Full Fuel Cycle Assessment of Alternative Transportation Fuels in California

L. Waterland, J. Pont, M. Hooks, M. Chan*, and M. Addy**
*TIAX LLC, Cupertino, CA, USA, waterland .larry@tiaxllc.com
**California Energy Commission, Sacramento, CA, USA, maddy@energy.state.ca.us

ABSTRACT

A full fuel cycle assessment of alternative transportation fuels in California was performed. Assessment results show that, alternative fuels like ethanol, natural gas, LPG, electricity, and hydrogen, can provide significant reductions in well to wheels GHG emissions when used in light duty vehicles, though alternative fuel pathways result in criteria pollutant emissions comparable to gasoline. For example, biofuel pathways can provide up to 75% direct GHG reductions compared to gasoline. Low carbon containing fuels like CNG and LPG also reduce GHG emissions 20% to 30% compared to gasoline. For heavy duty vehicles, many fuels provide a GHG benefit, but not as significant as that for light duty vehicles, and criteria pollutant emissions for alternative fuel pathways are generally either similar to or slightly below the diesel baseline. For example, electric heavy duty vehicles provide the most significant direct GHG benefit, at 55% reduction, followed by fuel cell and CNG vehicles at 23% to 24% reduction.

Keywords: full fuel cycle, well-to-wheels, greenhouse gas, criteria pollutants

1 INTRODUCTION

California Assembly Bill (AB) 1007 requires the California Energy Commission to "develop and adopt a state plan to increase the use of alternative transportation fuels" in California. It directs the Commission to work with the California Air Resources Board (ARB), and other state agencies in developing this plan, termed here the Alternative Fuels Plan. In developing the Alternative Fuels Plan, the Agencies must perform three tasks:

1. Evaluate the alternative fuels on a full fuel cycle basis
2. Set goals for 2012, 2017, and 2022 ensuring no net material increase in air pollution, water pollution or other substances known to damage human health[1]
3. Recommend policies that ensure the alternative fuel goals will be met.

[1] The Energy Commission and ARB extended analyses for the State Alternative Fuels Plan to 2030 and 2050. The additional periods allow an assessment of alternative non-petroleum transportation fuels and technologies with longer development times.

In support of AB 1007 policy making, a California specific full fuel cycle assessment (FFCA) was performed for a variety of alternative transportation fuels. FFCA emissions were determined on a well-to-wheels (WTW) basis, which includes fuel production and distribution, or fuel cycle emissions, and vehicle emissions. Energy inputs and greenhouse gas (GHG), criteria pollutant, and toxic air contaminant emissions, along with water impacts are provided for baseline gasoline and diesel vehicles, and estimates of the effect of alterative fuel operation are evaluated. Fuel cycle analyses of this type have been used for many years to support the quantification of energy use and vehicle impacts. [1,2,3,4,5,6] This study builds on these past efforts to provide a much more complete and in-depth analysis.

2 ASSESSMENT APPROACH

Full fuel cycle emissions were determined on a well-to-wheels (WTW) basis. WTW emissions are divided into two components: the fuel cycle or well-to-tank (WTT) and the vehicle cycle or tank-to-wheels (TTW). WTT impacts include all emission events from fuel production to final transport and vehicle fueling. TTW impacts include vehicle exhaust and evaporative emissions. The WTT and TTW emissions and energy consumption for each fuel/feedstock combination are combined to give WTW results.

Emissions of greenhouse gases (GHGs) and criteria pollutants are discussed in this paper. GHG emissions from the fuel cycle processes and vehicle operation evaluated include CO_2, nitrous oxide (N_2O), and methane (CH_4). All WTW emission results are provided on a g/mi basis. Emissions associated with the production of materials for vehicles or facilities typically fall into the category of life cycle analysis, and are not covered in the full fuel cycle analysis presented herein.

WTT emissions include those associated with feedstock production, fuel refining, transport, and local delivery . Overarching assumptions were made in two areas: geographic boundaries for emission quantification, and marginal fuel production. GHGs were quantified on a global basis while criteria and air toxic pollutant emissions were quantified both globally and within California. The WTT analysis was completed using the latest version of the GREET1.7 [7] model as the platform. The primary parameters that affected the WTT analysis include:

- Natural gas/ renewable power electricity mixes for vehicle and fuel production applications in California

- Transportation modes and distances that reflect transit to California and allow for separate accounting of emissions within California
- Fuel production technologies that are consistent with the assessment scenario timeframe
- Fuel delivery truck and agricultural equipment emissions decline as lower emitting engines are introduced
- California emission control requirements and offset requirements for stationary equipment and fueling stations applicable in the state

To meet California and worldwide demand for the fuels considered in this study, it has been assumed that new growth in production capacity will be required. Therefore, any increases in alternative fuel production or power generation due to a reduction in petroleum consumption are assumed to come from new, more efficient plants built to meet growing demand. This overarching assumption regarding feedstock and fuel supplies is referred to as marginality. This marginal approach was also applied to the gasoline and diesel base cases – marginal gasoline and diesel products are produced overseas and shipped to California. This assumption is validated by the fact that California refineries are essentially operating at capacity and increases or decreases in petroleum consumption will not affect their emissions.

For the TTW portion of the fuel cycle, two separate calculation steps were performed. First, baseline and alternative fueled vehicle efficiencies were determined. Baseline vehicle fuel consumption values on a fleetwide basis for each analysis year and vehicle class were provided by ARB. Fuel consumption estimates for the alternative fueled mid-size vehicles were defined to be consistent with the comparative performance of conventional and alternative fueled vehicles. Comparable estimates were defined for alternative and conventional fueled urban buses.

The ratios of alternative fuel vehicle fuel consumptions relative to the baseline vehicles are assumed to remain constant over time. Therefore, as the baseline vehicle fuel consumptions decline over time, so do the fuel consumptions of the alternative fuel vehicles. This assumption will likely need to be revisited as more information becomes available. The vehicle fuel economies and finished fuel carbon content are combined to estimate vehicle GHG emissions.

The second TTW calculation step is estimation of criteria pollutant emissions. California's EMFAC2007 [8] model was used to determine vehicle criteria pollutant emissions for conventional gasoline and diesel vehicles for different scenario years on a g/mi basis. These results reflect the impact of vehicle retirement and mileage assumptions for the entire vehicle fleet.

The criteria pollutant emissions for the base case vehicles decline significantly over the scenario years evaluated (2012, 2017, 2022, and 2030). An overriding assumption in determining the criteria pollutant emissions for the alternative fuels was that blend fuels must meet petroleum fuel emission standards for NO_x and HC (with a CO credit), as determined by ARB's Predictive Model. [9] Further, alternative fuel vehicles (e.g., LPG and CNG) must meet prevailing fuel specific California emission standards.

3 SELECTED RESULTS

3.1 GHG Emissions

The WTW GHG emissions for selected feedstock/fuel/vehicle combinations are presented here. Many other combinations of results are available in the full WTW final report. [10] Figure 1 provides midsize passenger car results 2022. Corresponding results for urban buses are shown in Figure 2.

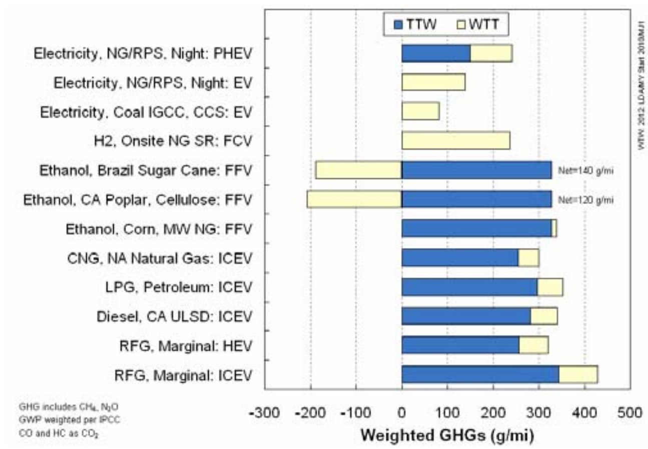

Figure 1: 2022 GHG Emissions for Spark Ignited Passenger Car Options

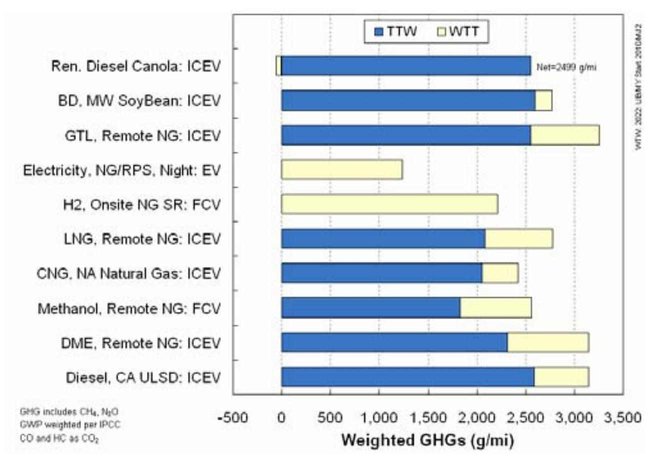

Figure 2 2022 GHG Emissions for Urban Bus Options

Five key conclusions can be made regarding GHG emissions from the FFCA of transportation fuels:

1. GHG emissions from fossil fuels depend on both the carbon content of the fuel and process energy inputs. In all cases except hydrogen and electricity, the vehicle GHG emissions dominate WTW emissions.
2. The effect of alternative fuel use in off-road equipment is comparable to the effect for o road vehicles
3. A wide range of GHG emission factors are achieved for various hydrogen and electric generation pathways. Greater GHG emission reductions are largely due to the higher vehicle efficiency for electric drive technologies.
4. Electricity pathways are highly dependent upon generation mix assumptions. An electric generation mix based on natural gas combined cycle power plants combined with California's Renewable Portfolio Standard (RPS) constraint is the most likely future marginal generation mix.
5. GHG emissions from biofuels production and use depend on agricultural inputs, allocation to byproducts, and the level and carbon intensity of process energy inputs.

The GHG emissions from biofuels production and use depend on many other factors. In particular, land use change assumptions can significantly impact GHG emissions for biofuel based pathways. Land use impacts require further study. The present analysis provides only the vehicle emissions based on the WTT process inputs employed. Emissions impacts associated with changes in land use will be addressed in future updates to the fuel cycle assessment. Land use issues associated with a modest growth in U.S. based energy crops are likely to be somewhat insignificant because energy crops are likely to replace other crops rather than expand agricultural areas. To the extent that this assumption holds true, the impact of differing agricultural land uses represents a small portion of the WTW impact. Land use impacts associated with biofuels sources outside the U.S. also require further study.

3.2 Criteria Pollutant Emissions

The WTW analysis takes into account vehicle and fuel production emissions consistent with vehicle operation in California. Figures 3 provides estimated WTW criteria pollutant emissions for selected light duty vehicle cases for 2022. Figures 4 provides the corresponding urban bus results for criteria pollutant emissions.

The key conclusions regarding criteria pollutant and air toxics emissions are:

1. California places stringent requirements on vehicle emissions and fuels properties. ARB requires that changes in fuel blends result in no increase in emissions. Therefore, the primary change in criteria pollutant emissions is expected to occur in the WTT portion of the fuel cycle.

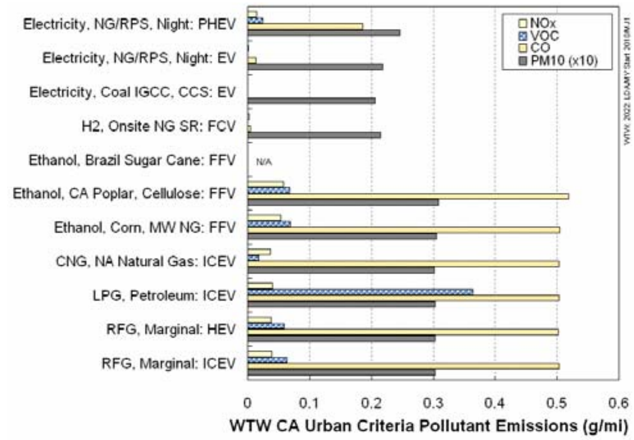

Figure 3: 2022 WTW Criteria Pollutant Emissions from Passenger Cars

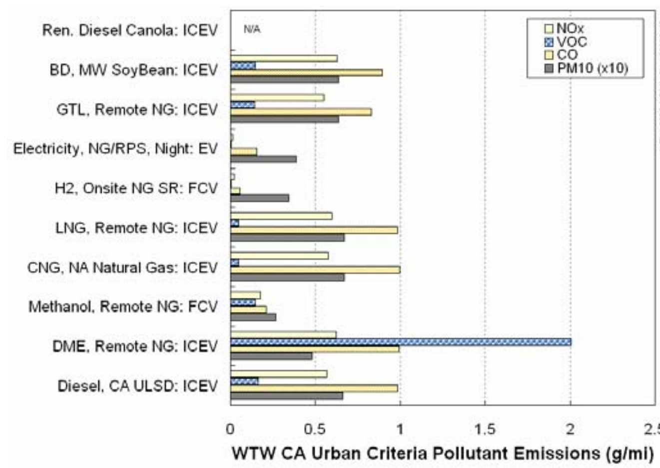

Figure 4: 2022 WTW Criteria Pollutant Emissions from Urban Buses

2. Assumptions regarding the marginal source of gasoline result in the attribution of emissions to refineries and fuel production facilities outside California. New fuel production facilities in California would be subject to stringent emission constraints. In general criteria pollutant emissions in California tend to decrease for fuels that are produced in the state. However, emissions outside of California are generally larger for fuels imported into the state.
3. Emissions from marine vessel and rail transport are the dominant source of fuel/feedstock delivery emissions in California. Agricultural equipment is also a significant source of emissions for biofuels. For the assumed transportation distances in California, delivery emissions from fuels transported by rail are comparable to those imported by tanker ship on a WTW basis.
4. Criteria pollutant emissions for electric transportation are comparable to, or lower than, those from conventional fuels. The lower emission levels result

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from efficient new power plants that are required to offset NO_x and VOC emissions combined with very efficient vehicles. Emissions associated with the average statewide generation mix are higher than the marginal mix, but are still below the baseline vehicle.

5. Emissions from hydrogen reforming and gasification production facilities are inherently low because the waste gas that is burned to generate process heat consists primarily of CO and hydrogen. However, limited source test data were identified to quantify these emission levels, especially PM.
6.

4 SUMMARY

The results of this full fuel cycle assessment using the GREET 1.7 model modified for California can be used to satisfy the requirements of AB 1007. The analysis and the key findings and recommendations are summarized below.

Alternative Fuels Provide GHG Benefits in Midsize Autos and Urban Buses Across the Evaluation Timeframe

- Depending on fuel pathway alternative fuels like ethanol, natural gas, LPG, electricity and hydrogen can provide significant reductions in well to wheels GHG emissions when used in midsize autos
  - Biofuels provide large reductions (~75% compared to gasoline) depending on processing intensity because CO_2 emissions are recycled through plant photosynthesis
  - Low carbon containing fuels like natural gas and LPG also reduce GHG emissions (20% to 30% compared to gasoline)
  - Zero carbon fuels and power production options also substantially reduce GHG emissions depending on the specific fuel or power production technology and associated pathways
  - Electricity use reduces GHG emissions compared to gasoline by 68% in electric vehicles (EVs) and 44% in plug in hybrid electric vehicles (PHEVs).
- For urban buses (heavy duty vehicles) many of the fuels provide a GHG benefit, but not as significant as for light duty vehicles.
  - Electric buses provide the most significant benefit at 55% reduction followed by hydrogen fuel cells and CNG at 23-24% reduction.
  - A 30% renewable diesel blend yields approximately 20% reduction while a 20% biodiesel blend provides approximately 12% reduction.
  - A 30% blend of gas-to-liquid (GTL30), with remote natural gas as feedstock, increase GHG emissions. However, utilizing a biomass feedstock provides a 28% reduction for the GTL30.

A number of pathways result in higher emissions of criteria pollutant emissions for both midsize autos and urban buses

- For midsize autos, alternative fuel pathways result in criteria pollutant emissions comparable to gasoline pathways
  - Natural gas based hydrogen pathways reduce criteria pollutant emissions
  - LPG has higher VOC emissions if not controlled
  - California cellulosic ethanol production and use increases NO_x and PM emissions slightly, with the impact decreasing over time
- For urban buses, criteria pollutant emissions for alternative fuel pathways are generally either similar or slightly below the diesel baseline.
  - Hydrogen and electric drive have lower emissions than diesel

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