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Implications of local lifecycle analyses and low carbon fuel standard design on gasohol transportation fuels ☆

Adam M. Boies [a,]*, Dane McFarlane [b], Steven Taff [c], Winthrop F. Watts [d], David B. Kittelson [d]

[a] Department of Engineering, University of Cambridge, Trumpington street, Cambridge CB2 1PZ, UK
[b] Great Plains Institute, Minneapolis, MN, USA
[c] Department of Applied Economics, University of Minnesota, Minneapolis, MN, USA
[d] Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN, USA

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ABSTRACT

State and regional policies, such as low carbon fuel standards (LCFSs), increasingly mandate that transportation fuels be examined according to their greenhouse gas (GHG) emissions. We investigate whether such policies benefit from determining fuel carbon intensities (FCIs) locally to account for variations in fuel production and to stimulate improvements in FCI. In this study, we examine the FCI of transportation fuels on a lifecycle basis within a specific state, Minnesota, and compare the results to FCIs using national averages. Using data compiled from 18 refineries over an 11-year period, we find that ethanol production is highly variable, resulting in a 42% difference between carbon intensities. Historical data suggests that lower FCIs are possible through incremental improvements in refining efficiency and the use of biomass for processing heat. Stochastic modeling of the corn ethanol FCI shows that gains in certainty due to knowledge of specific refinery inputs are overwhelmed by uncertainty in parameters external to the refiner, including impacts of fertilization and land use change. The LCA results are incorporated into multiple policy scenarios to demonstrate the effect of policy configurations on the use of alternative fuels. These results provide a contrast between volumetric mandates and LCFSs.

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1. Introduction

As the U.S. moves towards lowering greenhouse gas (GHG) emissions from its transportation fleet, states may evaluate policies, such as low carbon fuel standards (LCFSs), to lower GHG emissions from transportation fuels. Policies designed to reduce the average fuel carbon intensity (AFCI) can achieve significant GHG emissions reductions in the transportation sector when combined with strategies to increase vehicle efficiency and lower the rate of growth of vehicle activity (Boies et al., 2009). Previous analyses have indicated that without policies such as LCFSs, GHG emissions from transportation would not be significantly reduced even if economy-wide GHG cap and trade policies were enacted (Yeh and Sperling, 2010). California has led the way in enacting low carbon fuel policies, but it is unique when compared with the rest of the nation because of its size (population 36.9 million (U.S. Census Bureau, 2009)) and its ability to influence automobile manufacturing markets and enact legislation (Clean Air Act, 1970). Minnesota (MN) is more typical to other states in terms of many transportation indicators, including vehicle activity, population and fuel consumption, and therefore serves as a convenient test case for how LCFS structure may affect an average state.

Fuels are often evaluated by lifecycle analyses (LCAs) using average national data (Larson, 2006; Wang, 1999a), but more accurate and specific methods and data are available to perform LCAs for fuels on a state and individual refinery basis. Localized differences in electrical generation, crude oil sources, biomass production practices, refinery efficiencies, and other parameters may cause the fuel carbon intensity (FCI) of specific fuel pathways to differ significantly from the national average. Development of FCIs using state- or refinery-specific data could aid in the development of policies that can lower transportation emissions of states in accordance with their unique profiles.

Minnesota is a convenient choice as a case study because it is a large producer of biofuels, has publically available refinery data and is near the median in several important transportation indicators. An LCFS has been proposed by the MN legislature (Cummins, 2009) and debates as to its final form are ongoing. As is the case nationally, the consumption of fuel for transportation

☆ **Brief**: The lifecycle greenhouse gas emissions of current and future transportation fuels are analyzed at the state level and incorporated into a low carbon fuel policy model.

* Corresponding author. Tel.: +44 1223 746972.
E-mail address: a.boies@eng.cam.ac.uk (A.M. Boies).

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accounts for the largest portion of GHG emissions in MN by any end use sector (EIA, 2010b). In 2000, an estimated equivalent of 36.3 million tonnes (40 million ton) of CO_2 were emitted by the MN transportation sector, an increase of 50% over 1980 levels. This is the highest growth rate in GHG emissions of any sector within MN (Ciborowski, 2007). Over 95% of fuel used for transportation in MN is derived from petroleum (Ciborowski, 2007), but renewable fuels are steadily gaining market share. Currently, MN has the highest renewable fuel mandate in the nation (Pew Center on Global Climate Change, 2010) with a requirement that all diesel fuel contain 5% biodiesel (B5) and that gasoline contain 10% ethanol (E10), which will increase to 20% ethanol pending US EPA approval (Minnesota Session Laws Chapter 52 S.F.4., 2004). While these blending requirements, which have been enacted in 11 states (Pew Center on Global Climate Change, 2010), ensure that biofuel consumption is high they do not ensure a reduction in GHG emissions unless further strategies are included that explicitly regulate the carbon intensity of biofuels.

In the current study, we conduct MN-specific LCAs for fuels used by the state's light-duty transportation fleet. This study focuses on near-term reduction options for lowering the carbon intensity of fuels for gasohol vehicles, which represent ~80% of all on road fuel consumption within MN (Ciborowski, 2007). We model the FCI of fuels by performing both point estimates and stochastic uncertainty analysis, incorporating a MN specific database of LCA inputs. Both the temporal nature and the uncertainty of FCI are discussed in the context of policies that seek to regulate the carbon intensity of fuel. The resulting state-specific FCIs are used within a policy model that analyzes different constructs of LCFS policies to determine how the consumption of different fuels will be affected. The policy model also seeks to determine the best method for creating incentives for reductions in lifecycle FCI.

2. Methods

To determine the relative change in emissions that results from consumption of different fuels, the entire fuel lifecycle for each fuel must be examined. A fuel lifecycle includes resource extraction, refining, distribution and storage, and energy consumption, i.e. from well-to-wheel. LCAs allow for comparison of dissimilar fuels on an equivalent basis. The primary lifecycle GHG emitted from traditional fossil fuels is CO_2, but biomass-based fuels may produce significant emissions of other GHGs, such as CH_4 and N_2O, which have higher global warming potential per unit mass. Therefore all GHGs are compared in terms of their equivalence to the 100-year global warming potential of CO_2, i.e. CO_2e (IPCC, 2007).

In the present study, LCAs were performed using Argonne National Lab's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (Wang, 1999b) version 1.8b to determine lifecycle GHG emissions per unit of energy (g CO_2e/MJ) for MN fuels. Minnesota specific lifecycle input data were used to determine the point estimates of FCI for individual refinery pathways. Uncertainty analysis was conducted using ranges representative of MN input in a stochastic simulation using Hammersley Sequence Sampling of 1000 iterations.

Each fuel pathway was examined using the default GREET average national electricity generation profiles as well as an electricity generation profile specific to the Midwest Independent Transmission System Operator (MISO) region which includes MN (see supporting information for additional information). The MISO manages the grid by bringing on or shutting down additional electricity generation to meet demand within an entire region (Plevin, 2009). A change in electricity demand in MN causes changes in the entire MISO and is therefore the appropriate level of analysis. The MISO electricity generation mix is heavily dominated by coal (79% of total electricity production), while nuclear, natural gas and other sources account for 14%, 3% and 4%, respectively (Rose et al., 2007). No assumptions were made for changes in the mix of electricity generation in the future. Several studies have discussed whether co-products emissions should be determined according to attributional or displacement methods. A recent study by Kaufman et al. (2010) states that for regulatory purposes an attributional approach is appropriate. However as this study is examining current and future production, the allocation of emissions to co-products produced during the refining of fuels, e.g. dried distillers grains and solubles (DDGS) from the production of corn ethanol, are assigned based on a displacement method (Wang, 1999a).

In this study we examine the impact of including GHG emissions associated with direct and indirect land use changes (LUCs) in the framework of an LCFS, but do not calculate LUCs directly. Recent studies have shown that the combined result of LUC emissions are significant, non-negative contributors to lifecycle emissions and are greater for biofuels than for petroleum based fuels (EPA, 2010a; Fargione et al., 2008; Searchinger et al., 2008; Yeh et al., 2009). Current and ongoing studies indicate that emissions from LUCs for corn ethanol can vary widely (9–104 g CO_2e/MJ, see supporting information), and depend greatly on crop yield on current and unused land, commodity prices, elasticities and refinery yields (EPA, 2010b; Glauber, 2009; Tyner et al., 2010). The effect of MN LCFS policy on land use, as well as broader economic implications, health impacts and FCIs of fuels not discussed in this study are included in a report to the MN Department of Commerce (Apland and Moon, 2011; Boies et al., 2011; Warner et al., 2011).

3. Results and discussion

3.1. Fossil fuels

Petroleum-based gasoline and diesel fuel account for the majority of transportation fuel used within MN (Boies et al., 2009). These fuels are imported into MN as either fully refined end-use products or as a crude oil, which is refined within the state. Currently, MN refines slightly less fuel than is consumed within the state (Ciborowski, 2007), and some refined fuel is exported to nearby markets. Therefore transportation fuels consumed in MN are a mixture of fuels produced within the state and imported from others. Currently MN is a large refiner of fuels derived from Canadian oil sands, a mixture of clay and bitumen that requires more energy to extract and refine than sweet crude oil. While oil sands currently account for only 1.4% of the global oil supply (Yeh and Sperling, 2010) an estimated 83% of the crude oil refined within the state comes from Canada (EIA, 2008). The percentage of Canadian crude that is heavy oil derived from oil sands imported into MN is uncertain but varies from 75–90% (NEB, 2008). The high consumption of Canadian oil sands in MN is largely a result of pipeline locations and a local refining industry that has made capital investments to refine oil sands.

To determine the total carbon intensity of fossil fuels produced in MN, LCAs were conducted for four fuel pathways: sweet crude to gasoline, sweet crude to diesel, oil sands to gasoline, and oil sands to diesel. GREET 1.8b default values were used for sweet crude oil production, of which 58% were assumed to come from abroad with the rest coming from US land and off-shore reserves. All oil sands data also came from GREET 1.8b and which modeled oil sands crude as coming from Canada via pipeline directly into MN. Fig. 1 shows that for petroleum-based fuels the largest contributor to GHG emissions is the release of carbon from tank-to-wheels,

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