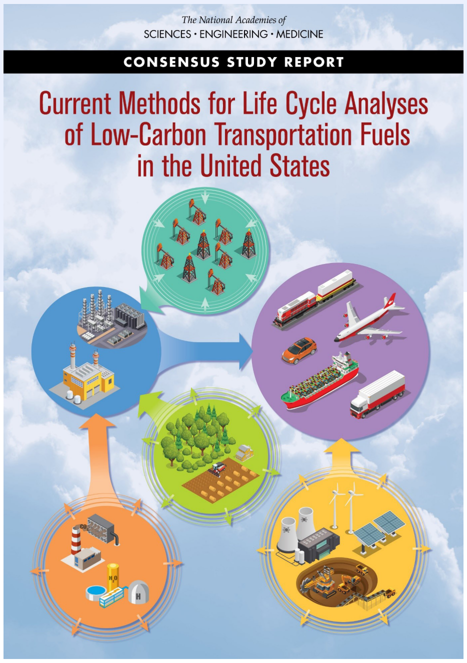
NATIONAL ACADEMIES *Sciences Engineering Medicine*

Consensus Study Report
Highlights

Current Methods for Life-Cycle Analyses of Low-Carbon Transportation Fuels in the United States



Transportation is the largest source of greenhouse gas (GHG) emissions in the United States. Petroleum accounts for about 90 percent of transportation fuels, with biofuels, natural gas, and electricity accounting for the rest. There are federal and state programs to reduce GHG emissions from transportation fuels, but they require the use of assessment techniques to calculate the GHG emissions of these fuels. Life-cycle assessment (LCA) is an approach that can be used to estimate the total emissions from products, including fuels. This report examines methodological approaches of LCA, considerations for estimating GHG emissions, issues that arise that are relevant for a low-carbon fuel standard, and methodological issues that arise for particular transportation fuel types.

UNDERSTANDING LIFE-CYCLE ASSESSMENT (LCA)

LCA can address a range of questions regarding GHG emissions of low-carbon transportation fuels. There are two broad approaches to LCA: attributional life-cycle assessment, which evaluates the emissions that can be estimated and assigned to a given fuel, and consequential life-cycle assessment, which evaluates how emissions would change if a given policy or set of actions were implemented. The approach to LCA should be guided by the question the analysis must answer. In general, practitioners should use attributional LCA when assigning emissions to products or processes, and use consequential LCA when they wish to understand the effects of a proposed decision or action on net GHG emissions. Practitioners should transparently document which approach or combinations of approaches they choose to use.

USING LCA IN A LOW-CARBON FUEL STANDARD POLICY

Public policy design informed by LCA should ensure that the consequential life-cycle impact of the proposed policy is likely to reduce net GHG emissions and increase net benefits to society. It should also consider changes in production and use of multiple fuel types, and should justify when it excludes the emissions consequences of certain fuels. Another consideration is which effects from emissions result from direct effects (e.g., production, combustion, and full supply chain for producing and distributing the fuel), market effects (e.g., changes in land use), or indirect effects (e.g., changes in demand).

Assessment methods need to appropriately characterize uncertainty and variability to aid stakeholders' interpretation of LCA results. Current and future low-carbon fuel standards should strive to reduce model uncertainties and compare results across multiple economic modeling approaches. They should likewise explicitly consider the implications of parameter uncertainty, scenario uncertainty, and model uncertainty for policy outcomes, and formulate a strategy to keep LCAs up to date, such as periodic reviews of key inputs. LCA that informs transportation fuel policy should be explicit about the feedstock and regions the assessment considers and conduct sensitivity analysis to understand the implications of variation in their assumptions. To be effective, assessments should document results for a range of input values, including time preferences and degree of risk aversion.

The scale of production of a fuel can affect the life-cycle implications of a fuel or technology in nonlinear ways. Production scale relates to how a fuel is produced and the composition of its supply chain, necessitating relevant information for informed LCAs.

Directly measuring activities along an entire fuel pathway can make it impractical to directly confirm the effects of a policy. Verification of emissions sources and effects can help policymakers understand the impact of a decision. For example, an agency could use satellite data to characterize international land use change that may be in part attributable to a low-carbon fuel standard. There are many framing questions that can be applied to lessen the impacts of uncertainty in LCA results and to inform policymakers of the effects of a policy as they unfold. Any verification system should be overseen by an appropriate agency or group of agencies, be revisited periodically to adapt to the emergence of new verification technologies and trends in relevant sectors, and be paired with complementary economic modeling.

Negative emissions (emissions subtracted from a portion of the life cycle), and their incorporation in life-cycle GHG calculations, raise important questions that warrant special scrutiny to distinguish between actual CO_2 removal, storage, and fuels pathways that include credits for avoided emissions. The carbon intensity of methane-derived fuels, carbon removed from the atmosphere by biomass, and changes in land use that alter soil carbon all need to be taken into account. Even measurements and metrics for common units of GHG emission measurement need to be transparently explained. Further research is needed to determine how best to measure, account for, and report negative emissions.

VEHICLE-FUEL COMBINATIONS AND EFFICIENCIES

Efficiency and production emissions of transportation fuels can vary widely both within and across vehicle fuel type technologies, making fair comparisons with single-point estimates challenging. To make a meaningful comparison of LCAs of transportation fuels, the vehicles that use those fuels should be considered. It should consider the range of vehicle efficiencies within each fuel type to ensure that the comparisons are made on comparable transportation services. For regulatory impact assessment, an LCA should consider a range of estimates for possible changes in the vehicle production emissions required to convert transportation fuels into transportation services, and the resulting changes in vehicle fleet composition.

FUEL-SPECIFIC CONSIDERATIONS

Fossil and Gaseous Fuels for Road Transportation, Aviation Fuels, and Maritime Fuels

Variations in the life-cycle GHG emissions of petroleum fuels (gasoline, diesel, jet fuel) as a result of their source and refinery should be explicitly included in a low-carbon fuel policy. More data and reporting are needed for petroleum and natural gas operations, including information on venting and flaring of methane, and emissions from storage tanks.

Hydrogen fuel can be made from multiple types of production processes. LCA that considers hydrogen fuel should clearly document key parameters chosen, including the choice of energy source for the hydrogen reforming process used, the carbon capture level from the waste gaseous stream, source of upstream electricity, and the rate of methane or CO_2 leakage. Where relevant, the approach to quantifying emissions of upstream natural gas production should align with those used elsewhere in a low-carbon fuel standard for other fuels produced from natural gas.

Many aviation fuels are petroleum-derived, but qualities unique to jet fuel and to alternative aviation fuels may require special consideration beyond the LCA approaches used for alternative fuels in other sectors. These include non-CO_2 effects from aviation fuels, like aviation-induced cloudiness, or the use of different alternative fuel and airframe combinations that may impact airplane efficiency and overall emissions.

Marine fuels have similar supply chains and LCA methodological considerations relative to other transportation fuels, but have unique life-cycle aspects that effect attempts to quantify their emissions, such as methane slip from liquefied natural gas combustion in marine engines. Baseline life-cycle GHG emissions for marine fuels should potentially be updated in the future as the industry adjusts to new regulations that could change the fuel type of deployed vessels.

Biofuels

Biofuels can be produced with a range of feedstocks, with corn and soybeans being the most common in the United States. LCA methods commonly used to estimate GHG emissions associated with crop production in conventional agricultural systems are largely similar regardless of the specific crop in question. Improved data on biofuel feedstock production, including energy consumption, yield, and fertilizer application at fine spatial resolutions may be useful for some applications.

Woody biomass is one of the most abundant biofuel feedstocks in the United States. The GHG emissions associated with the production of woody biomass come from multiple sources, including the use of energy and materials for forest management, harvesting, storage, and transportation. Additional research should be done to assess changes in forest management practices induced by increased demand for woody biomass, and research and data collection efforts should be carried out for improved data and modeling related to forest feedstock production and storage.

GHG emissions associated with the conversion of biomass into fuel come from multiple sources, including on-site combustion of fuels, direct emissions from conversion processes, and upstream emissions associated with the production of the chemicals, enzymes, and electricity used by biorefineries. Mass or energy balance are the most common methods used to estimate GHG emissions of biorefineries, though policymakers should exercise caution in crediting them for GHG sequestration unless a verification system is in place. Verification is also recommended when applying credits for carbon sequestration to soil or reduced use of fertilizer.

Large-scale production of biofuels has an effect on various markets at regional, national, or global scales and can affect prices in these markets, potentially triggering other changes in production and consumption decisions that may cause secondary effects on GHG emissions. More research is needed to understand induced land use changes from biofuels, improve assessment of the effects of land use change, and develop different modeling approaches that can assess market-mediated effects of biofuels.

Electricity as a Vehicle Fuel

Plug-in electric vehicles (PEVs), which include battery electric vehicles and plug-in hybrids, use energy stored in an onboard battery for propulsion and charge the battery using electricity from the power grid. Attributional LCA approaches assign a portion of total power grid GHG emissions to PEV charging, while consequential LCA approaches estimate power grid emissions with and without PEV charging, presenting the difference as the consequential effect of PEV charging. The latter approach should be used to estimate power grid emissions implications and clearly characterize uncertainty of estimates due to assumptions, especially for future scenarios. More research should be done to estimate how upstream emissions in the power sector change in response to changes in generation, and LCAs that estimate the implications of PEV policies should transparently assess the sensitivity and robustness of its findings, and consider how interaction with existing policies may affect outcomes.

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