aid in incentivizing behaviors that reduce GHG emissions) while lowering implementation costs.

Improving policy effectiveness. Currently, a gallon of low-carbon fuel or a unit of energy (such as an MJ) of low-carbon fuel (for example, sugarcane ethanol) may receive different CI ratings under different low-carbon fuel policies due to methodological difference. This can create incentives for shuffling of fuels from regions that assign higher CI values to regions that assign lower CI values to the same fuels as long as the costs of shuffling are lower than the costs of compliance (Kessler, Yeh, and Sperling 2012; Leiby and Rubin 2012). Shuffling will reduce the effectiveness of low-carbon fuel policies by appearing to achieve GHG emission reductions on paper even though no net GHG emission reduction takes place in reality. In the worst case, net emissions could actually increase due to the extra transport distance required to shuffle fuels and/or feedstock. The incentives for shuffling fuel between LCFS regions will disappear if fuels and feedstock are treated equally across policies.

Reducing compliance costs. Setting of different stringency levels in different LCFS policies leads to different compliance costs and a mix of compliance options. If the compliance options are limited to local/regional resources, the compliance costs will be higher than if mitigation options can be shared across regions. Similarly, if the compliance goals of regional LCFS policies can be harmonized (compliance in one region counted toward compliance in another region) while ensuring that the overall stringency level can be achieved, significant cost savings and less fuel/feedstock shuffling will occur (Eggert and Greaker 2012).

13.1 Feedstock certificate harmonization

The European Union has developed a harmonized certification scheme at the EU level. If similar certification schemes are adopted across all low-carbon fuel policies, certificates will be able to be traded across regions, yielding harmonized low-carbon feedstock for fuel production. Other low-carbon fuel policies should look at the possibility of utilizing current certification schemes to assess compliance in some capacity. For instance, if a certified product could be used to support pathway approval or proof of pathway compliance under the California LCFS, harmonization of feedstock certificate would occur. Once feedstock certificate is harmonized, each LCFS implementation could apply their rules for calculating CI *based on the same pathway information* that is consistent across LCFS regions.

13.2 Carbon credit harmonization

Unlike a feedstock or fuel certificate that carries information that qualifies a feedstock or a fuel, an LCFS credit is effectively an allowance to emit 1 tonne of CO_2 (where allowances are limited by the baseline of each standard). There is considerable appeal in generating credits under low-carbon fuel policies, as they allow for flexibility in assessing compliance and could conceivably be transferable to other GHG emission reduction programs such as cap-and-trade.

We have identified two different approaches to achieving credit harmonization: (1) unifying the credit generation methodology, or (2) using credit multipliers to treat further regional policy differences, such as the inclusion of iLUC (indirect land use change) and treatment of HCICO (high-carbon-intensity crude oil) in calculating fuel CI values.

Methodology unification. Standardizing the method of doing LCA calculations is essential for the harmonization of LCFS/fuels programs. As discussed, the first step toward this harmonization will be to develop a credible and consistent Chain-of-custody (CoC) tracking and reporting mechanism; this will allow the same information to be accurately conveyed to each region. Using the life-cycle approach, it can be expected that each state or region will have its own lookup table for determining CI values. This is due to the fact that average input materials, production processes, and emission factors differ from region to region, as each region will have different resource and technology mixes for fuel production (Griffin et al. 2012; Yang 2012).

If standard methodologies and procedures are established, including underlying assumptions, for determining how CI is calculated, there will be no need for a standardized baseline, a standardized year target, or a single CI lookup table to allow for credit trading across regions. A credit represents a tonne of CO_2 reduction across the entire harmonized region calculated using a consistent methodology (Kessler, Yeh, and Sperling 2012).

Credit multiplier. For one region to accept credits from another region, it will be necessary for the credits to be valued similarly. If the underlying methodology for generating a credit in one region is not identical to how another region generates credits, there will clearly be a disconnect between the credits, and their values will not be identical, thus hindering credit trading.

Credit multipliers could be effectively utilized if a credit market were established that normalized all credits generated in different policy regions to a reference LCFS region, such as a national LCFS in the United States, or a theoretical LCFS region, to generate "equivalent credits" (if a reference region is chosen) or "theoretical credits" (if a theoretical LCFS region is used) to allow for credit trading. While this approach could work, it creates unnecessary policy redundancy and confusion, which could substantially increase implementation costs.

In summary, the first step toward harmonization is to adopt a globally consistent certification system, starting at the feedstock level. Certificate harmonization allows for robust policy frameworks and thus more room for policy/political differences while still remaining effective. Achieving a harmonized certification system will require a full chain of custody in order to provide transparent and detailed information for biofuel production across regions. Overall the long-term, methodology unification will be the most effective and easy to implement toward credit harmonization, allowing credits to be traded across countries or regions to increase policy effectiveness and efficiency and lower the overall compliance costs.

Conclusions

This report discusses thirteen key issues that must be addressed in the design of an LCFS for the United States. The underlying technical analyses supporting various recommendations are summarized in the Technical Analysis Report (TAR).

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