FULL FUEL CYCLE ASSESSMENT WELL TO WHEELS ENERGY INPUTS, EMISSIONS, AND WATER IMPACTS

Preparation for the

AB 1007 (Pavley) Alternative Transportation Fuels Plan Proceeding

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ABSTRACT

This study determines the energy inputs, greenhouse gas (GHG) emissions, criteria pollutant emissions, air toxics emissions, and multimedia impacts from the production and end use of a variety of conventional and alternative fuels that are considered options for on road vehicle and off road equipment applications in California.

Examining emissions on a full fuel cycle basis for alternative-fueled vehicles is important when assessing the overall environmental impact of these vehicles from both a global and local perspective. Emissions associated with fuel production are a significant portion of the total GHG emissions attributable to the full fuel cycle. Also, criteria pollutant emissions, air toxics emissions, and multimedia effects associated with the production and distribution of fuels can be significant in comparison with tailpipe and exhaust emissions. Emissions associated with the production or decommissioning of facilities or vehicles were not in the project scope.

The purpose of the study is to identify if any alternative fuel production options result in a net material increase in full fuel cycle emissions. In order to provide the information necessary to make this determination, criteria pollutant emission calculations are based on vehicle operation and emissions in California non attainment areas. Total global GHG emissions are also calculated.

Fuel cycle emissions vary substantially based on factors such as the time frame of interest, vehicle fuel economy, the degree of emission control, and assumptions regarding feedstock sources and fuel production conversion efficiency. These factors and others are examined 17 different vehicle/fuel combinations with 50 different fuel production pathways.

The results are presented in three volumes. The fuel cycle, or well to tank (WTT), impacts include feedstock production, processing, fuel production, and fuel delivery. Vehicles, or tank to wheels (TTW), emissions as well as vehicle energy consumption are analyzed separately. Finally the vehicle and fuel cycle are combined on a well to wheels (WTW) basis, the subject of this report.

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SECTION 1. INTRODUCTION

The California Energy Commission's *2005 Integrated Energy Policy Report* and comments to the report from Governor Schwarzenegger make clear that the state needs to promote the efficient use of petroleum products and promote reductions in the demand for petroleum. California Assembly Bill (AB) 1007 reaffirms the ongoing need to address these critical transportation energy issues. While primarily directed to increase non-petroleum fuel use in California, AB 1007 responds to several other policy directives and state and federal legislation, including reduction of greenhouse gas emissions and improved air quality.

Chaptered in September 2005 (Chapter 371, Statutes of 2005), AB 1007 (Pavley) requires the 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), State Water Resources Control Board, Department of Food and Agriculture, and "other relevant state agencies" in developing this plan, termed here the Alternative Fuels Plan. AB 1007 defines an alternative fuel as any non-petroleum fuel including electricity, ethanol, biodiesel, hydrogen, methanol, and natural gas that has demonstrated the ability to meet applicable vehicular emission standards.

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

3. Recommend policies that ensure the alternative fuel goals will be met.

In support of AB 1007 policy making, TIAX has performed a California specific full fuel cycle analysis for a variety of alternative transportation fuels. This analysis is one of several ongoing work efforts that provide a foundation for Energy Commission activities in response to AB 1007. This report is part of a three volume set of reports describing the full fuel cycle analysis assumptions and results. The intention has been to clearly present all important assumptions that have been made in the quantification of fuel cycle emissions so that stakeholders may understand how the final emission estimates were determined.

Full fuel cycle emissions are determined on a well-to-wheels (WTW) basis, which includes fuel production and distribution, or fuel cycle emissions, and vehicle emissions. The fuel cycle, or well-to-tank (WTT) emissions and energy inputs, and the vehicle, or tank-to-wheel (TTW) emissions and energy consumption, are provided in separate volumes of the three volume set of reports on the analysis. The combination of the vehicle and fuel cycle results into the well to wheels (WTW) analysis is examined in this report. Energy inputs and greenhouse gas (GHG) and criteria pollutant emissions from baseline gasoline and diesel vehicles, toxic air contaminant emissions, and water impacts are provided and estimates of the effect of alterative fuel operation are included. Greenhouse gas emissions from the fuel cycle processes and vehicles include CO_2, nitrous oxide (N_2O), and methane (CH_4). Full fuel cycle emissions on a g/mi basis are included in this report. 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 in this report

Fuel cycle analyses have been used for many years to support the analysis of energy use and vehicle impacts. Table 1-1 lists a number of past studies that have had a fuel cycle analysis component in them. This study builds on these past efforts to provide a much more complete and in-depth analysis.

The complete WTW analysis is discussed in the following report sections:

Section 2 — Full Fuel Cycle Analysis. This section describes the analysis approach and identifies the information sources used to supply the data needed to perform the analysis. The approach to the WTT and TTW portions of the full WTW analysis are separately discussed.

Section 3 — Well to Wheel Analysis Results. The energy inputs, GHG emissions, and criteria pollutant emissions results for the full fuel cycle for select vehicle/ fuel/ fuel production pathways are presented in some detail by fuel in this section. Air toxics emissions and multimedia impacts for the production and use of each fuel are also described.

Section 4 — Discussion. This section discusses the effects of the dominant assumptions on the analyses, key points of the analyses, or results that require further attention. Projections of the year 2012 full fuel cycle analyses to the out years of 2017, 2022, and 2030 are outlined.

Section 5 — Conclusions. This section summarizes key conclusions of the analyses.

Section 6 — Recommendations. This section outlines recommendations for addressing limitations of the analysis methodology and information needs to allow better analyses to be performed.

Table 1-1. Past Studies with a Fuel Cycle Analysis Component

Study, Year	Focus
ARB Fuel Cycle Emissions – Reactivity Basis, 1996	CA emissions evaluated for SoCAB. Reactivity adjusted HC emissions. Vapor mass and speciation data for alcohol blends. HC losses tied to ARB emissions inventory.
ARB Fuel Cycle Emissions – Refinement, 2001	Refine CA emission analysis for near ZEV candidates. Dispatch modeling of power generation for EV charging.
AB2076 – Petroleum Dependency, 2003	Use 2001 analysis as input to Benefits of Displacing Gasoline and Diesel.
CA H2 Highway, 2005	Hydrogen production and vehicle analysis. Assessment of renewable power for transportation fuels. Apply analysis to CA instead of SoCAB.
GM/ANL, 2001, 2003, 2005	GM modeling of comparable vehicles. GREET model for fuel cycle. Average criteria pollutants.
UCD/LEM, 1997-2005	Extensive analysis of all fuel pathways, biofuels land use.
EUCAR, 2005	European analysis. Extensive evaluation of biofuels.

SECTION 2. FULL FUEL CYCLE ANALYSIS

This report presents the results of a full fuel cycle analysis of increasing alternative transportation fuel use in California. Specifically, the full fuel cycle energy and emissions impacts of each alternative fuel are quantified and compared to the emissions from gasoline and diesel vehicles in 2012, 2017, 2022 and 2030. The use of fuels in the year 2050 was also considered as part of the AB1007 process. In 2050, the effect of emissions standards on vehicles and the introduction of advanced technology are reflected in the analysis for 2030.

The boundaries of the full fuel cycle analysis, shown in Figure 2-1, include emissions generated during the extraction of feedstocks, processing or refining, transport, local distribution, and vehicle emissions. Vehicle emissions include both evaporative and tailpipe emissions. The construction and decommissioning of fuel and vehicle production facilities fall into the category of lifecycle analysis, and are not covered in this full fuel cycle analysis.

Full fuel cycle analyses are commonly divided into two parts: the well-to-tank (WTT) portion and the tank-to-wheels (TTW) portion. The combination of the WTT and TTW analyses represent the full fuel cycle analysis, or the well-to-wheels (WTW) analysis. Many different terms are used to define activities in the full fuel cycle; to eliminate confusion the terms are used in the following manner in this report:

WTT – Impacts associated with feedstock extraction, transport to processing, processing/refining, and distribution, expressed in per unit energy in the fuel

TTW – Vehicle refueling, evaporative and exhaust emissions expressed as per mile of vehicle driven

WTW – WTT plus TTW impacts expressed as per mile driven with the split between the upstream (WTT) and vehicle (TTW) emissions indicated.

The reporting of the present analysis has been done in three volumes according to the natural division discussed above: WTT, TTW and WTW. The WTT report presents the assumptions made and resulting energy consumption and emissions associated with producing each finished fuel from a variety of different feedstocks. The TTW report presents the assumptions made and resulting emissions from each vehicle type and finished fuel combination. This volume presents the WTW results from pairing finished fuels and feedstocks with vehicles.

Many factors affect well-to-wheel fuel cycle emissions. The most significant parameters, shown in Table 2-1, affect the amount of fuel or feedstock required in the fuel cycle, emission control requirements, or the composition of fuels. The WTW analysis results are extremely dependent on assumptions made, particularly in the WTT portion of the analysis. Therefore, an effort was made to clearly and prominently indicate key assumptions and uncertainties. Some of these assumptions may be discussed in this volume, but the reader is directed to the companion WTT and TTW volumes for a comprehensive discussion of assumptions. The following sections

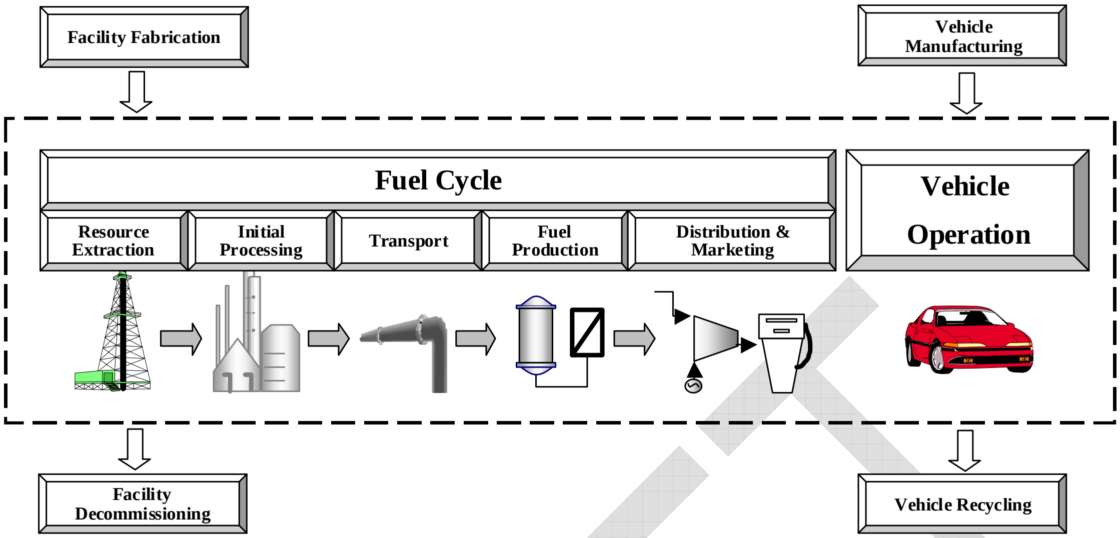

Figure 2-1. Total Vehicle Energy Cycle

Table 2-1. Effect of Study Parameters on Fuel Cycle Results

Parameter	Effect on Fuel Cycle Analysis
Timeframe	Affects emission rules and infrastructure capacity
Production Technology	Affects energy inputs and emissions
Region	Affects stationary source and vehicle emission standards, and transport distances
Vehicle Technology	Fuel cycle emissions and vehicle CO_2 are proportional to fuel consumption. Assumed vehicle NO_x and CH_4 emissions are proportional to fuel consumption. CH_4, N_2O, and CO emissions vary with vehicle technology.

describe the approaches used for the WTT and TTW analyses. Again, for more detail on methodology, assumptions, analysis tools, fuel properties, and so forth, please refer to the individual companion WTT and TTW reports.

2.1 Well-to-Tank Analysis Approach

The WTT analysis was done using the latest version of the GREET1.7 model as the platform. Many emission factors and transport modes and distances were modified to reflect alternative fuel use in California. Overarching assumptions were made in two areas: geographic boundaries for emission quantification, and emission marginality. The following sections briefly describe each approach and then provide the matrix of finished fuel and feedstock combinations considered. For details on the analysis approach, please consult the companion WTT report.

2.1.1 Geographic Boundary Assumptions

The region where fuel production occurs was tracked in the fuel cycle analysis. Geographic distributions of pollutant emissions were analyzed to identify the regions affected by various phases of the fuel cycles. This helps to evaluate the impact on local emission inventories and air quality, as well as taking into consideration the differences between local emission rules. Although this analysis is not necessary for greenhouse gas emissions, which have global impacts, the activities leading to local emissions often cause greenhouse gas emissions as well. As a result, the study also geographically distributed greenhouse gas emission sources. The percentage of feedstock extracted or fuel produced in each area was determined. Emissions from fuel production were then allocated according to the locations noted in Table 2-2.

Table 2-2. Analysis Boundaries

<table>
<tr><th>Parameter</th><th colspan="5">Analysis Metric</th></tr>
<tr><td rowspan="2">Energy Inputs</td><td colspan="2">Petroleum</td><td>Fossil Fuel</td><td colspan="2">Non Fossil</td></tr>
<tr><td colspan="2">CA</td><td colspan="2">North America</td><td>ROW</td></tr>
<tr><td>GHG Emissions</td><td colspan="2">CA</td><td>US</td><td colspan="2">Rest of World (ROW)</td></tr>
<tr><td rowspan="2">Criteria Pollutant Emissions</td><td colspan="2">CA Nonattainment</td><td colspan="3">Other CA, US, ROW</td></tr>
<tr><td>Marginal CA</td><td>Offset Emissions</td><td>Average CA</td><td>Upset Condition</td><td>Distressed Resource</td></tr>
<tr><td>Multimedia Impacts</td><td colspan="2">CA</td><td colspan="3">Outside CA</td></tr>
</table>

While GHG emissions were quantified on a global basis, only criteria and air toxic pollutant emissions occurring within California and California waters were considered. The study looked at criteria and air toxic emissions from the perspective of exposure to an individual in California. Although the total emissions from global fuel production and transportation are important, policy makers outside California can also address air quality goals with a variety of measures.

Stringent stationary source emission standards in California limit the emissions associated with conventional fuel production, fuel transport through marine terminals, electric power generation, and alternative fuel production facilities. Moreover, most new stationary sources located in ozone nonattainment areas must offset their emissions of NO_x and VOC, resulting in no net increase, and oftentimes a decrease, in emissions of these pollutants. Criteria pollutant and air toxics emissions were further grouped by emissions in California nonattainment areas and emissions occurring outside California. California specific emission factors provided the basis for estimating emissions from equipment in California, while a composite of U.S. emission factors provide the basis for emissions outside of California.

In addition to emissions from fuel production, emissions for fuel or feedstock transportation and distribution were also divided into the four geographic distribution categories. For example, emissions for ships entering and exiting the San Pedro Bay ports were attributed to California for a portion of the trip. The rest of these emissions were attributed to the rest of the world (ROW). Both land and sea transport emissions were allocated proportionally according to their transport route.

2.1.2 Marginal Emissions

For this analysis, production capacity in California and many other regions involved in the logistics of fuel supply are well enough understood that a first order estimate of the marginal sources provides a good basis for the study assumptions. To meet California and worldwide demand for most of the fuels considered in this study, new growth in production capacity will be required. Any increases in fuel production or power generation due to a reduction in petroleum use were assumed to come from new, more efficient plants built to meet growing demand. Therefore, the overarching assumption regarding fuel cycle emissions was marginality.

Population growth projections and related trends in California gasoline consumption indicate a larger than 30-percent increase in gasoline demand over 2002 levels by 2030. Industry experts anticipate that in-state refinery capacity will not increase substantially and that all of the gasoline use that could be displaced by alternative fuel use would be imported. Because of this assumption, this marginal analysis considers WTT emissions associated with imported finished petroleum fuels.

Another consequence of a marginal analysis is that no hydroelectric or nuclear power is included in the electric generation mix needed to supply increased demand. Reducing gasoline demand by increasing electric power demand for alternative fuel production or other electric transportation options does not increase the output from nuclear or hydroelectric generation facilities. Thus, the marginal source of electric power was assumed to be natural gas combined cycle combustion turbines and renewable power that complies with California's Renewable Portfolio Standard (RPS) goals.

Natural gas marginal considerations preclude the use of California natural gas. Because only a small percentage of natural gas consumed in California is produced in-state, a marginal approach requires continued pipeline imports from other continental locations and imports of foreign LNG. These assumptions result in greater energy inputs and GHG emissions for natural gas or natural-gas-derived fuels than those derived from California natural gas.

The change demand for gasoline and natural gas in California will not affect the emissions in the state because of the overall supply and demand for these fuels as well as permitting constraints. However, the attribution of these emissions to average fuel usage still remains an interesting point of comparison. The criteria pollutant and toxics emissions from existing conventional fuel production facilities are discussed in the WTT report and can also be compared with the marginal emissions shown here.

The key WTT assumptions employed were:

- Additional petroleum fuel demand is met by importing finished liquid fuels to California
- Marginal electric power demands from fossil fuels are projected to be met by natural gas power generation with sufficient renewables to meet the Renewable Portfolio Standard goals.
- Emissions from new stationary sources are consistent with local permitting requirement
- Emissions from fuel transport vehicles are consistent with California Air Resources Board (ARB) requirements
- Marginal natural gas supplies originate from outside California
- New Source Review and other offset requirements limit NO_x and PM emissions from new power plants and fuel production facilities
- Changes in land use for agriculture are to be addressed separately from the WTT analysis.

2.1.3 Fuel and Feedstock Analysis Matrix

The finished fuel and feedstock combinations considered in the WTT analysis are shown in Tables 2-3 and 2-4. The analysis reflects a variety of pathways for many of the fuels to illustrate the impact of different production technologies or delivery routes. The production locations given in the tables affects the emissions constraints for the fuel production facility, as well as the delivery distance and transportation mode used to calculate energy inputs and emissions. Many of the fuels analyzed in this study are available today as fuels or industrial chemicals. Others could be produced with either a straightforward adaptation or significant investment in fuel production infrastructure. The status of fuel production technologies is also indicated in Tables 2-3 and 2-4. Therefore, the reader should recognize that the comparisons made here with new fuel technologies are only applicable if they are produced at a commercial scale.

Table 2-3. Finished Liquid Fuels and Feedstocks Considered

Fuel	Feedstock	Production Location	Existing Pathway	New Application	New Technology
CARBOB/ E5.7	Crude Oil, SE Asia Heavy Crude Oil Tar Sands	Singapore Venezuela Canada	X X X		
CA RFG0	Crude Oil, SE Asia	Singapore		X	
CA RFG - E10	Crude Oil, SE Asia	Singapore		X	
Diesel, ULSD (10 ppm S)	Crude Oil, SE Asia	Singapore	X		
LPG	Crude Oil Natural Gas	California Arizona	X X		
CNG	Natural Gas LNG Landfill Gas	Texas, Canada Chile CA	X 	 X X	
LNG	Natural Gas Pipeline NG	Chile CA		X X	
Methanol	Natural Gas	Chile			
DME	Natural Gas	Chile			X
Fischer Tropsh Diesel	Natural Gas Biomass (Poplar) Coal	Malaysia CA CA	X 		 X X
Biodiesel (vegetable oil)	Palm Oil Soy Bean Oil	Malaysia Midwest	X X		
E-Diesel	Corn, Midwest	Midwest	X		
Ethanol, E85	Corn, Midwest Corn, Midwest Sugar Cane Poplar Switch Grass Forest Residue	Midwest CA CA, Brazil CA CA CA	X X X 		 X X X

Table 2-4. Fuel/Feedstock Scenarios for Electricity Generation and Hydrogen Production

Fuel	Feedstock	Production Location	Existing Pathway	New Application	New Technology
Electricity	CA Average Mix	Various	X		
	CA Marginal, 20% RPS	CA	X		
	Dedicated Renewable Power	CA	X		
	Petroleum Coke	CA			X
Hydrogen	NG SR, LH_2, 20% RP	CA	X		
	NG SR, LH_2, 100% RP	CA		X	
	NG SR, Pipeline	CA		X	
	Petroleum Coke, Gasification	CA			X
	Biomass, Gasification	CA			X
	On Site NG SR, 20% RP	CA	X		
	On Site NG SR, 700 bar, 20% RP	CA	X		
	On Site NG SR, 100% RP	CA		X	
	On-Site Electrolysis, CA Marginal	CA	X		
	On-Site Electrolysis, 70% RP	CA		X	

RPS = Renewable portfolio standard
RP = Renewable Power

2.2 Tank-to-Wheels Analysis Approach

For the TTW analysis, emissions from onroad and offroad equipment were compared to a base case. Each vehicle or equipment category uses predominately either gasoline or diesel fueled vehicles. In this analysis, the dominant fuel for each vehicle and equipment category was selected as the base case for comparison with alternative fuel operation.

For on-road vehicles, the analysis considered the difference between the introduction of new fuels as blends, and new vehicle technologies. When fuel formulations change or new blends are introduced, all of the vehicles on the road can be affected immediately. However, new vehicle technologies displace conventional vehicle technologies. Therefore blend options and new vehicle technology options were treated with different baseline vehicle emission rates. Vehicles utilizing blended fuels were compared to the California mix of vehicles, while new alternative fuel vehicle technologies were compared to a new vehicle utilizing the base case petroleum fuel.

The basic approach to the TTW emission analysis can be divided into two parts: vehicle fuel economy assumptions and vehicle emission factor assumptions. This section briefly discusses these two components of the TTW analysis and refers the reader to the companion TTW report for more details and references.

2.2.1 Vehicle Fuel Economy Assumptions

Vehicle and equipment fuel economy was used to convert the WTT emissions per unit energy in the finished fuel into a vehicle g/mile basis so it can be added to the g/mile vehicle emissions. A considerable amount of effort went into determining the fuel economies for the base case vehicles as well as the fuel economies for these vehicles utilizing fuel blends and new alternative fuel and vehicle technologies. For on-road vehicles, the Energy Commission's CalCars model and ARB's EMFAC models were utilized. For off-road equipment, ARB's recently updated off-road model was employed. The emissions for on-road and off-road vehicles are presented in the TTW report on a g/mi and a g/gal of finished fuel basis for a wide range of vehicle applications. Table 2-5 provides the matrix of all the vehicles evaluated for each finished fuel. Recall that many of the finished fuels can be made from several different feedstocks. Figure 2-2 provides a summary of the fuel economies assumed for each of the light duty vehicle options.

Table 2-5. Baseline Vehicles for Estimating Alternative Fueled Vehicle Emissions

Fuels	Mid-Size Passenger Car		Urban Bus	
	New	Blend Displacing Gasoline	New	Blend Displacing Diesel
RFG - E0	—	A	—	—
RFG - E5.7	**N (CAT)**	**A (CAT+NCAT)**	—	—
RFG - E5.7, HEV	N	—	—	—
RFG - E10	N	A	—	—
Diesel	—	—	**N (DSL)**	**A (DSL)**
LPG	N	—	—	—
CNG	N	—	N	—
LNG	—	—	N	—
Methanol	—	—	N	—
DME	—	—	N	—
FT blends (30%)	—	—	—	A
Ethanol - E85	—	A	—	—
E-diesel	—	—	—	A
Biodiesel, BD20	—	—	—	A
Electricity	N	—	—	—
Hydrogen ICEV	N	—	N	—
Hydrogen FCV	N	—	N	—

Baseline vehicles shown in bold.
A = Average fleet, all vehicles on the road.
N = New Technology.

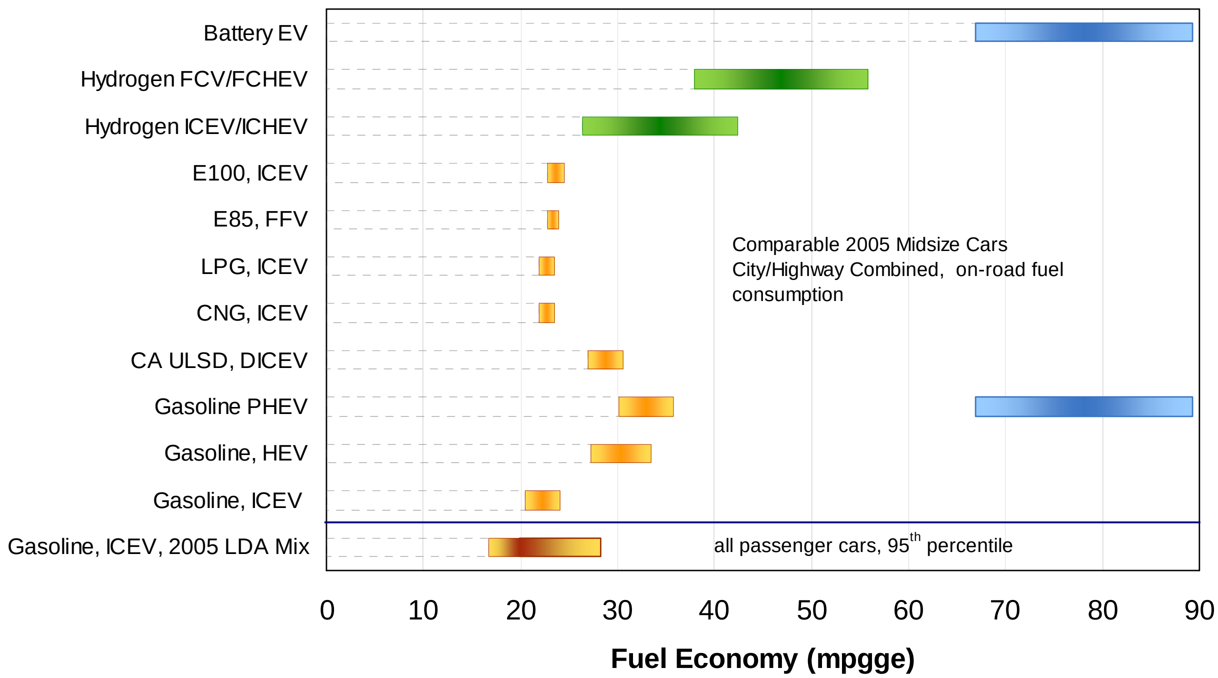

Figure 2-2. Summary of Light-Duty Vehicle Fuel Economies Utilized in TTW Analysis

2.2.2 Vehicle Emission Factors

The second component of the WTT analysis was the set of assumptions for vehicle emission factors. TTW emissions include vehicle evaporative emissions and vehicle tailpipe emissions. Three different classes of pollutants were considered: criteria pollutants, GHGs, and air toxics. The methodologies utilized to determine accurate emission factors for each finished fuel/vehicle combinations are described in the following paragraphs.

For on-road diesel and gasoline vehicles, exhaust and evaporative criteria pollutant emission factors were obtained from ARB's EMFAC2007 model. For the alternative fuels, adjustment factors were applied to the appropriate EMFAC values. The specific adjustment factors for each fuel are documented in the TTW report. The same approach was utilized for off-road equipment. The ARB Offroad model data were used for the base case and adjustment factors were applied to determine alternative fuel emission factors.

An overriding assumption in determining the adjustment factors for the alternative fuels was that blend fuels must meet petroleum fuel emission standards for NO_x, HC (with a CO credit), and weighted air toxics emissions as determined by ARB's Predictive Model. Further, alternative fuel vehicles (e.g., LPG and CNG) must meet prevailing fuel specific California emission standards.

GHG emissions considered included CO_2, CH_4, and N_2O. The CO_2 emissions were calculated directly from the carbon content of the fuel after accounting for fuel that is converted to CH_4, CO, and evaporative emissions. The CH_4 and N_2O emission factors utilized in this analysis were the values in the California Climate Action Registry reporting protocols. The N_2O emission factor warrants further study, because data are limited and the emission factor used is a fixed g/mi value rather than a g/GJ value. The effect is that the same amount of N_2O is emitted regardless of the amount of fuel utilized per mile.

Refrigerants from vehicle air conditioning systems are also a source of GHG emissions. Refrigerant emissions were not included in the analysis because these would not change with different fuel options, unless alternative refrigeration cycles such as those considered for electric drive systems are used. Furthermore, air conditioning losses are typically not considered part of the fuel cycle.

Finally air toxics emissions were estimated by applying factors from ARB's Speciate model to the ROG emission factor established by EMFAC and the Offroad model.

2.3 Well-To-Wheels Emissions Estimation

To determine the full fuel cycle emissions for each pollutant and each vehicle/finished fuel/feedstock combination, the WTT and TTW parts of the fuel cycle are combined. Specifically, for each finished fuel, each pollutant's WTT emission factor is multiplied by the vehicle's fuel economy and then added to the vehicle's emission factor. Figure 2-3 schematically indicates how the two results are combined.

WTW Emissions gram/mi	=	WTT Finished Fuel Emissions gram/MJ	X	Vehicle Fuel Economy MJ/mile	+	Vehicle Emissions g/mile

Figure 2-3. Summing up Fuel Cycle Emission Components

SECTION 3. WELL TO WHEEL ANALYSIS RESULTS

The combined results of the WTT and TTW analyses for each of the vehicle/finished fuel/feedstock combinations evaluated are presented here. Secti ons 3.1 through 3.9 present the energy, GHG emissions, and criteria pollutant emissions for each fuel considered in the analyses. Air toxics emissions and multimedia impacts are also briefly discussed in each section.

The energy inputs, GHG emissions, and criteria pollutant emissions for the vehicle/ fuel/ feedstock combinations described in this section are presented in a set of bar chart figures and summary tables for each fuel in the following subsections. Tables that document the GREET model and other calculation results that are shown in the figures are included in the Appendix of this report.

3.1 Conventional (Petroleum) Fuels: Gasoline and Diesel

This subsection presents the results for the mid-size passenger vehicles operated on gasoline and diesel fuels.

3.1.1 Gasoline Fueled Vehicles

Figures 3-1 and 3-2 present the WTW energy consumption and GHG emission results, respectively, for each of the gasoline fuels considered for both conventional vehicles and HEVs. Results for an ethanol/gasoline blend (E10) are also shown in the figures. The ultimate energy source contribution to fuel cycle energy consumption is also illustrated in Figure 3-1. Table 3-1 summarizes the energy and GHG impacts for this fuel. Figure 3-3 illustrates the criteria pollutant emission impacts; these results are summarized in Table 3-2 along with the air toxic emissions and multimedia impacts.

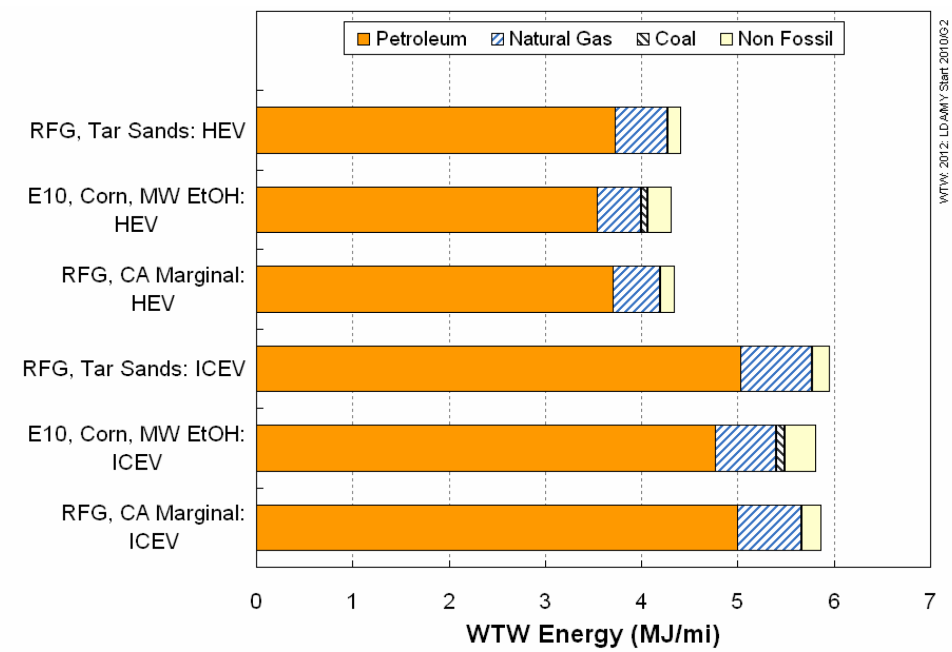

Figure 3-1. WTW Energy Consumption for Gasoline Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

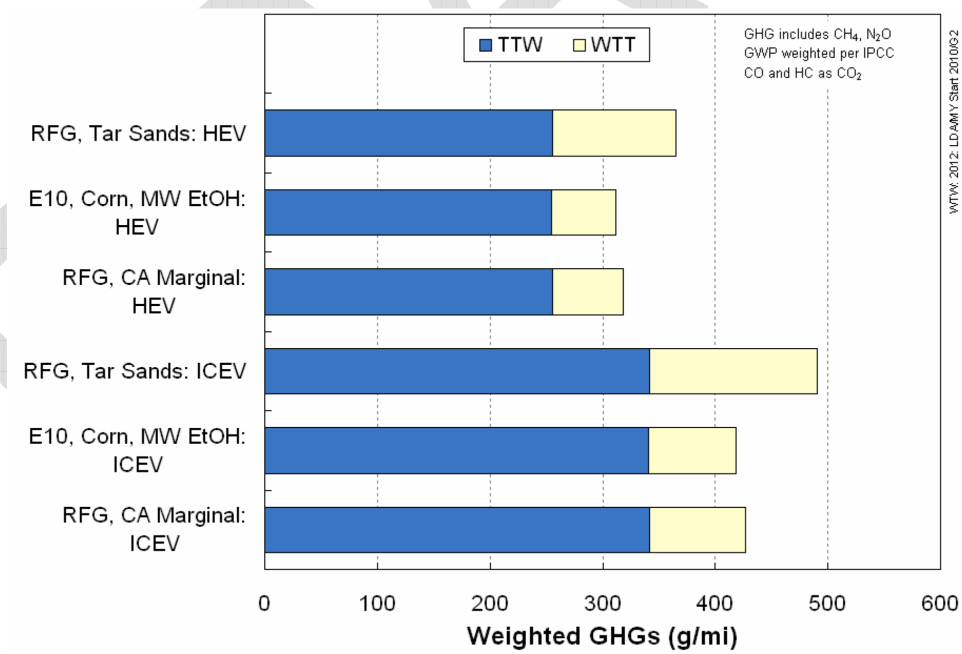

Figure 3-2. WTW GHG Emissions for Gasoline Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

Table 3-1. Energy and GHG Impacts of Gasoline Vehicles

Parameter	Energy and GHG Impact		
Energy Factors	• Advanced gasoline technologies such as HEVs can reduce fuel consumption by 20 to 40% • Requirement for producing reformulated gasoline affects energy inputs and rejected pentanes with related transportation logistics • If E10 is produced it will require less sulfur, lower aromatics and more hydro treating of the blending component • Future gasoline fuels are more carbon intensive with growth in heavy oil and tar sands requiring hydro treating • Blends impact the entire gasoline pool including off-road vehicles with the same energy impact the same as that for on-road vehicles		
GHG Factors	• GHG reductions are proportional to reduction in energy consumption for HEVs		
Comparison	**HEVs, Passenger Cars, and Gasoline Blends (On- and Off-road)**		
Energy Impact		**Petroleum**	**Fossil Fuels**
	HEV	-25 to -40%	-25 to 40%
	CA RFG0	+1%	+1%
	E10	-2%	-1%
	Tar Sands	+2%	+20%
GHG Impact	HEV	-25 to -40%	
	CA RFG0	+ 1%	
	E10	-1%	
	Tar Sands	+15 to 35%	

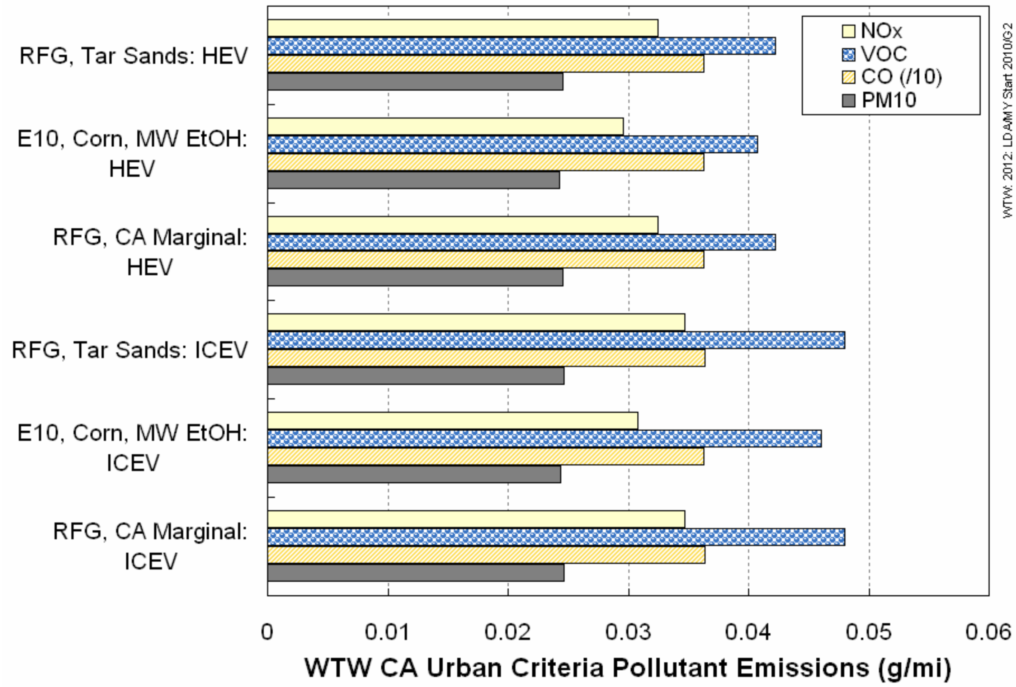

Figure 3-3. WTW Criteria Pollutant Emissions for Gasoline Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

Table 3-2. Pollutant Impacts of Gasoline Vehicles

Parameter	Pollution Impact
Criteria Pollutants	• Reduction in vehicle fuel consumption for HEV results in proportional reduction in fuel cycle criteria pollutants • Marginal fuel cycle criteria pollutant emissions include marine vessel, rail, local truck delivery, and storage/fueling losses • California refinery emissions are not included in the marginal emission calculations • Transportation logistics for ethanol blending and transporting rejected pentanes contribute to fuel cycle emissions • ARB requires no net change in NO_x and weighted HCs (with the weighted CO credit) for different gasoline blends. Vapor pressure is also limited to 7 RVP. Some blends may need to adjust levels of sulfur, aromatics, and other components to achieve no increase in emissions. • Vapor emissions for off-road vehicles would be affected by changes in vapor density as off road vehicles are not equipped with evaporative emission controls and fewer fuel dispensers use Stage 2 vapor recovery
Toxics	• Reduction in vehicle fuel consumption for HEV results in proportional reduction in fuel cycle toxics, primarily diesel PM and refueling spillage • Non petroleum ethanol reduces precursors for benzene and 1-3 butadiene but increases precursors for acetaldehyde • ARB requires no increase in weighted toxics from vehicle and evaporative emissions. Other constraints on fuel formulation could result in a reduction in aromatics to meet NO_x requirements • Ethanol delivery requires transport to bulk terminals by truck rather than pipeline. Total fuel cycle PM in California does not increase for the mix of delivery modes assumed here.
Multimedia Impacts	Ethanol in blends displaces gasoline hydrocarbons. Ethanol biodegrades more rapidly in the environment. Underground tank leaks can affect the fate of gasoline leaks

Comparison	Passenger Cars, HEVs	Gasoline Blends (On and Off Road)
CA Criteria Pollutants – 2012		Same
NO_x	-2%	
VOC	-5%	
CO	-2%	
PM	same	
2022	Impact diminishes with new technology engines	Same
Weighted Toxics	Same to small reduction in benzene and diesel PM	Same
Multimedia Impacts	25% reduction in petroleum based hydrocarbons	Same

3.1.2 Diesel Fueled Light-Duty Vehicles

Similarly for diesel fuels, Figures 3-4 and 3-5 provide the energy and GHG emissions results, respectively, for diesel fuel use in light duty vehicles. Table 3-3 summarizes these results. Again, the ultimate fuel contributions to the energy consumption for each fuel/vehicle combination are illustrated in Figure 3-4. Figure 3-6 illustrates the criteria pollutant emissions for diesel fueled light duty vehicles while Table 3-4 summarizes these results along with the air toxic emissions and multimedia impacts.

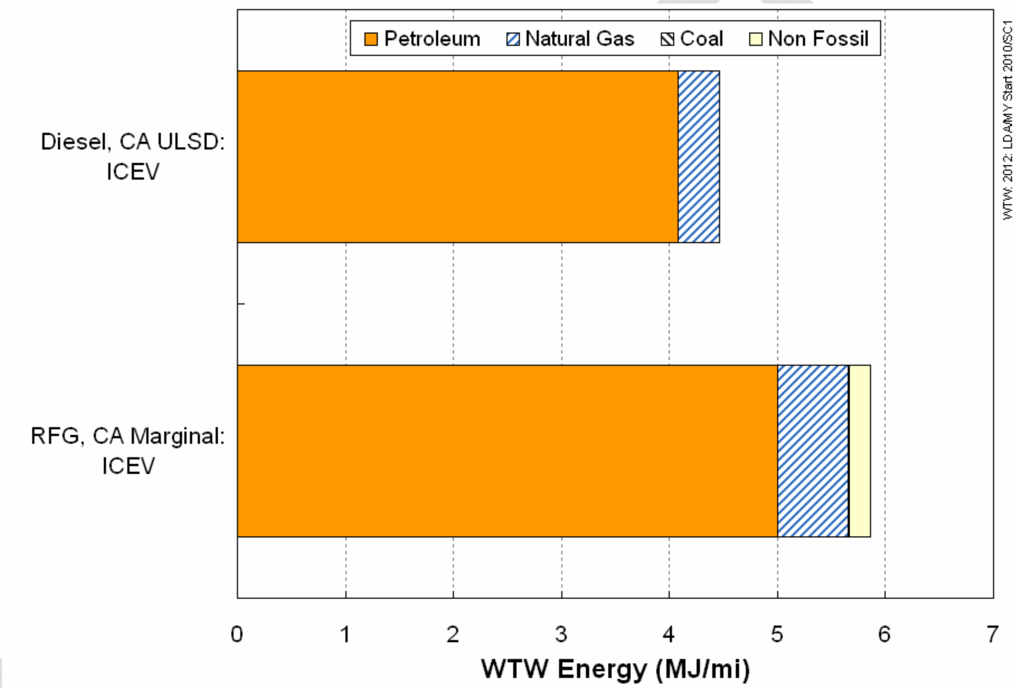

Figure 3-4. WTW Energy Consumption for Diesel Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

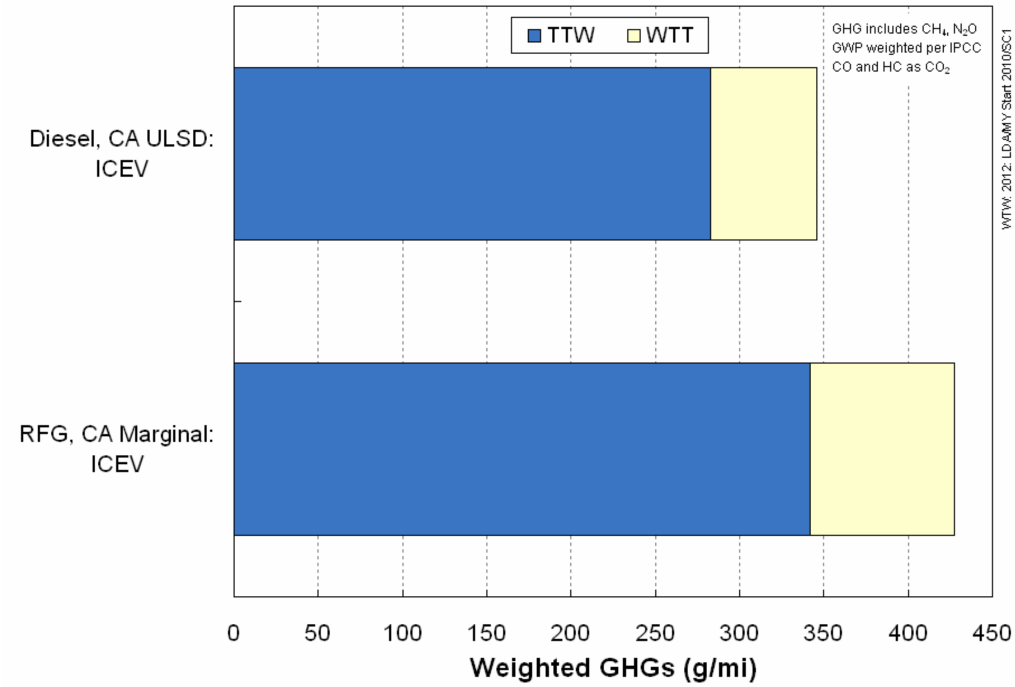

Figure 3-5. WTW GHG Emissions for Diesel Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

Table 3-3. Energy and GHG Impacts of New Diesel Passenger Cars

Parameter	Energy and GHG Impact
Energy Factors	• Low allocation of refinery energy to diesel because gasoline is the primary fuel consumed in California • Improvement in energy consumption over gasoline vehicles • Increased hydro treating is required to achieve low sulfur specifications
GHG Factors	• Lower energy inputs in the fuel cycle are partially offset by higher carbon content in the fuel
Comparison	**Passenger Cars**
Energy Impact	-25% petroleum -27% fossil fuel
GHG Impact	-20 to -25%

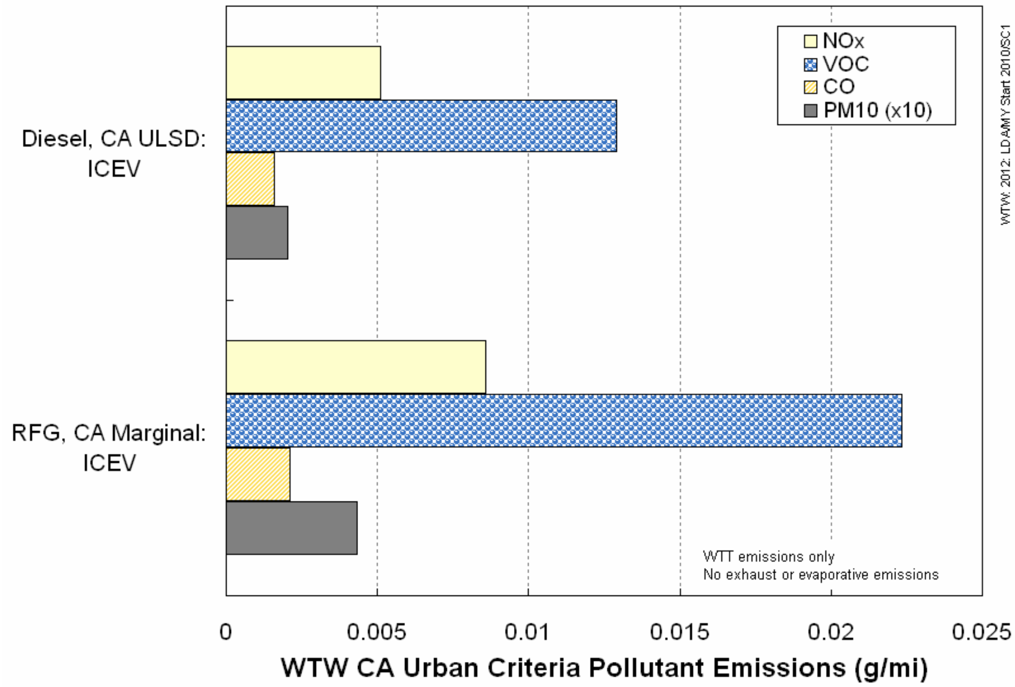

Figure 3-6. WTW Criteria Pollutant Emissions for Diesel Fuels in Mid-Size Vehicles, Fuel Cycle Only, (2012 New Vehicle Stock)

Table 3-4. Pollution Impacts of New Diesel Passenger Cars

Parameter	Pollution Impact
Criteria Pollutants	• Diesel cars would be certified to meet ARB regulations. A mix of diesel and gasoline cars would need to meet the prevailing LEV requirements for each model year • A carmaker's mix of diesel and gasoline cars could not result in a net increase in tailpipe emissions • Very low vapor pressure results in a net reduction in VOC emissions throughout the fuel cycle • Improved fuel economy results in lower emissions from fuel delivery
Toxics	• Benzene and 1-3 butadiene are reduced from fuel spills but diesel contains PAHs. Diesel PM must meet ARB regulations
Multimedia Impacts	• Fuel that is spilled at station does not evaporate rapidly. A larger fraction may enter storm water run off
Comparison	**Passenger Cars**
Criteria Pollutants	VOC -40% CO, NO_x, -20%
Weighted Toxics	Same
Multimedia Impacts	Same to slight increase

3.2 Ethanol

The results for ethanol blends are presented in this section – note that the results for corn based ethanol are summarized separately from those for ethanol produced from sugar cane and biomass/cellulosic conversion processes. Figures 3-7 and 3-8 present the energy and GHG impacts for ethanol fuels. Table 3-5 summarizes these results for corn based ethanol, while Table 3-6 summarizes these results for biomass and sugarcane based ethanol.

Figure 3-9 provides criteria air pollutant emissions for the ethanol fuels. Tables 3-7 and 3-8 summarize these results for corn based ethanol and sugarcane/biomass derived ethanol, respectively.

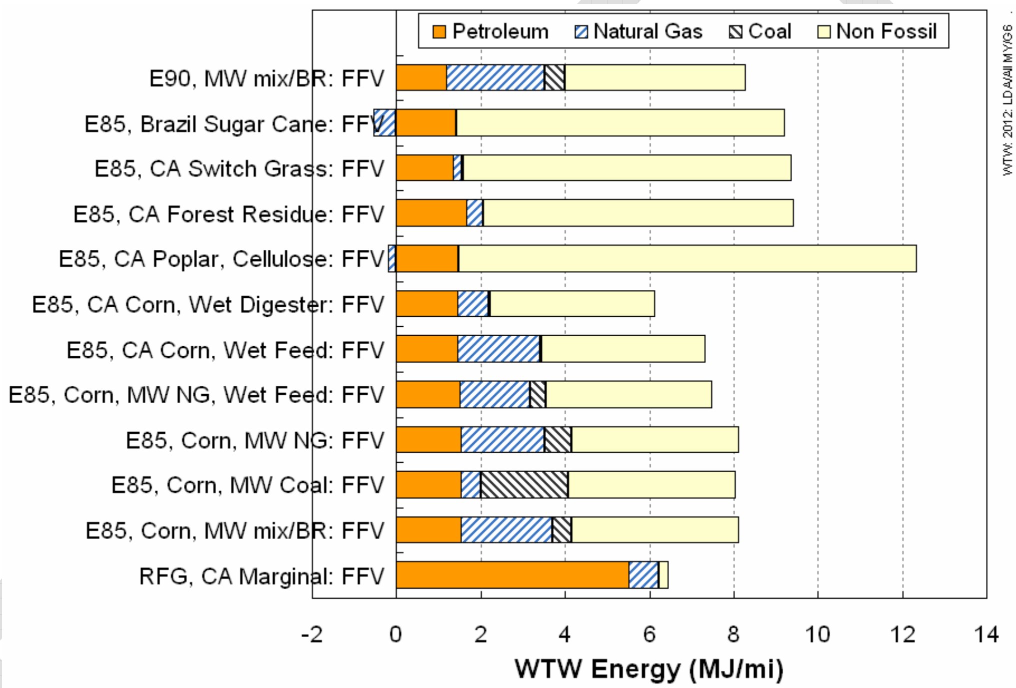

Figure 3-7. WTW Energy Consumption for Ethanol Fuels in Mid-Size Vehicles (2012 Existing Vehicle Stock)

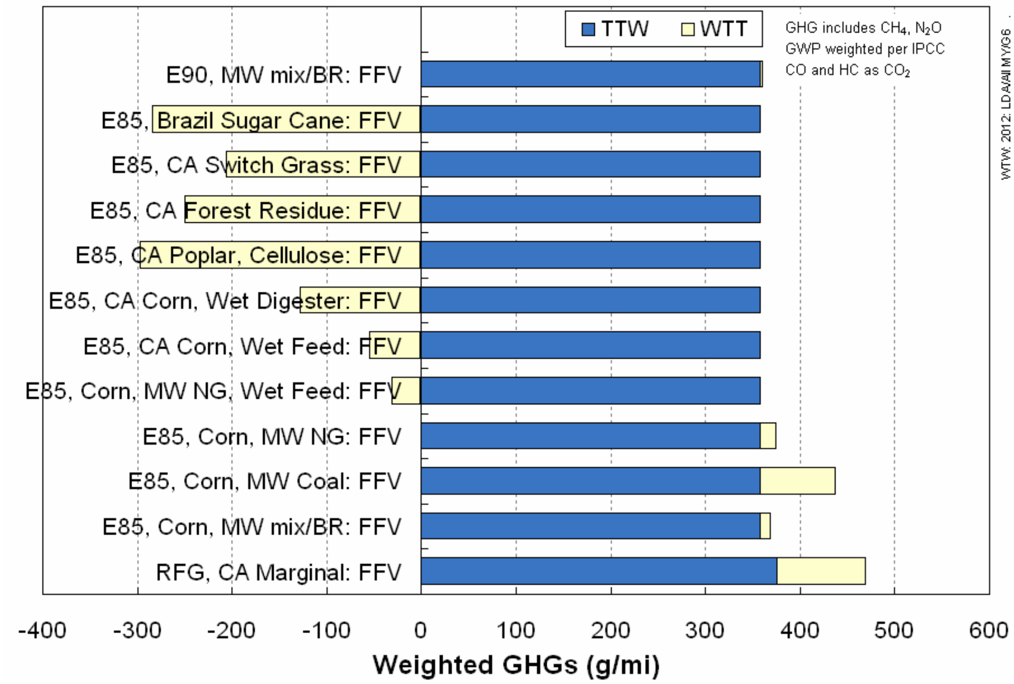

Figure 3-8. WTW GHG Emissions for Ethanol Fuels in Mid-Size Vehicles (2012 Existing Vehicle Stock)

Table 3-5. Energy and GHG Impacts of E85 Vehicles – Corn Based Ethanol

Parameter	Energy and GHG Impact	
Energy Factors	• Corn production requires fuel inputs for farming, fertilizer, and ethanol plants • Trend towards declining nitrogen inputs and no till farming, high starch corn, and improved crop yields reduce energy input per bushel of corn year after year • New ethanol plants are dry mills which generate byproduct animal feed (DGS), 35 % of energy is allocated to feed • Producing wet DGS reduces ethanol plant energy from 36,000 to 25,500 Btu/gal • Starch free DGS reduces ruminant methane production and had significant GHG impact from feeding corn • Strategy for using byproduct as animal feed is limited by the cattle population • DGS from California ethanol plants reduces rail shipments of feed corn • E85 FFV analysis includes 3% improvement in energy consumption	
GHG Factors	• Range in GHG emissions depending on energy source and plant energy requirements • Impact of displaced agriculture crop needs to be examined (for example reduced exports of cotton) • Improvements in agriculture can increase GHG benefit further • GHG impact is expressed on an E85 basis. Similar impact could be achieved with low level blends without improvement in energy consumption	
Comparison	**Passenger Cars (E85 basis)**	
Energy Impact	- 75% petroleum - 30 to - 60% fossil fuel	
GHG Impact	Coal based plant Midwest corn California corn	-5% -5 to 30% -30 to -50%

Table 3-6. Energy and GHG Impacts of E85 Vehicles – Sugar Cane and Biomass Based Ethanol

Parameter	Energy and GHG Impact	
Energy Factors	• Feedstock production requires fuel inputs for farming, fertilizer, and ethanol plants with generally lower inputs than corn • Sugar cane production requires unique agricultural circumstances with plentiful water and warm climate (probably limited to Brazil on a large scale) • Fossil energy input for sugar cane and biomass are relatively low. Biomass residue provides fuel for ethanol plant • E85 FFV analysis includes 3% improvement in energy consumption	
GHG Factors	• Range in GHG emissions depending on plant efficiency and excess electric power that is generated • Impact of land use needs to be considered. Converting forest to energy crops results in a multi decade GHG deficit. • Cellulose based technology is not yet proven so plant performance and byproducts may differ significantly from the analysis • GHG impact is expressed on an E85 basis. Similar impact could be achieved with low level blends without improvement in energy consumption	
Comparison	**Passenger Cars (E85 basis)**	
Energy Impact	- 70% petroleum - 70 to -85% fossil fuel	
GHG Impact	Sugar Cane Cellulose	-80% -70 to -87%

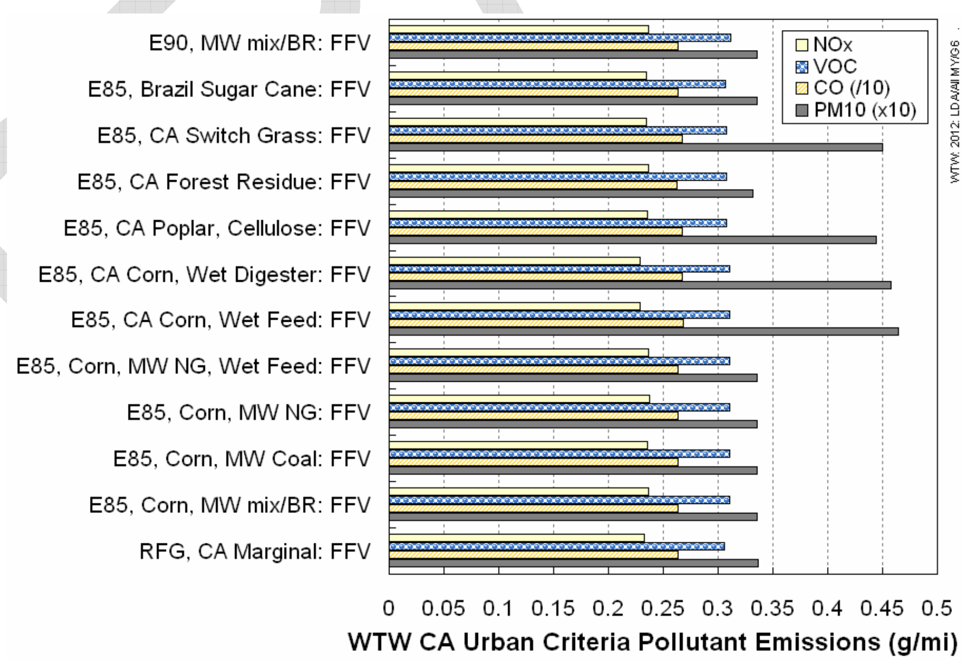

Figure 3-9. Criteria Pollutant Emissions for Ethanol Fuels (2012 Existing Vehicle Stock)

Table 3-7. Pollution Impacts of E85 Vehicles – Corn Based Ethanol

Parameter	Pollution Impact
Criteria Pollutants	• Fuel cycle criteria pollutant emissions include marine vessel, rail, and local truck delivery • Transportation logistics for ethanol blending and exporting rejected pentanes contribute to fuel cycle emissions • Ethanol is not distributed by pipeline. For E10 and E85 blending, denatured ethanol must be hauled to blending terminals by truck resulting in extra diesel truck emissions. • California plants will be required to offset NO_x and VOC emissions
Toxics	• ARB regulations require no net increase from vehicle exhaust plus evaporative emissions • Actual vehicle emissions will have less benzene and more acetaldehyde with a net decrease in weighted toxics emissions • Reduced benzene and 1-3 butadiene in fuel lower toxics from fuel spillage and stationary losses
Multimedia Impacts	• Most corn is grown using dry land farming (no irrigation). The requirements for the next 5 billion gallons of corn based ethanol production need to be examined • Gasoline is displaced with ethanol which biodegrades more rapidly • Fate of E85 in underground tank leaks is complex with no likely net impact.

Comparison	Passenger Car	
Criteria Pollutants	VOC NO_x CO PM	+1 to +2% -2 to +2% 0 to +2% 0 to +38%
Weighted Toxics	Same to possible reduction in weighted emissions	
Multimedia Impacts	-85%; reduction in hydrocarbon related transport	

Table 3-8. Pollution Impacts of E85 Vehicles – Sugarcane and Biomass Based Ethanol

Parameter	Pollution Impact Base
Criteria Pollutants	• Fuel cycle criteria pollutant emissions include local truck delivery and agricultural equipment in California. Brazilian ethanol is imported by marine vessels • Transportation logistics for ethanol blending and exporting rejected pentanes contribute to fuel cycle emissions • California plants will be required to offset NO_x and VOC emissions • Combustion technologies with enhanced particulate control (such as gasification) will be required for plants to be permitted in California non attainment areas • Declining emissions from off road farming and logging equipment result in reduced fuel cycle impact over time
Toxics	• ARB regulations require no net increase from vehicle exhaust plus evaporative. • Actual vehicle emissions will have less benzene and more acetaldehyde with a net decrease in weighted toxics • Reduced benzene and 1-3 butadiene in fuel lower toxics from fuel spillage and stationary losses
Multimedia Impacts	• Sugar cane is grown in areas with significant rainfall that cannot be replicated in many areas of the world. Sugar cane for a California based ethanol plant depends on a unique set of environmental conditions to secure its access to water. • Gasoline is displaced with ethanol which biodegrades more rapidly • Fate of E85 in underground tank leaks is complex with no likely net impact.

Comparison	Passenger Car	
Criteria Pollutants	Brazil Sugar Cane California Biomass	Same 0 to 5% increase in near term due to agricultural equipment
Weighted Toxics	Same to possible reduction in weighted emissions	
Multimedia Impacts	-85%; reduction in hydrocarbon related transport	

3.3 Biodiesel

This subsection presents the results for light duty (mid-size passenger car) and heavy duty (urban bus) diesel vehicles operated on biodiesel fuels. Figures 3-10 and 3-11 present the WTW energy consumption and GHG emission results for the biodiesel fuels evaluated as well as for the corresponding baseline diesel vehicles. Table 3-9 summarizes the energy and GHG impacts for these fuels. Figure 3-12 provides the criteria pollutant emission impacts of using biodiesel fuels in the respective vehicle evaluation cases. These results are summarized in Table 3-10 along with the air toxics emissions and multimedia impacts. Table 3-10 also notes that biodiesel blends can be used in off road equipment with comparable criteria pollutant and air toxics emissions, and multimedia impacts.

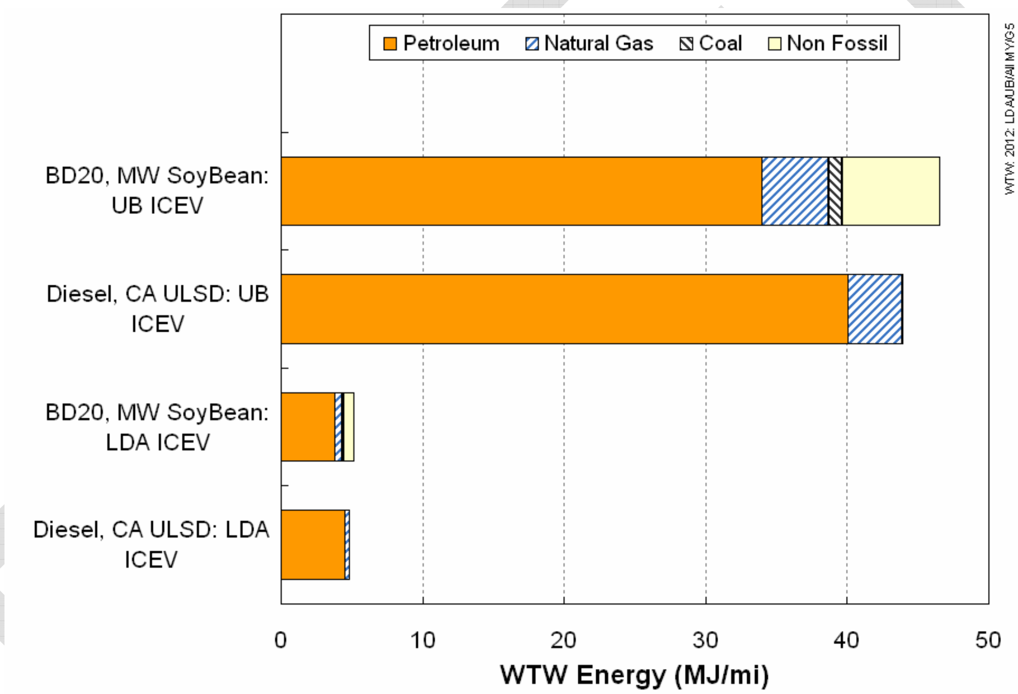

Figure 3-10. WTW Energy Consumption for Biodiesel Fueled Vehicles – BD20 (2012 Existing Vehicle Stock)

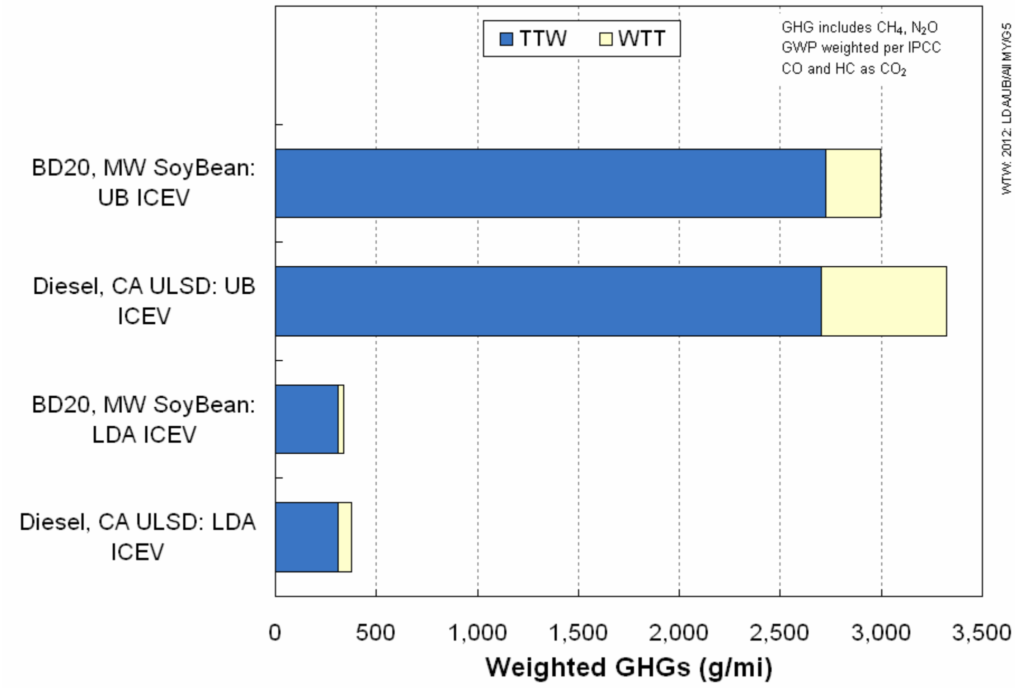

Figure 3-11. WTW GHG Emissions for Biodiesel Fueled Vehicles – BD20 (2012 Existing Vehicle Stock)

Table 3-9. Energy and GHG Impact of Biodiesel Vehicles – BD20

Parameter	Energy and GHG Impact
Energy Factors	• Petroleum and other fuels are inputs for farming and esterification • Allocate 35% of soybean oil to byproducts • Mustard seed and rapeseed can be grown as cover crops with low energy inputs
GHG Factors	• Relatively low fossil energy inputs reduce GHG emissions, although N_2O emissions from farming can diminish benefits • While not likely in the U.S., converting forest to agricultural use results in an increase in GHG emissions for decades • Effect of displaced crop needs to be examined • Need to address sustainable agriculture for tropical oils
Comparison	**Passenger Cars and Heavy-Duty Vehicles**
Energy Impact	-10% petroleum and fossil fuel
GHG Impact	-8 to – 12% (plus any impacts on land use changes)

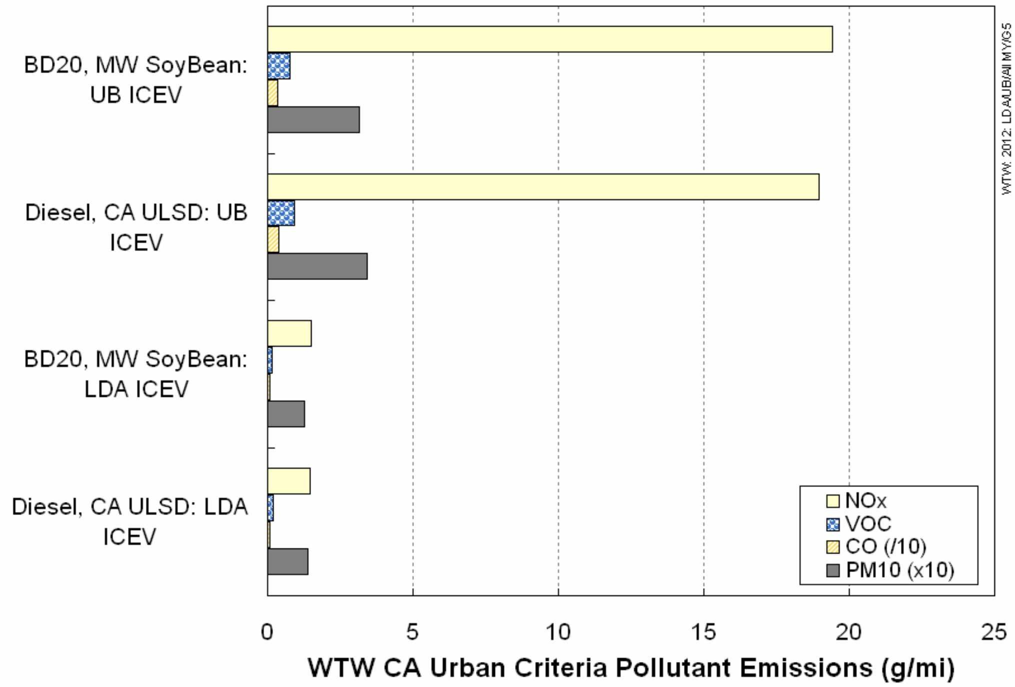

Figure 3-12. Criteria Pollutant Emissions for Biodiesel Fueled Vehicles –BD20 (2012 Existing Vehicle Stock)

Table 3-10. Pollution Impacts of Biodiesel Vehicles – BD20

Parameter	Pollutant Impact
Criteria Pollutants	• Modest reduction in HC, CO, and PM for existing vehicles. Impact on new technologies is under evaluation • Need to assure fuel quality to meet stringent future emission standards with new engines • Fuel cycle criteria pollutants include rail or marine vessel and local truck delivery • Biodiesel blends can also be used in off-road equipment. Slower introduction of new engine technologies could result in greater emission benefits than those achieved with new on-road vehicles
Toxics	• Non petroleum vegetable oils reduce precursors for benzene and 1-3 butadiene • Diesel PM is reduced with older technology engines. Impact on new engines is being determined
Multi-media Impacts	• Biodiesel biologically decomposes rapidly
Comparison	**Passenger Cars, Heavy-Duty Vehicles, and Off-Road Equipment**
Criteria Pollutants – 2012	
NO_x	0 to + 3%
VOC	-20%
CO	-10%
PM	-10%
2022	Emission impacts could diminish with new technology engines
Weighted Toxics	Same to small reduction in benzene and diesel PM
Multimedia Impacts	-20% reduction in petroleum based hydrocarbons

3.4 Natural Gas

This subsection presents the results for vehicles operated on natural gas fuels. Figures 3-13 and 3-14 illustrate the WTW energy consumption and GHG emission results, respectively, for light duty (mid-size passenger car) CNG vehicles as well as for baseline gasoline vehicles. Table 3-11 summarizes the energy and GHG impacts for these fuels. Figures 3-15 and 3-16 illustrate the corresponding WTW energy consumption and GHG emission results for both CNG and LNG use in heavy duty diesel vehicles, as well as for baseline diesel fuel vehicles. Table 3-12 summarizes the energy and GHG impacts for these fuels. Figure 3-17 provides the criteria pollutant emission impacts of using CNG in light duty vehicles. Figure 3-18 provides the corresponding criteria pollutant emission impacts of using both CNG and LNG in heavy duty diesel vehicles. The CNG criteria pollutant emissions results are summarized in Table 3-13 along with the air toxics emissions and multimedia impacts. Table 3-14 provides the corresponding summary of the criteria pollutant emissions impacts of CNG and LNG use in heavy duty diesel vehicles, along with the air toxics emissions and multimedia impacts for these natural gas fuels.

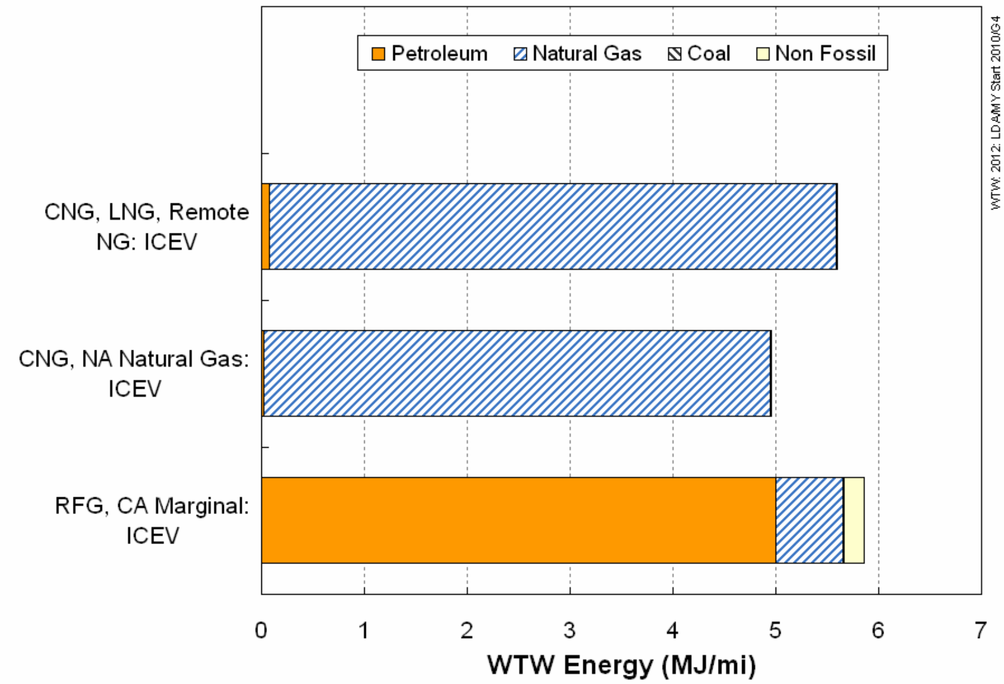

Figure 3-13. WTW Energy Consumption for CNG Vehicles (2012 New Vehicle Stock)

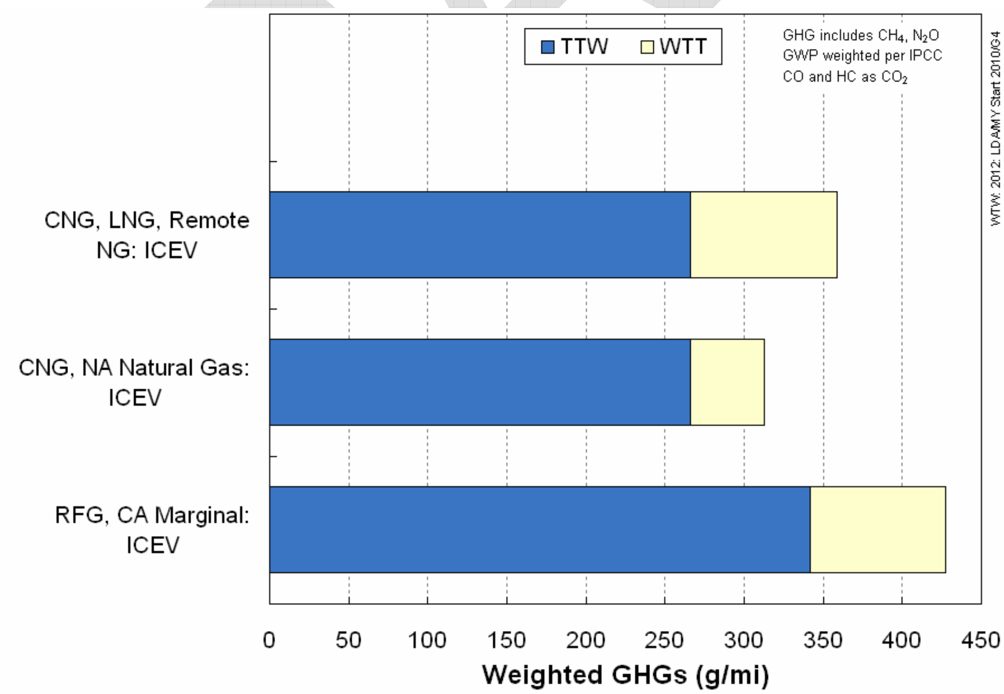

Figure 3-14. WTW GHG Emissions for CNG Vehicles (2012 New Vehicle Stock)

Table 3-11. Energy and GHG Impacts of CNG Vehicles

Parameter	Energy and GHG Impact	
Energy Factors	• Almost no petroleum in the fuel cycle. • Natural gas represents the rest of the fuel cycle with imports of LNG contributing up to 20% of future supplies • Growth in renewable power for compression energy • New technologies are closing the gap between heavy-duty natural gas and diesel engine efficiency	
GHG Factors	• Low carbon intensity of natural gas reduces vehicle GHG emissions • Methane leaks in the fuel cycle are a significant portion of WTT GHG emissions even after low U.S. T&D losses are taken into account	
Comparison	**Passenger Cars**	**HDVs**
Energy Impact	-90%+ petroleum +0 to +10% fossil fuel	-90%+ petroleum +5 to +15% fossil fuel
GHG Impact	-15 to -27% -23 to -18%	-10 to 0% -15 to -5%

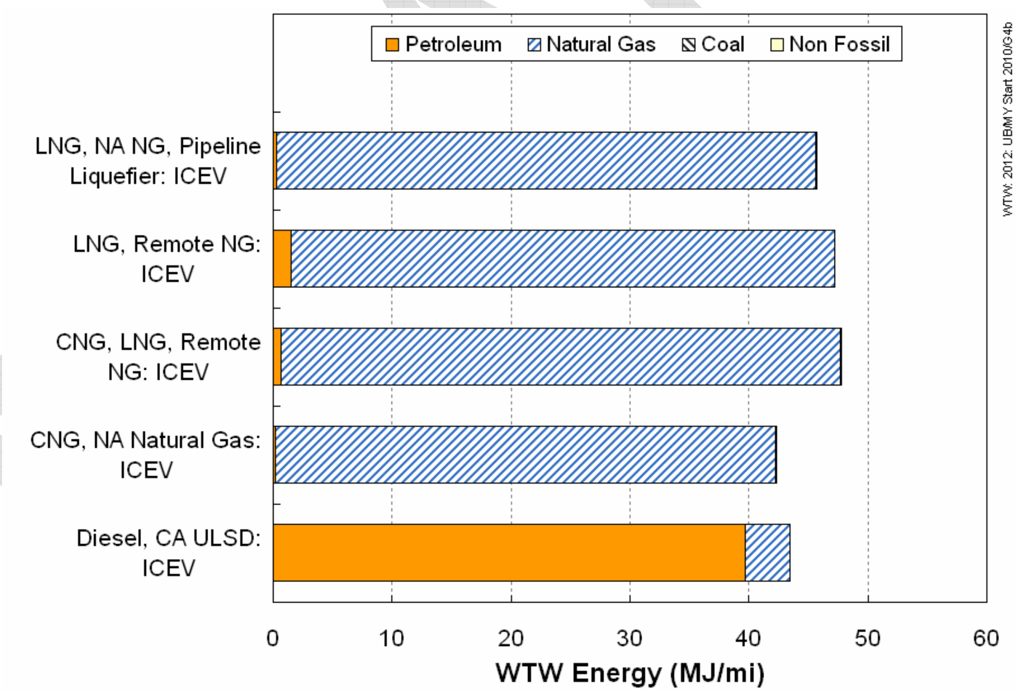

Figure 3-15. WTW Energy Consumption for LNG and CNG Heavy Duty Vehicles (2012 New Vehicle Stock)

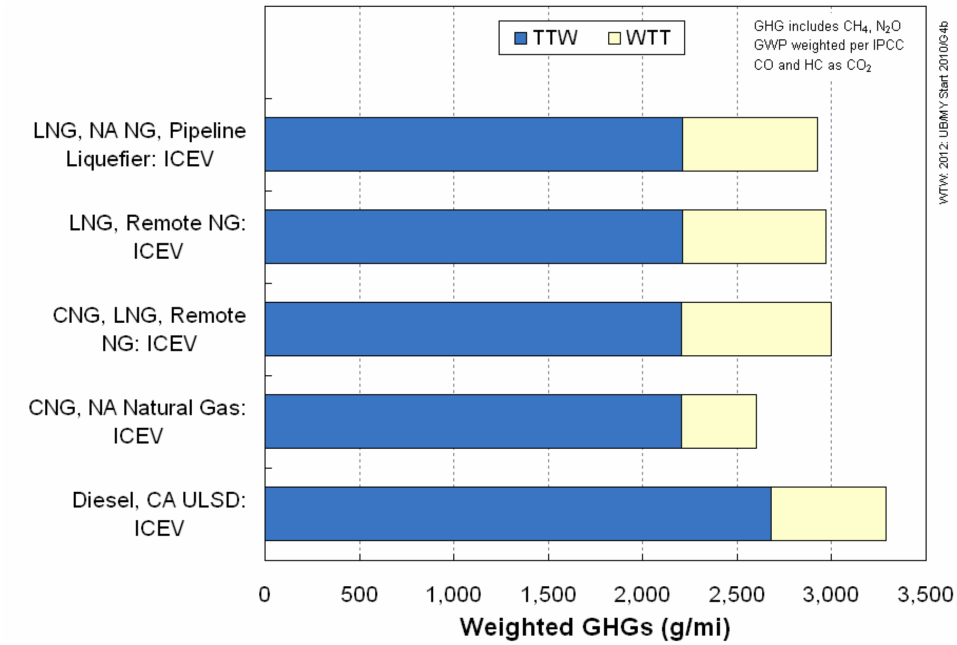

Figure 3-16. WTW GHG Emissions for LNG and CNG Heavy Duty Vehicles (2012 New Vehicle Stock)

Table 3-12. Energy and GHG Impacts of LNG Vehicles

Parameter	Energy and GHG Impact
Energy Factors	• Almost no petroleum in the fuel cycle. • Natural gas represents the remainder of the fuel cycle with imports of LNG contributing up to 20% of future supplies • Growth in renewable power for California based liquefiers • New technologies are closing the gap between heavy-duty natural gas and diesel engine efficiency
GHG Factors	• Low carbon intensity of natural gas reduces vehicles GHG emissions • Methane leaks in the fuel cycle are a significant portion of WTT GHG emissions (even after low U.S. T&D losses are taken into account for local liquefaction) • LNG terminals and tanker ships capture and recycle boil off methane • Modern LNG fueling stations use recirculation pumps to avoid pressure build up in tank and venting • Significant venting events can occur during upset conditions, which are not prevented by ARB regulations
Comparison	**HDVs**
Energy Impact	90%+ less petroleum 5 to 10% more fossil fuel
GHG Impact 2012 2022	 -10 to -0% -15 to -5%

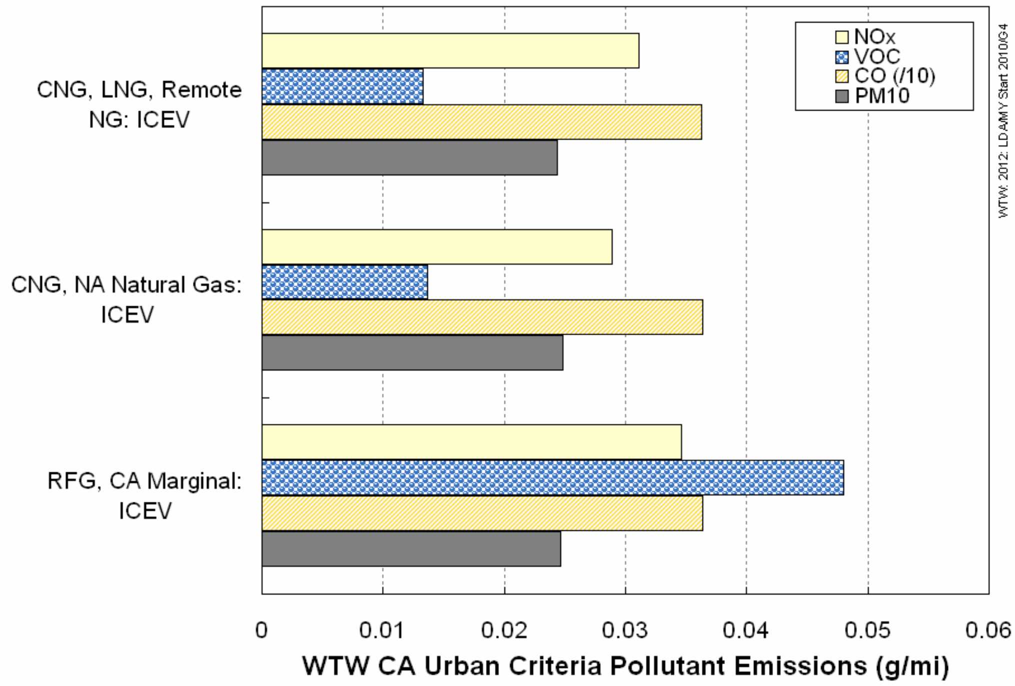

Figure 3-17. Criteria Pollutant Emissions for CNG Vehicles (2012 New Vehicle Stock)

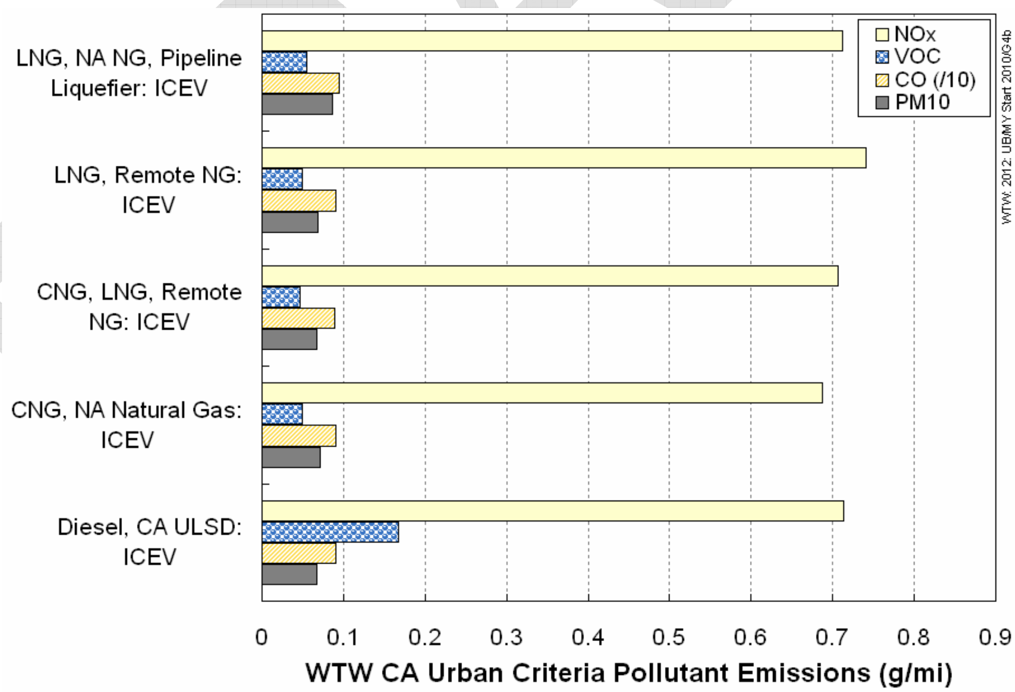

Figure 3-18. Criteria Pollutant Emissions for LNG and CNG Heavy Duty Vehicles (2012 New Vehicle Stock)

Table 3-13. Pollution Impacts of CNG Vehicles

Parameter	Pollutant Impact	
Criteria Pollutants	• Primary emission sources are natural gas engines and electric power plants for compression	
Toxics	• Benzene, 1-3 butadiene, and diesel PM are reduced compared with conventional fueled vehicles • Formaldehyde from power plants and engines contributes to fuel cycle emissions.	
Multimedia Impacts	• Gaseous fuel, spills do not affect water systems. • No diesel used to haul CNG.	
Comparison	**Passenger Car**	**HDV**
Criteria Pollutants	VOC -72% Other 077 to +1%	Reduction in PM, with declining benefit as diesel improves
Weighted Toxics 2012 2022	 -80% -80%	 -40% -20%
Multimedia Impacts	Over -90% hydrocarbon spills	

Table 3-14. Pollution Impacts of LNG Vehicles

Parameter	Pollutant Impact
Criteria Pollutants	• Primary emission source is natural gas engines and electric power plants for compression
Toxics	• Benzene, 1-3 butadiene and diesel PM are reduced compared with conventional fueled vehicles • Formaldehyde from power plants and engines contributes to fuel cycle emissions.
Multimedia Impacts	• Gaseous fuel, spills do not affect water systems. No diesel used to transport CNG.
Comparison	**HDV**
Criteria Pollutants	Reduction in PM, with declining benefit as diesel technology improves
Weighted Toxics 2012 2022	 -40% -20%
Multimedia Impacts	Over -90% hydrocarbon spills

3.5 Electricity

This subsection presents the results for mid-size passenger electric vehicles. Figures 3-19 and 3-20 present the WTW energy consumption and GHG emission results for each of the electricity cases evaluated as well as for baseline gasoline vehicles. Table 3-15 summarizes the energy and GHG impacts for this fuel, noting the impacts for both on road vehicles and off road (forklifts) equipment. Figure 3-21 provides the criteria pollutant emission impacts of electric vehicles. These results are summarized for both on road and off road vehicles in Table 3-16 along with the air toxics emissions and multimedia impacts.

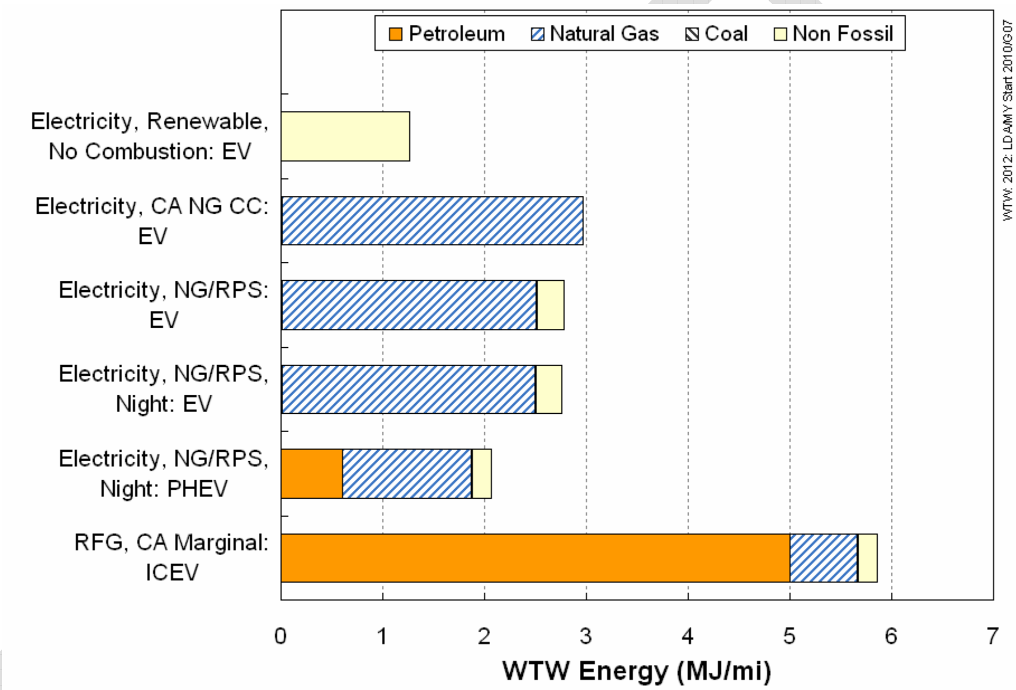

Figure 3-19. WTW Energy Consumption for Electric Vehicles, both On-Road and Off-Road Forklift (2012 New Vehicle Stock)

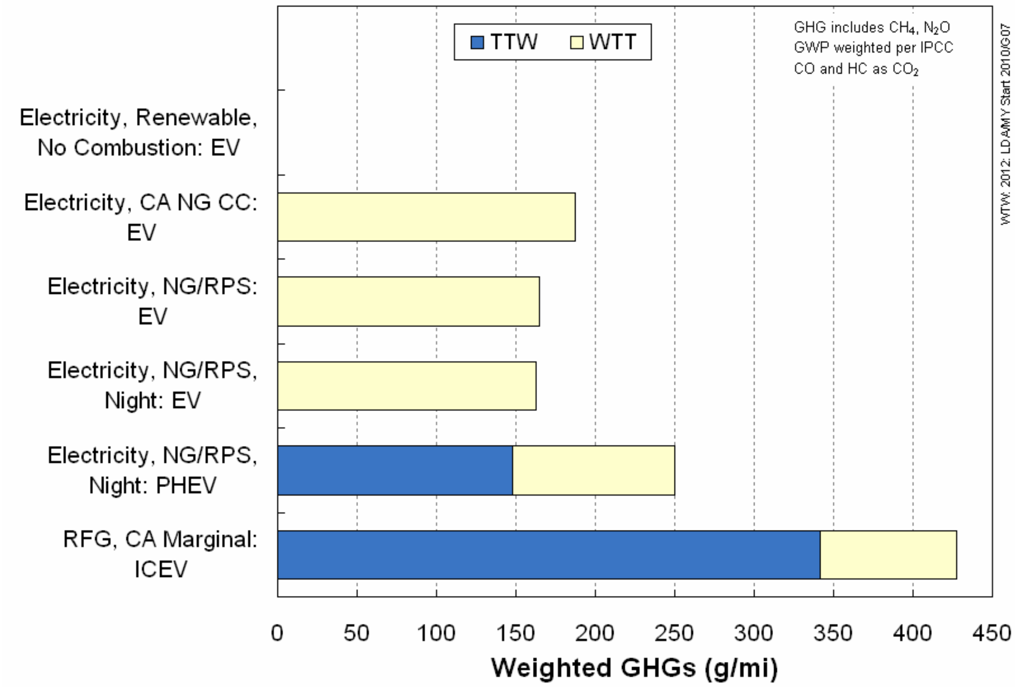

Figure 3-20. WTW GHG Emissions for Electric Vehicles, both On-Road Off-Road and Forklift (2012 New Vehicle Stock)

Table 3-15. Energy and GHG Impacts of Electric Vehicles

Parameter	Energy and GHG Impact		
Energy Factors	• Almost no petroleum in the fuel cycle. • Growth in renewable power • Option to buy larger fraction of renewable power • Improvement in fuel economy for PHEV operating on gasoline • Reduced energy consumption in forklift applications due to high efficiency at idle and low load		
GHG Factors	• Natural gas combined cycle represents best estimate of permanent sustainable load growth • Natural gas combined cycle/RPS mix results in a GHG intensity of 460 to 490 g/kWh • Constraints on California power purchase assure low GHG mix and prevent import of coal based power • Night-time charging from wind power could support growth in RPS and help eliminate need for idling standby generation		
Comparison	**Battery Electric Car**	**PHEV Car**	**Forklift vs. LPG**
Energy Impact Petroleum Fossil	 -90% -50%	 -90% petroleum -60% Fossil	 -90% petroleum -60% Fossil
GHG Impact	-50%	-40%	-50%

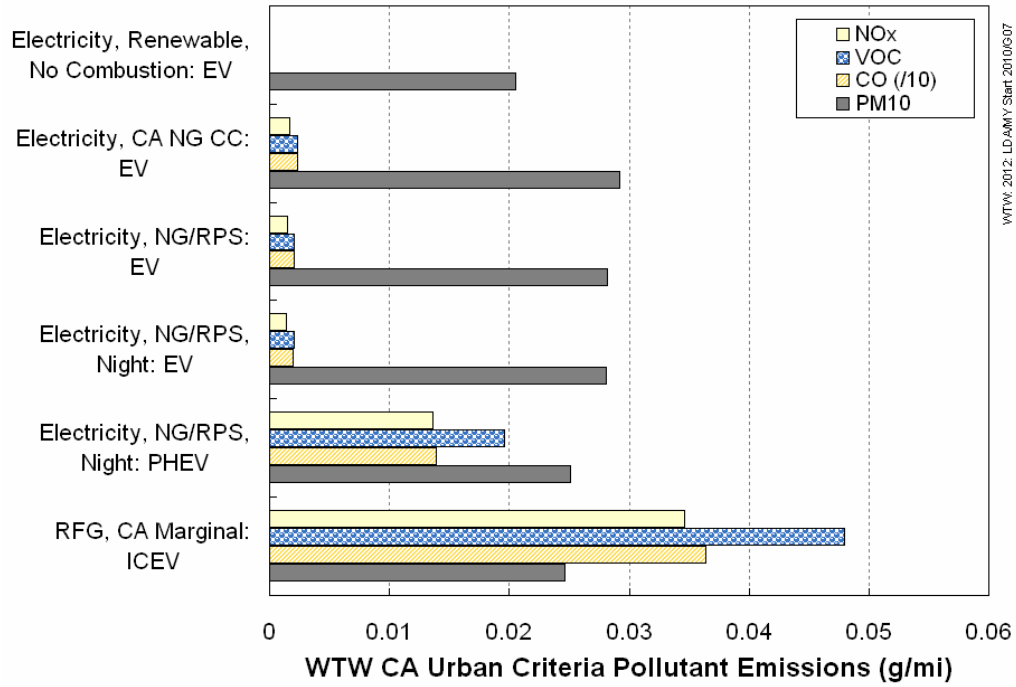

Figure 3-21. Criteria Pollutant Emissions for Electric Vehicles (2012 New Vehicle Stock)

Table 3-16. Pollution Impacts of Electric Vehicles

Parameter	Pollution Impact		
Criteria Pollutants	• Zero emissions from battery electric vehicles • PHEVs can be equipped for all electric operation; however the trend is to provide vehicles with smaller electric drive systems that operate in blended mode • Emission certification of blended mode vehicles could be lower than other vehicle categories. These vehicles could then contribute to meeting the automakers mix • Offset requirements on stationary sources limit NO_x and VOC emissions from power plants • PM from electric power generation are a significant contribution to the fuel cycle. The source of these PM emissions should be investigated to assess whether ambient (air intake) PM significantly affect the emitted levels.		
Toxics	• Benzene, 1-3 butadiene, and diesel PM are eliminated compared with conventional vehicles • Formaldehyde from power plants and engines contributes to fuel cycle emissions but toxic emissions are well below those for conventional fuels		
Multimedia Impacts	• No fuel spills associated with electric operation • No engine oil spills with battery EVs • Smaller engine and less fuel and oil consumption for PHEVs		
Comparison	**Battery Electric Car**	**PHEV Car**	**Forklift vs. LPG**
Criteria Pollutants	PM -17 to 19% -90% other pollutants	PM +2% -60% other pollutants	PM +2% -99% VOC -60% other pollutants
Weighted Toxics	-70% toxics	-70% toxics	-70% toxics
Multimedia Impacts	Over -90% from reduced hydrocarbon spills		Same

3.6 Gas-to-Liquids (GTL)

This subsection presents the results for heavy duty diesel vehicles operated on GTL fuels. Figures 3-22 and 3-23 present the WTW energy consumption and GHG emission results for the GTL fuels evaluated as well as for baseline diesel vehicles. Table 3-17 summarizes the energy and GHG impacts for these fuels. Figure 3-24 illustrates the criteria pollutant emission impacts of using GTL fuels in heavy duty diesel vehicles. These results are summarized in Table 3-18 along with the air toxics emissions and multimedia impacts.

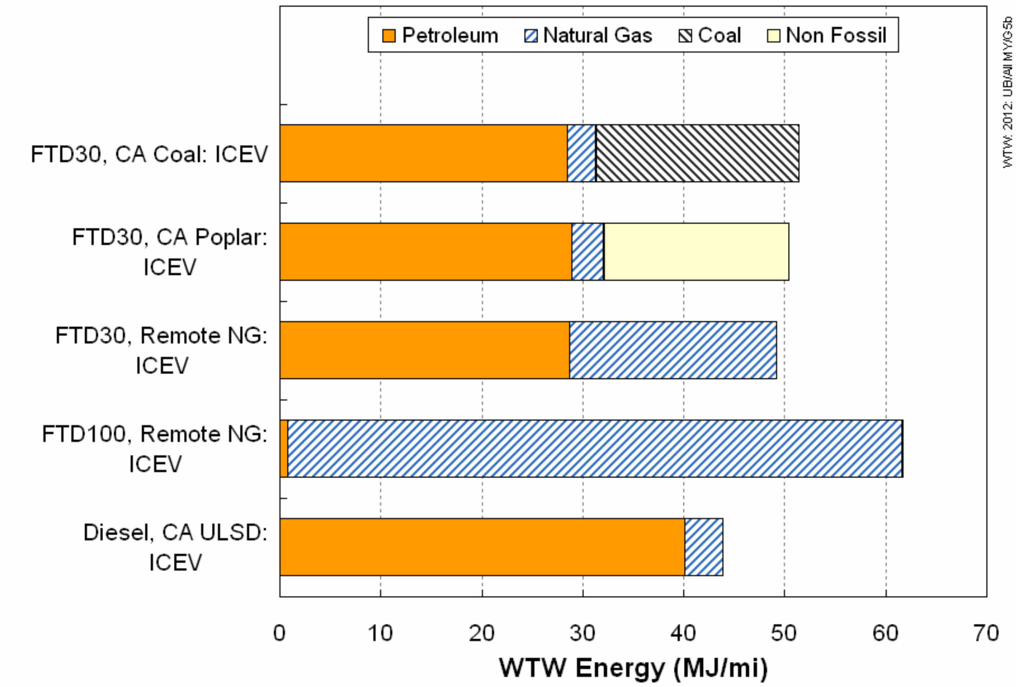

Figure 3-22. WTW Energy Consumption for GTL Vehicles (2012 Existing Vehicle Stock)

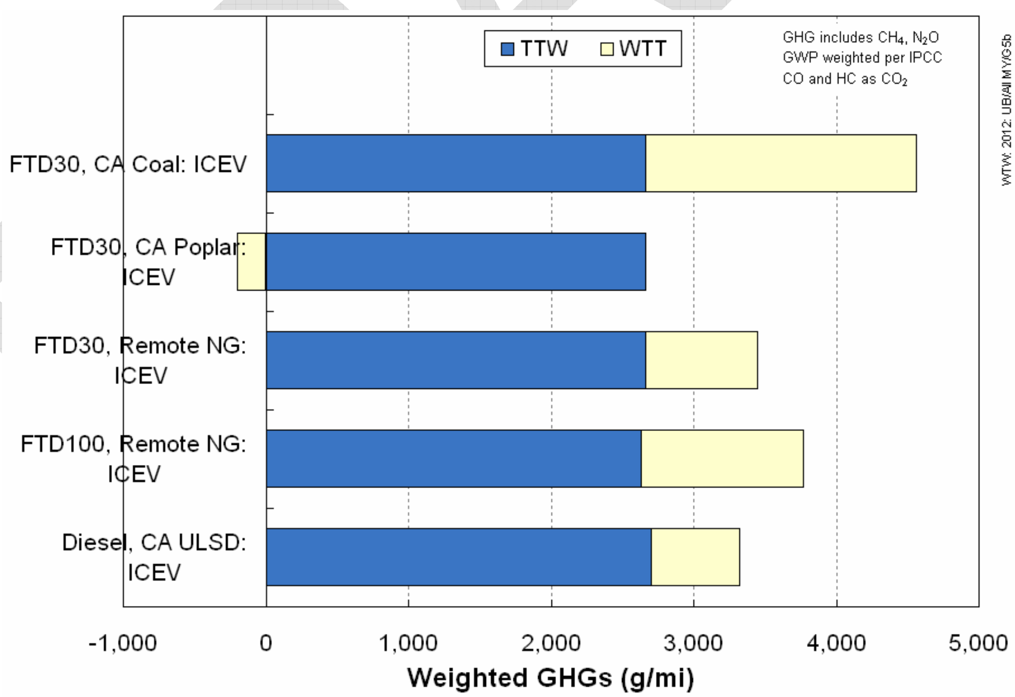

Figure 3-23. WTW GHG Emissions for GTL Vehicles (2012 Existing Vehicle Stock)

Table 3-17. Energy and GHG Impacts of GTL Vehicles

Parameter	Energy and GHG Impact	
Energy Factors	• Almost no petroleum in the fuel cycle. • GTL provides an alternative pathway to import remote natural gas, which represents most of the energy in the fuel cycle • Dedicated FT100 engines can be built with potential efficiency and emission benefits that were not quantified	
GHG Factors	• Slight decrease in carbon intensity of fuel compared with diesel • Current GTL technology results in an increase in GHG emissions with the refinery energy allocation used in this analysis • Future GTL systems will be more efficient and achieve parity with diesel fuel • Biomass or coal with sequestration result in GHG reductions	
Comparison	**Heavy-Duty Buses**	
Energy Impact	-90% petroleum +10 to +30% fossil fuel (remote natural gas)	
GHG Impact	Natural Gas Biomass Coal Coal with sequestration	+4 to + 14% -26% +40% -50%

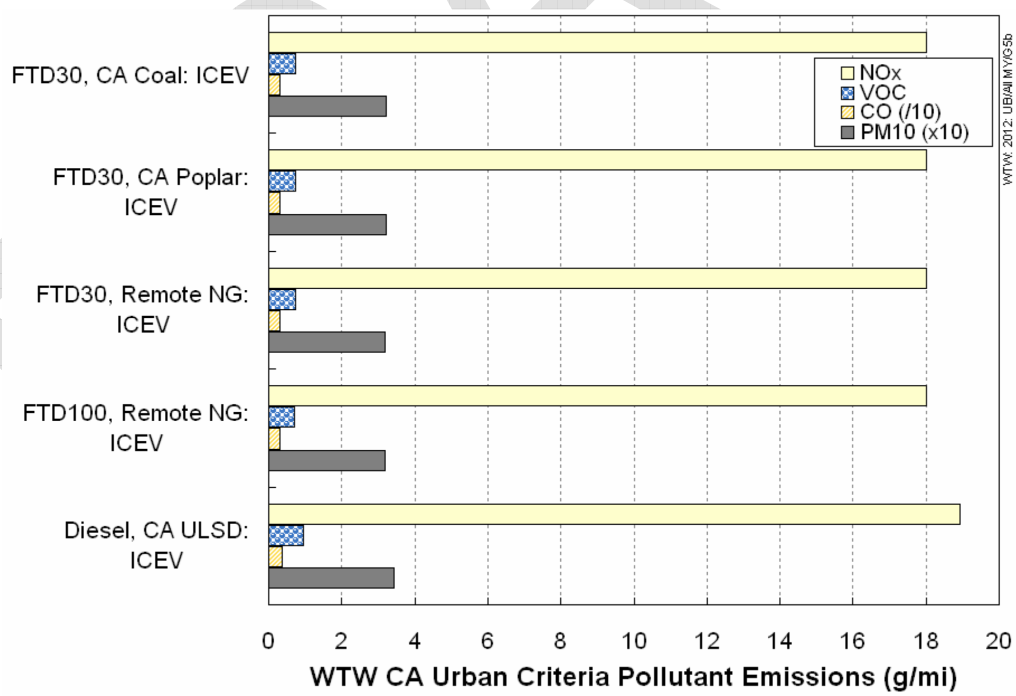

Figure 3-24. Criteria Pollutant Emissions for GTL Vehicles (2012 Existing Vehicle Stock)

Table 3-18. Pollution Impacts of GTL Vehicles

Parameter	Pollution Impact
Criteria Pollutants	• Primary emission source is natural gas engines and electric power plants for compression • FT30 blends result in modest reductions in criteria pollutant emissions from engines
Toxics	• Benzene, 1-3 butadiene, and diesel PM are reduced compared with conventional fueled vehicles because FT fuels contain no aromatics
Multimedia Impacts	• Hydrocarbon fuel with similar distribution network as diesel. Zero aromatics content
Comparison	**Heavy-Duty Bus**
Criteria Pollutants	Reduction in PM, with declining benefit as diesel improves
Weighted Toxics	Reduced compared to diesel
Multimedia Impacts	Same hydrocarbon spills

3.7 Hydrogen

This subsection presents the results for light duty (mid-size passenger car) hydrogen fueled vehicles. Figures 3-25 and 3-26 present the WTW energy consumption and GHG emission results for each of the hydrogen fueled vehicle cases evaluated as well as for baseline gasoline vehicles. Table 3-19 summarizes the energy and GHG impacts for this fuel, noting the impacts for on road light duty and heavy duty (fuel cell bus) vehicles, and off road (forklifts) equipment. Figure 3-27 provides the criteria pollutant emission impacts of the hydrogen fueled vehicle cases evaluated, as well as for the corresponding baseline gasoline vehicles. These results are summarized in Table 3-20 for passenger car, forklift, and fuel cell bus applications, along with the air toxics emissions and multimedia impacts.

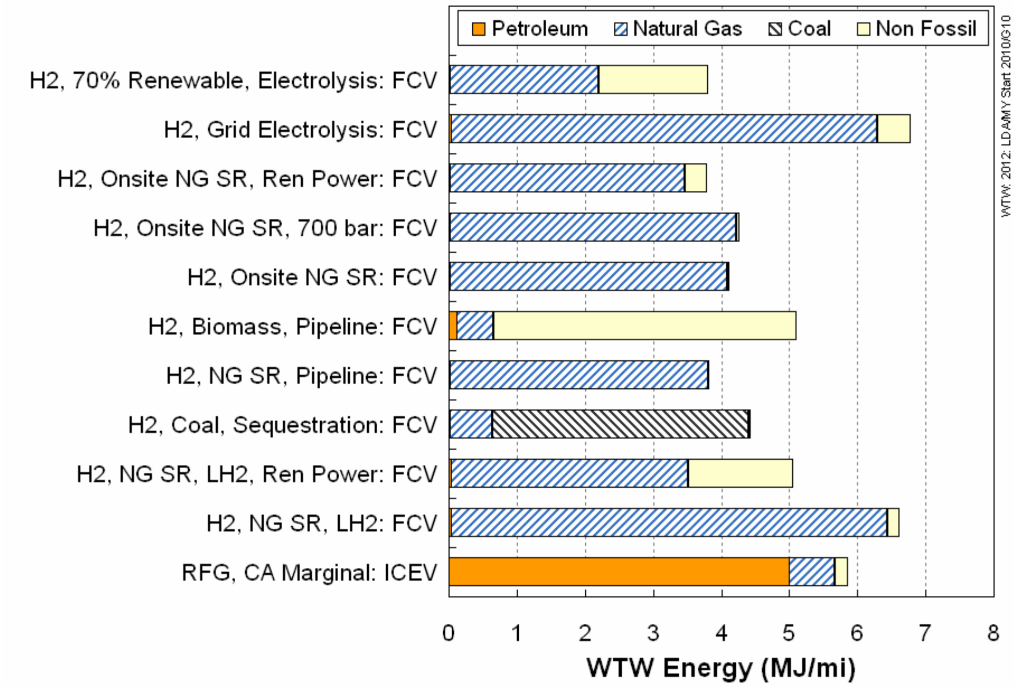

Figure 3-25. WTW Energy Consumption for Hydrogen Vehicles (2012 New Vehicle Stock)

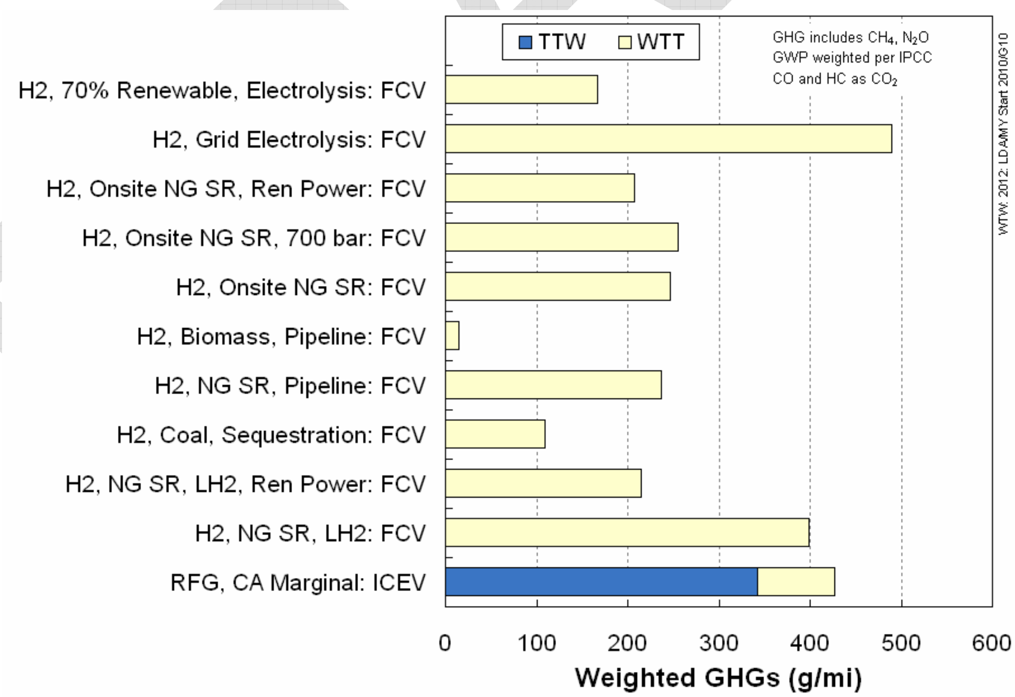

Figure 3-26. WTW GHG Emissions for Hydrogen Vehicles (2012 New Vehicle Stock)

Table 3-19. Energy and GHG Impacts of Hydrogen Vehicles

Parameter	Energy and GHG Impact			
Energy Factors	• Almost no petroleum in the fuel cycle. • Option to produce hydrogen from a variety of fossil and renewable resources • Growth in renewable power for compression, liquefaction, or electrolysis • Option to buy larger fraction of renewable power for electrolysis or power portion of other pathways • Forklift applications likely to be based on electrolysis fuel supply because of low fuel usage • Improved energy efficiency in forklifts with reduced idle fuel consumption offsets some of the energy losses from electrolysis			
GHG Factors	• Low carbon intensity of hydrogen vehicles reduces GHG emissions • Methane leaks in the fuel cycle (reforming pathways) are a significant portion of WTT GHG emissions			
Comparison	**Fuel Cell Car**	**ICE Car**	**FC Forklift vs. LPG**	**Fuel Cell Bus**
Energy Impact				
Petroleum	-90%	-90%	-90%	-90%
Fossil Fuels				
Natural Gas H_2	-20%	+20%	-20%	-20%
Biomass H_2	-85%	-65%	—	-85%
Electrolysis H_2	-20 to + 40	0 to + 60	-40% to + 20%	-20 to + 40
GHG Impact				
Natural Gas	-40% to -50%	-40% to -50%	-50%	-40% to -50%
Biomass	-60% to -80%	-60% to -80%	—	-60% to -80%
Electrolysis	-40% to + 60%	-40% to + 60%	-40% to + 20%	-40% to + 60%

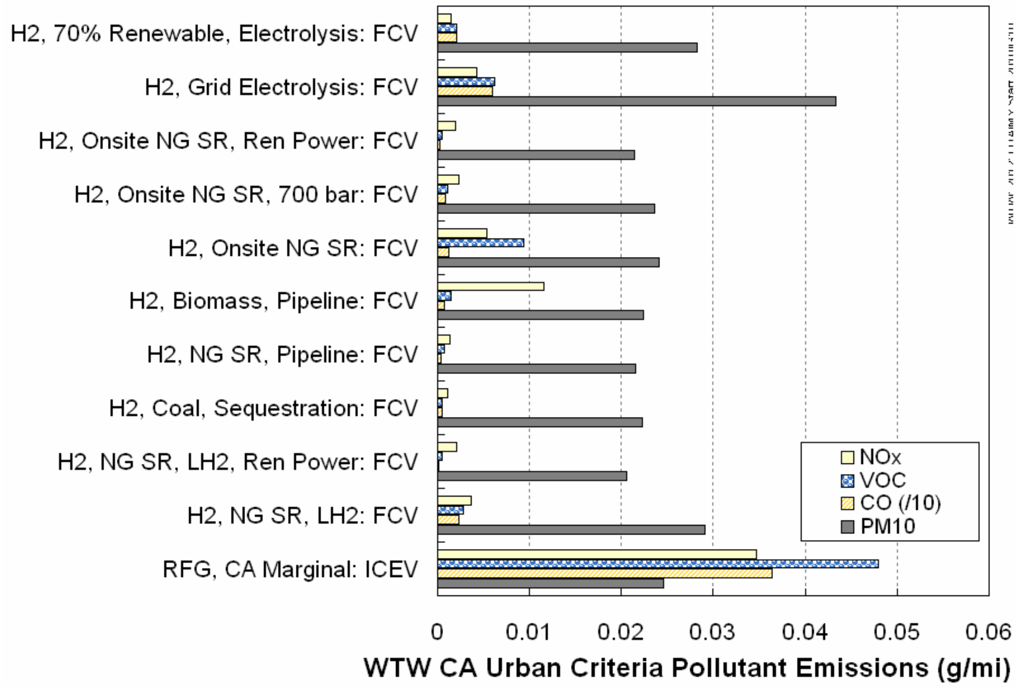

Figure 3-27. Criteria Pollutant Emissions for Hydrogen Vehicles (2012 New Vehicle Stock)

Table 3-20. Pollution Impacts of Hydrogen Vehicles

Parameter	Pollutant Impact		
Criteria Pollutants	• Zero emissions from fuel cell and only NO_x emissions from ICEV • PM emissions from hydrogen reformers result in comparable or lower WTW emissions • Offset requirements on stationary sources limit NO_x and VOC emission. Emissions from small onsite reformers are still very low. • PM from electric power generation contributes to the fuel cycle • Diesel PM emissions from LH2 truck are comparable to those for distributing fossil fuels as FCV is uses 2x less energy • Eliminate venting of LPG from forklifts		
Toxics	• Benzene, 1-3 butadiene, and diesel PM are eliminated compared with conventional vehicles • Formaldehyde from power plants and engines contributes to fuel cycle emissions but weighted toxics emissions are well below those for conventional fuels		
Multi-media Impacts	• Gaseous fuel, spills does not affect water systems. • No engine oil leaks with FCVs • No diesel used to haul fuel except LH2 pathways		
Comparison	**Passenger Car**	**Fuel cell Forklift vs. LPG**	**Fuel Cell Bus**
Criteria Pollutants	Slight reduction in PM Significant reduction in all other pollutants		Large reduction in PM. Significant reduction in all other pollutants
Weighted Toxics	-70% toxics		
Multi-media Impacts	Over -90% hydrocarbon spills		

3.8 Synthetic Fuels (Methanol and DME)

This subsection presents the results for the heavy duty vehicle (urban bus) cases evaluated using the synthetic fuels methanol and DME. Figures 3-28 and 3-29 present the WTW energy consumption and GHG emission results for each of these cases as well as for the corresponding baseline diesel vehicle. Table 3-21 summarizes the energy and GHG impacts for these synthetic fuels. Figure 3-30 illustrates the criteria pollutant emission impacts for the synthetic fuel evaluation cases. These results are summarized in Table 3-22 along with the air toxics emissions and multimedia impacts.

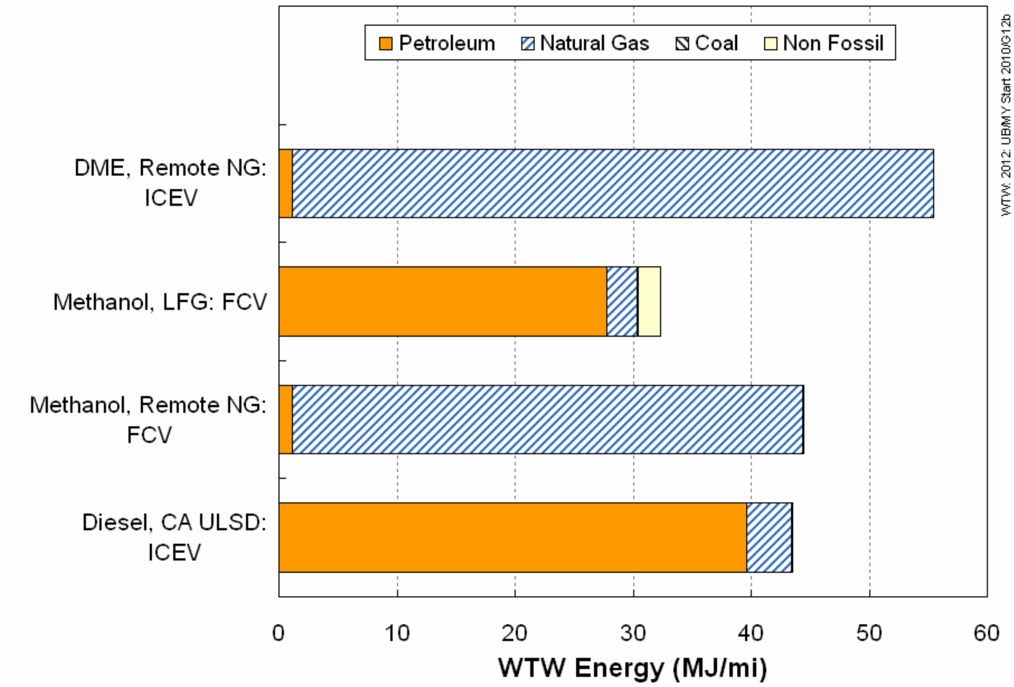

Figure 3-28. WTW Energy Consumption for Synthetic Fuel Vehicles

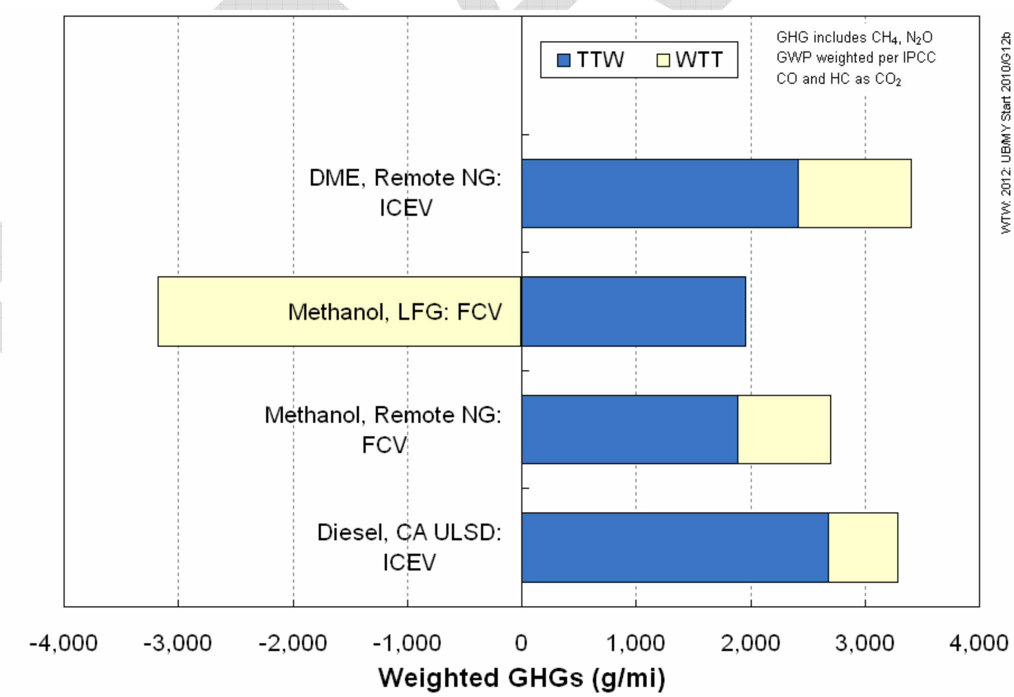

Figure 3-29. WTW GHG Emissions for Synthetic Fuel Vehicles

Table 3-21. Energy and GHG Impacts of Methanol and DME Buses

Parameter	Energy and GHG Impact	
Energy Factors	• Almost no petroleum in the fuel cycle. • Methanol and DME provide an alternative pathway to import remote natural gas, which represents most of the energy in the fuel cycle • DME engines should have slight improvement in efficiency as no PM after treatment is required • Methanol fuel cell power train results in more efficient vehicle offsetting increased energy use in fuel cycle	
GHG Factors	• Low carbon intensity of fuel compared with diesel but more GHG emissions in the fuel cycle • Fuel grade DME plants have not been built yet • Improvements in methanol fuel cycle is possible with dedicated fuel grade methanol plant	
Comparison	**Heavy-Duty Buses**	
Energy Impact	-90% petroleum 0 to +10% fossil fuel	
GHG Impact	DME Methanol FCV	0 to + 5% -5 to 0%

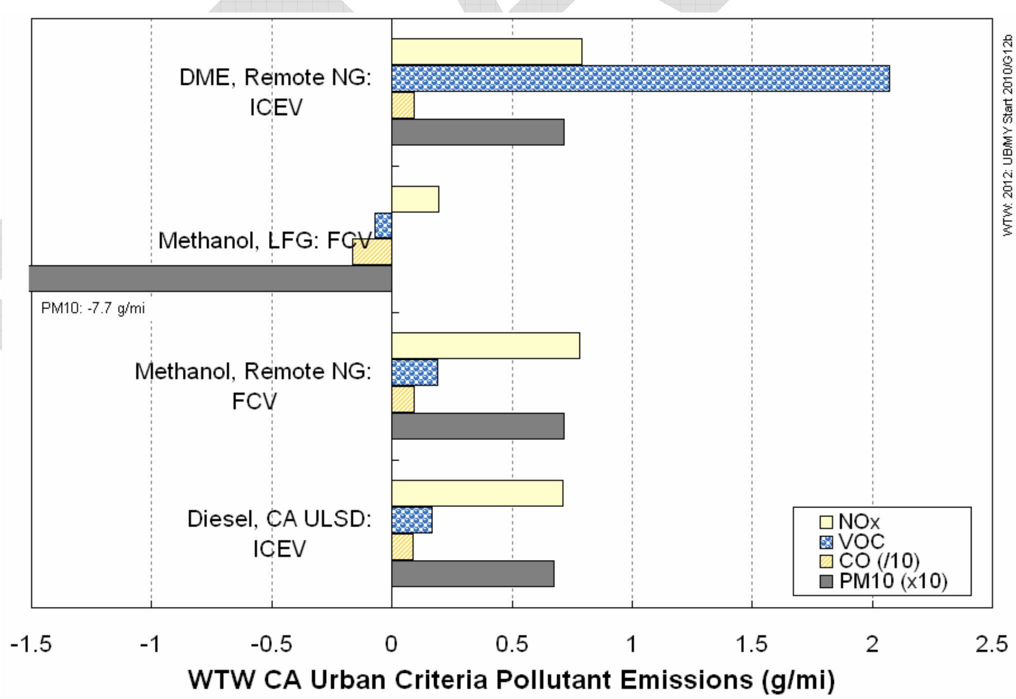

Figure 3-30. Criteria Pollutant Emissions for Synthetic Fuel Vehicles

Table 3-22. Criteria Pollutant Impacts of Methanol and DME Buses

Parameter	Pollution Impact	
Criteria Pollutants	• Primary emission source is natural gas engines and electric power plants for compression	
Toxics	• Benzene, 1-3 butadiene and diesel PM are reduced compared with conventional fueled vehicles	
Multi-media Impacts	• Gaseous DME does not affect water systems. • Methanol rapidly biodegrades	
Comparison	**Heavy Duty Bus**	
Criteria Pollutants	Reduction in PM, with declining benefit as diesel technology improves	
Weighted Toxics	DME Methanol FC Bus	-10 to -20% -10 to -20%
Multi-media Impacts	Over -90% hydrocarbon spills	

3.9 LPG

This subsection presents the results for mid-size passenger LPG fueled vehicles. Figures 3-31 and 3-32 present the WTW energy consumption and GHG emission results for each of the LPG vehicle cases evaluated as well as for the corresponding baseline gasoline vehicle. Table 3-23 summarizes the energy and GHG impacts for this fuel. Figure 3-33 provides the criteria pollutant emission impacts of LPG vehicles. These results are summarized in Table 3-24 along with the air toxics emissions and multimedia impacts.

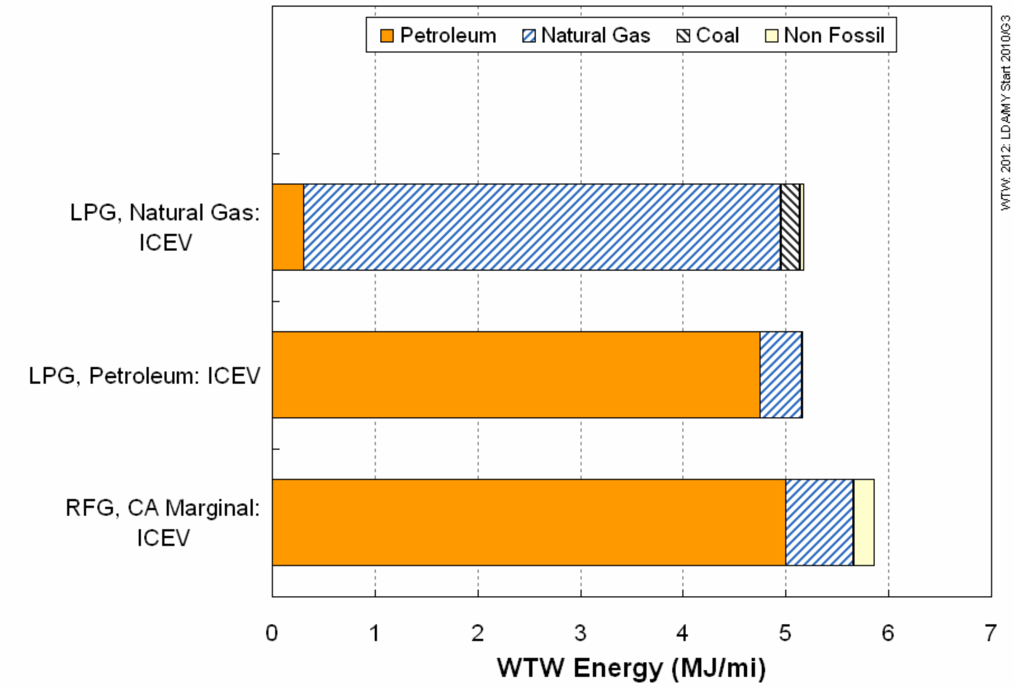

Figure 3-31. WTW Energy Consumption for LPG Vehicles (2012 New Vehicle Stock)

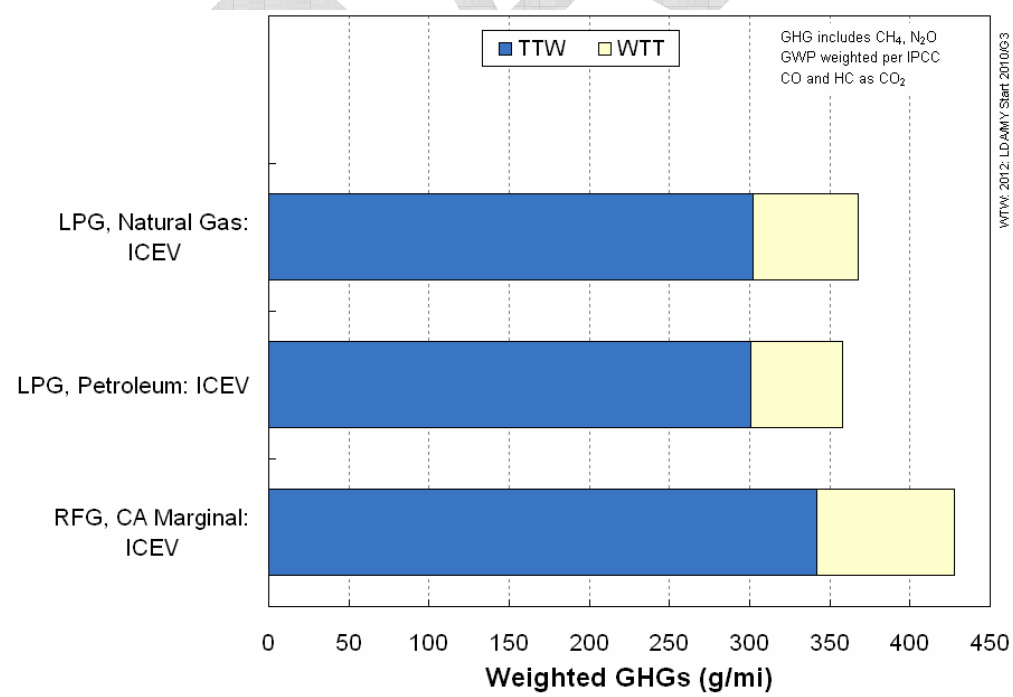

Figure 3-32. WTW GHG Emissions for LPG Vehicles (2012 New Vehicle Stock)

Table 3-23. Energy and GHG Impacts of LPG Vehicles

Parameter	Energy and GHG Impact
Energy Factors	• Byproduct of natural gas processing or crude oil refining • Low allocation of refinery energy to LPG because it is a byproduct and refinery units are not built to increase LPG output. • California LPG is exported to Mexico. Displaced products and elasticity of demand should be examined. • Spark ignited engines can achieve energy equivalent performance for light- and medium- duty vehicle applications
GHG Factors	• Low carbon intensity of LPG fuel and low fuel cycle energy input reduces vehicles GHG emissions
Comparison	**Passenger Cars**
Energy Impact	-20% petroleum -25% fossil fuel
GHG Impact 2012 2022	 -23 to – 18% -23 to – 18%

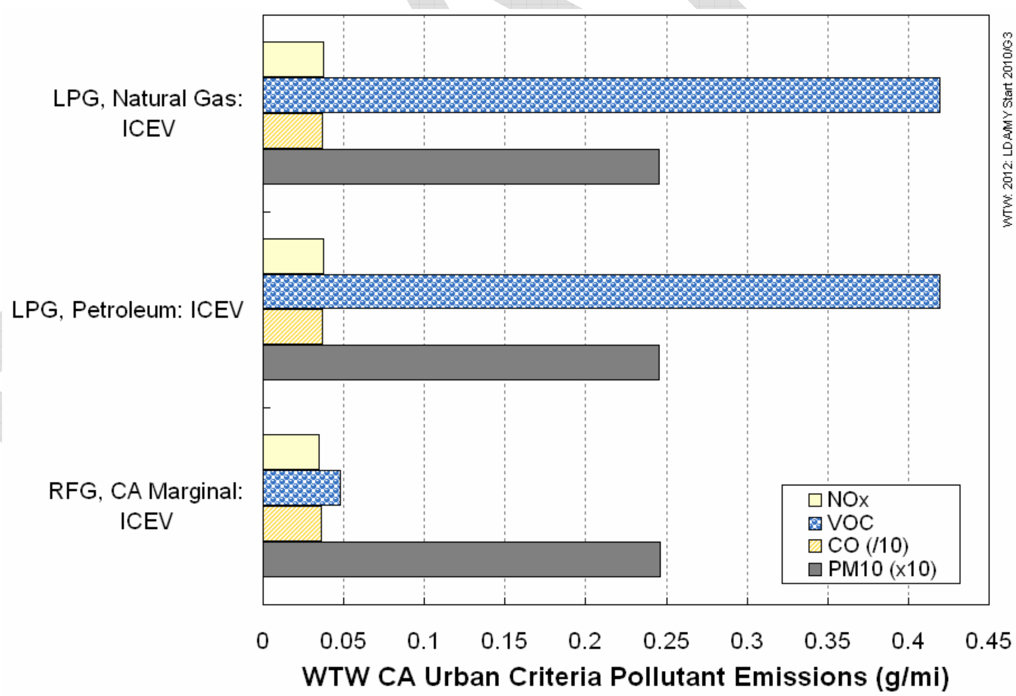

Figure 3-33. Criteria Pollutant Emissions for LPG Vehicles (2012 New Vehicle Stock)

Table 3-24. Pollution Impacts of LPG Vehicles

Parameter	Pollution Impact
Criteria Pollutants	• Vehicle exhaust is comparable to gasoline vehicle • Lower energy inputs in fuel cycle • LPG transported by rail and distributed by truck • Venting losses from product and vehicle storage tanks result in over 10 times the HC emissions compared with gasoline • Emission regulations do not require limiting venting losses. Codes for vehicles and ASME vessels would need to be modified. • Propylene, a smog precursor from refinery based LPG, can be blended with natural gas based LPG to meet vehicle specifications. Otherwise LPG with high propylene is sold to stationary market.
Toxics	• Benzene and 1-3 butadiene are reduced compared with conventional fueled vehicles
Multi-media Impacts	• Gaseous fuel, spills do not affect water systems.
Comparison	**Passenger Car**
Criteria Pollutants	VOC +1,000% Other pollutants 0%
Weighted Toxics	-20%
Multi-media Impacts	Over -90% via reduction of hydrocarbon spills

SECTION 4. DISCUSSION

The WTW analysis illustrates the key effects of alterative fuels on energy impacts, GHG emissions, criteria pollutant emissions, air toxics emissions, and multi media impacts. Effects that reflect dominant assumptions, key points of the analysis, or require further attention are discussed here. Again, tables that document the effects of the scenario years on energy inputs and emissions results for the fuel and vehicle combination discussed in this section are given in the Appendix.

4.1 Energy Inputs

Energy inputs are largely driven by vehicle efficiency and process energy inputs for fuel production. For many fuels, the energy inputs for fuel production facilities are well understood with key questions only related to modest changes in energy efficiency or process parameters. However, a wider range of uncertainty exists for biofuels because of the wide range in agricultural practices and the assumed allocation of the energy inputs to byproducts.

4.1.1 Petroleum Production and Refining

A wide range of petroleum processing pathways provide gasoline and diesel fuels for the U.S. A combination of trends in fuel production and distribution affects the carbon intensity of gasoline and diesel. Some of the factors affecting petroleum fuels include:

Use of heavy oil from locations including Venezuela is increasing. Venezuelan gasoline is distributed to the U.S. government defined (and used by DOE's Energy Information Agency [EIA]) Petroleum Administration for Defense Districts (PADD) 2 and does not actually reach California. Similarly, petroleum produced from tar sands requires significantly higher energy to extract and process the feedstock to gasoline. Again, Canadian tar sands based fuel does not reach California and is distributed to PADD 3.

The question of refinery energy inputs and allocation to petroleum products remains uncertain. Aggregate data from EIA can be used to determine the energy inputs for gasoline production. However the allocation of energy to products is more complex. Refinery models have typically been used to identify the energy used by refinery unit, and relate that to the product slate. New refinery modeling to support the Energy Commission and EPA is ongoing.

European refineries are configured to produce a larger fraction of diesel fuel than gasoline. Producing additional gasoline could enhance the efficiency of the refinery or reduce the sales of CARBOB to California. These considerations support a range in refinery efficiency estimates from 84 to 90 percent.

4.1.2 Alterative Fuel Production

A variety of alternative fuel production options have been analyzed Not all of these options are built on a commercial scale and some of the options may not receive sufficient investor interest to become commercially viable.

4.1.3 Power Generation

Electricity generation factors into the WTW analysis as both a feedstock and a fuel. In both cases, this marginal analysis assumed that the electricity would come from new generation capacity. A variety marginal electricity scenarios were evaluated ranging from an entirely renewable mix and the current average grid mix in California. The true marginal power generation has been determined to be combined cycle natural gas combustion turbines with the California Renewable Portfolio Standard (RPS) imposed upon it.

Having said this, the resources utilized to achieve the RPS standard (wind, solar, geothermal, biomass combustion) drive the results. In the analysis we used emission factors from existing biomass fueled boilers, which had a significant impact on criteria pollutant emissions. If it is assumed that new biomass boilers provide the electric power satisfying the RPS, the emissions would be much lower; new biomass boilers will have to be equipped with Best Available Control Technology including ESP/Fabric Filters for PM, SCR for NO_x, and oxidation catalysts for CO/VOC. Moreover, if they are located in nonattainment areas, they will be required to offset annual emissions of the nonattainment pollutants, resulting in no net emission increase.

Another subtlety of the RPS requirement is the heavy reliance on wind power. Experience in Texas, where utilities are currently subject to an RPS-like requirement, has similar to the planned RPS, has   A certain percentage of power sold must come from renewable resources. A counterproductive result of this requirement is that intermittent supplies of windpower require operation of natural gas fired boilers to run at low loads simultaneously, ready to ramp up to cover periods when the wind generators stop producing power. One might therefore argue that wind power is not zero emission.

4.1.4 Fuel Cycle Modeling

Results for the fuel cycle analysis depend on dominant assumptions regarding process energy inputs and allocation of byproducts. Some of the details of fuel cycle analysis are computationally complex but these have only a modest impact on the overall fuel cycle results. For example, fuel cycle energy inputs also depend on the complex interaction of fuels that support the fuel chain and the second order energy inputs associated with fuel production. These second order effects are important primarily only for diesel, natural gas, electricity and gasoline, and even then the contribution towards fuel cycle energy is small.

It is apparent from the analysis in this project that different fuel cycle modeling tools provide very similar results. Key differences in the assumptions typically involve allocation to by products and assumptions on land use impacts.

4.1.5 Transportation Logistics

Transportation distances and logistics also affect total fuel cycle energy, but the energy inputs represent at most six percent of the fuel cycle. The differences in transportation options that were analyzed for the different fuel options has a significant effect on local criteria pollutant emissions, but only a modest effect on energy inputs and GHG emissions. The emissions associated with fuel transportation were determined in the WTT report for a variety of delivery modes. Differences between ship and rail transport as well as transportation distances have a significant effect on the fuel cycle diesel PM and weighted air toxics emissions. In some instances the emissions for fuel production inside California are higher, while the emissions outside of California are higher for other fuels. The emissions in California non attainment areas are grouped into the urban emissions category in the GREET model. The breakdown of emissions by fuel delivery mode can be determined using the GREET model configured for California boundaries.

4.2 Greenhouse Gas (GHG) Emissions

The broad range of factors contributing to the fuel cycle were included in the analysis. These include:

- Fuel cycle energy inputs and carbon intensity of fuel
- Vehicle and fuel cycle equipment N_2O emissions
- Releases of N_2O from agriculture
- Credit for byproduct energy
- Credit for byproduct agricultural products

The analysis covered a range of fuel production pathways that were intended to examine the range of possible GHG impacts. In addition to the process related emissions, a fuel cycle analysis ideally should also take into account the following:

- Impact of land use changes on short term releases of carbon
- Effect of displacement of products

The analysis here represents the energy and pollution impacts that are directly related to fuel production and use. The impact of displaced products and land use changes need to be addressed on a case by case basis and clearly added to the analysis results as a separate item.

4.3 Criteria Pollutant Emissions

The analysis discussed in this report considers criteria pollutant emissions from stationary and mobile sources within California. Emissions associated with transportation of fuels by truck, rail, and tanker ship are anticipated to decline as Tier 4 Standards, requiring selective catalytic reduction (SCR) for NO_x control and particulate filters for PM control, are adopted and implemented. Tier 4 standards have been adopted for on-road heavy-duty vehicles, and are currently being developed by EPA for marine and rail engines.

New alternative fuel production facilities located in California will need to go through New Source Review permitting, which will require that all new equipment utilize Best Available Control Technology (BACT) for all criteria pollutants. Because most of California urban areas are classified as ozone nonattainment areas, these facilities will also be required to offset their NO_x and VOC emissions by surrendering emission reduction credits (ERCs) to the local permitting agency. In most cases, the ERC to emission ratio is more than one, meaning that the emissions are more than offset by the surrender of ERCs. The net effect is that local NO_x and VOC emissions will not increase due to installation of new alternative fuel production facilities.

One anomaly associated with the adopted protocol of only accounting for criteria pollutant emissions produced within California is that it unfairly favors out of state alternative fuel production. In general, it is assumed that criteria pollutant emissions from California facilities will be lower than equivalent facilities outside of California.

One area identified for further investigation is the PM emission factor for natural gas combined cycle combustion turbines (CCCTs). The emission factor utilized for these units, taken from AP-42, may be high. It is suggested that source test data from recent installations of CCCTs be obtained and evaluated to establish a more accurate PM emission factor.

Limited data were found on several criteria pollutant emission rates for natural gas power plants because the primary focus has been on NO_x emissions. The uncertainty in the NMOG emission rate corresponds to the range in emission factors for boiler and turbine power plants. The actual NMOG fraction from these plants may require further study. Source tests for power plants are typically performed with total hydrocarbon (THC) analyzers, and speciation data that would determine the fraction of non-methane hydrocarbons is limited. In any event, the NMOG emissions from natural gas power plants result in low emissions on a g/mi basis in the analyses completed for the report.

Gasoline vehicle fuel economy, power plant efficiency, and transmission losses play significant roles in CO_2 emissions from EV operation; a 20 percent difference in the emissions of this pollutant in the comparison of EV operation to gasoline fuel vehicle operation results. Because total NMOG from EV operation is very low, variations in these parameters have a limited effect on total NMOG. However, the sensitivity of power plant efficiency on CO_2 emissions is a significant issue. An Energy Commission analysis indicates an energy consumption of 8,700 Btu/kWh for a new power plant while representatives of the utility industry indicate this value should be below 7,000 Btu/kWh (HHV basis). A key parameter in the marginal heat rate for EV operation is the total generation capacity. The Commission's analysis is based on future reserve margins being lower than historical levels as deregulation would tend towards lower operating costs. However, low reserve margins also result in pressure on power prices. In practice, more power generation capacity will be required in California regardless. Thus, increased generation capacity would tend to increase the number of new high efficiency power plants.

4.4 Air Toxics Emissions

WTW air toxics emissions are compared on a weighted basis in Figure 4-1. The weighting factor is based on ARB's unit risk factors for air toxic constituents. The weighting factor is the ratio of the unit risk factors normalized to the risk factor for formaldehyde. The primary sources of marginal toxic emissions include diesel exhaust from transportation fuels, spilled gasoline and E85 (a source of benzene and 1-3 butadiene), diesel fuel as a source of PAHs, and power plant emissions. Oil refineries are also a leading source of toxic air contaminants in California; however, these emissions would not change with a modest growth in alternative fueled vehicle use. The air toxic emissions are proportional to NMOG emissions, with additional diesel PM from truck, rail, and ship transport. Toxic emissions for E85 are notably high because of the additional truck delivery legs associated with product delivery, combined with the lower energy density of the fuel. Emissions from LPG are lower because of the transportation distances assumed to correspond to urban areas.

PM emissions were also calculated for the different fuel options for the purpose of determining weighted toxics emissions. These results are included in the WTT report. One particularly interesting aspect of power plant emissions is the PM level, which is not particularly well quantified. Source tests for power plants do not characterize the background PM emissions which could include pollen, sea salt, and road dust. New combined cycle power plants operate at very high excess air levels which would tend to exacerbate the PM emissions. Power plant PM emissions were not included in the toxics calculation as only diesel PM is categorized as a toxic air contaminant by ARB. Only compounds that are determined to cause cancer or long term harmful health effects in small doses are categorized as toxics by ARB.

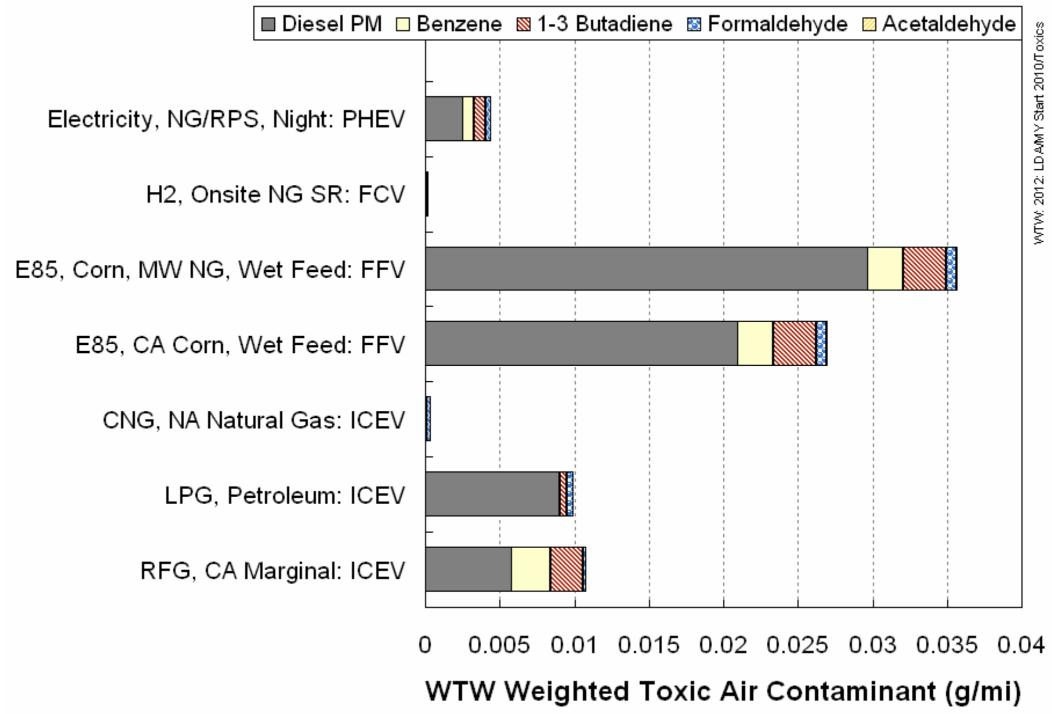

Figure 4-1. Urban California Weighted Air Toxics Emissions for New Passenger Car Vehicles (g/mi)

4.5 Effect of Scenario Year

A variety of factors affecting the WTW emissions impact the results over the range of scenario years (2012, 2017, 2022, and 2030) that were analyzed. The key factors affecting energy inputs, GHG emissions, and criteria pollutants are:

- Roll in of the RPS to 33 percent for California power generation
- Introduction of CO_2 emission regulations on passenger cars and light trucks
- Improvement in battery technology and power electronics for electric vehicles
- Improvements in fuel and agricultural production technologies
- Improvement in the thermal efficiency of natural gas combine cycle power plants
- Improvement in GTL plant efficiencies
- Reduction in nitrogen input and expansion of no till corn farming
- Modest improvement in methanol and hydrogen reforming technologies
- Introduction of fuel grade DME plants
- Improvement in cellulosic conversion yields and reduced enzyme inputs for ethanol production

- Introduction of hydrogen pipelines
- Introduction of advanced synthetic fuel and hydrogen technologies including biomass and coal gasification
- Reduction in vehicle emissions for the average fleet mix, which would include a larger mix of ZEV vehicles and low emission diesel technologies.
- Reduction in heavy-duty truck emissions used to transport fuel and possible reductions in other goods movement emissions
- Roll in of light duty vehicle ORVR evaporative control systems
- Aging of new technologies (assumed to be introduced in the year 2010) with a growth in vehicle emissions due to deterioration

The impacts of key time dependent parameters in the analyses are illustrated in Figures 4-2 through 4-4 for new gasoline fueled vehicles. The trends in GHG emissions over time are also illustrated for ethanol production from biomass, CNG, PHEV passenger cars, and GTL fueled buses in Figures 4-5 through 4-8.

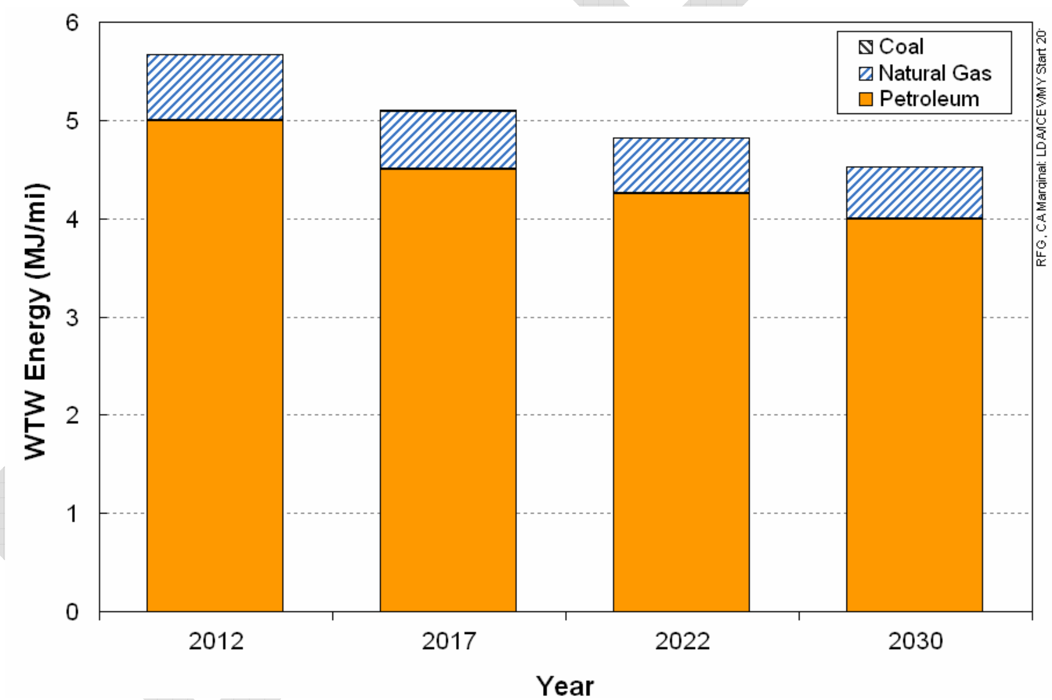

Figure 4-2. WTW Energy Inputs for Gasoline Passenger Cars (MJ/mi)

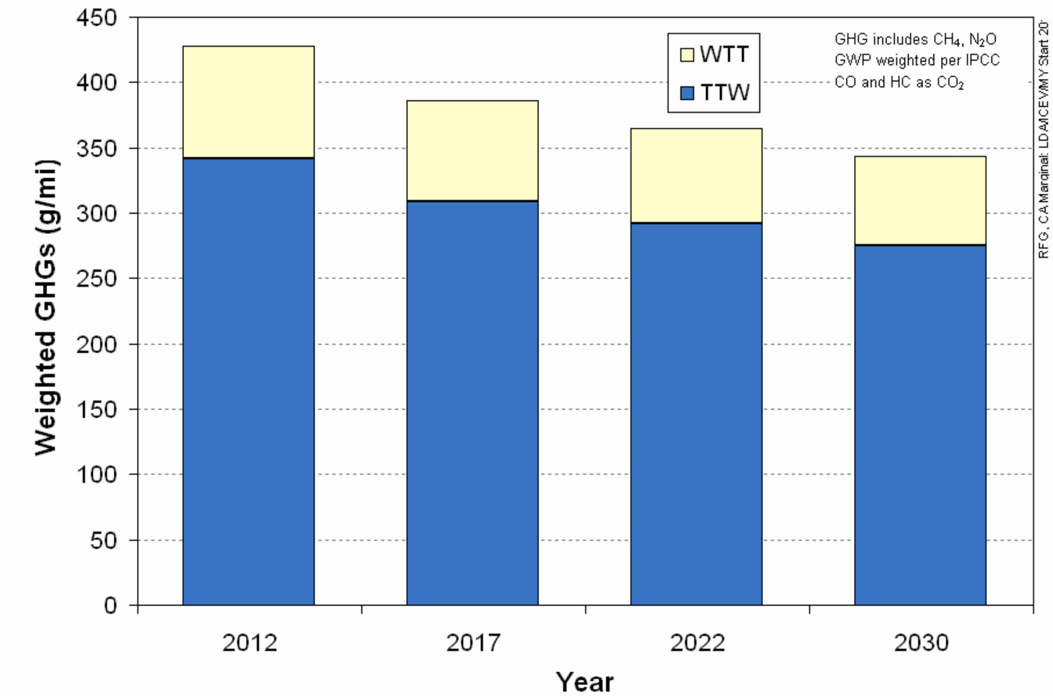

Figure 4-3. WTW GHG Emissions for Gasoline Passenger Cars (g/mi)

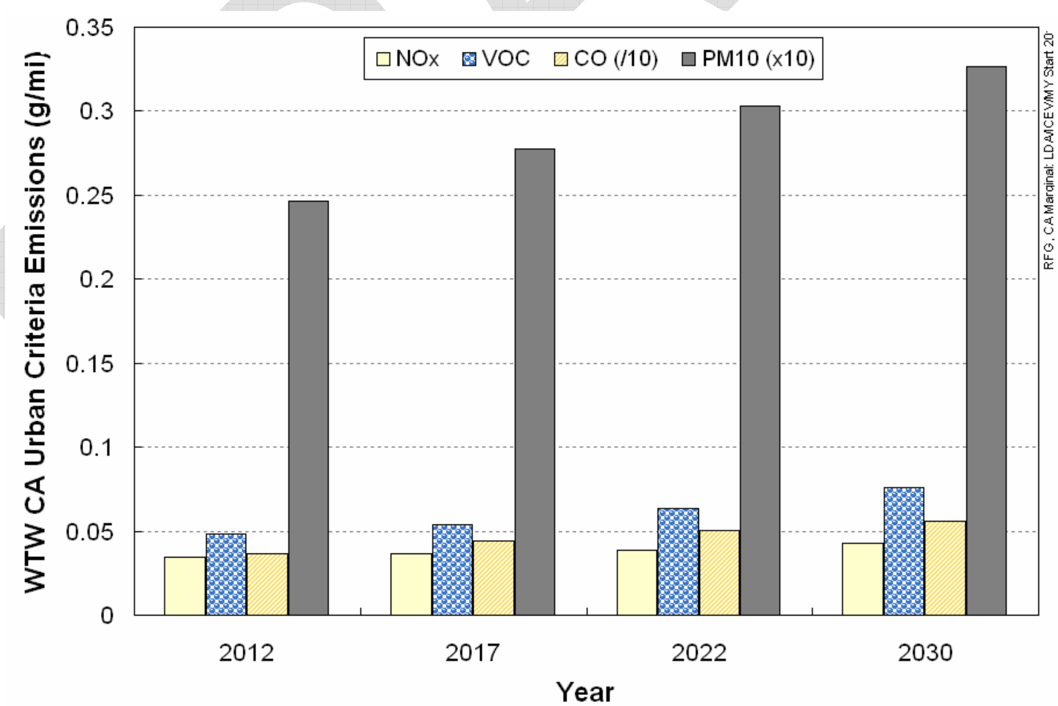

Figure 4-4. WTW Criteria Pollutant Emissions for Gasoline Passenger Cars (g/mi)

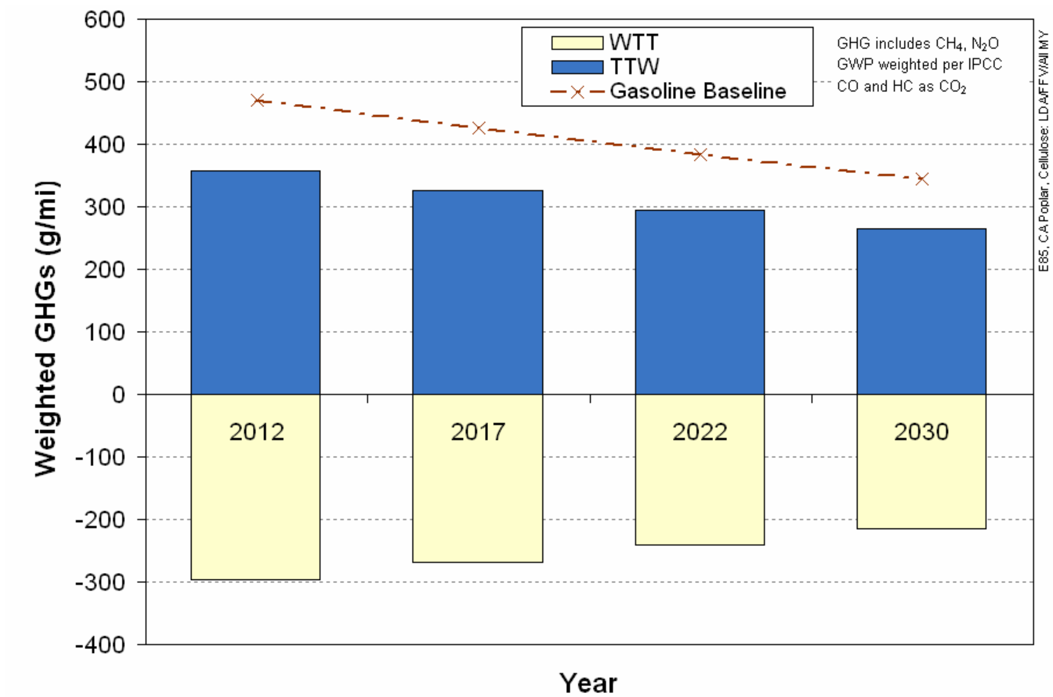

Figure 4-5. WTW GHG Emissions for Biomass Based E85 Passenger Cars (g/mi)

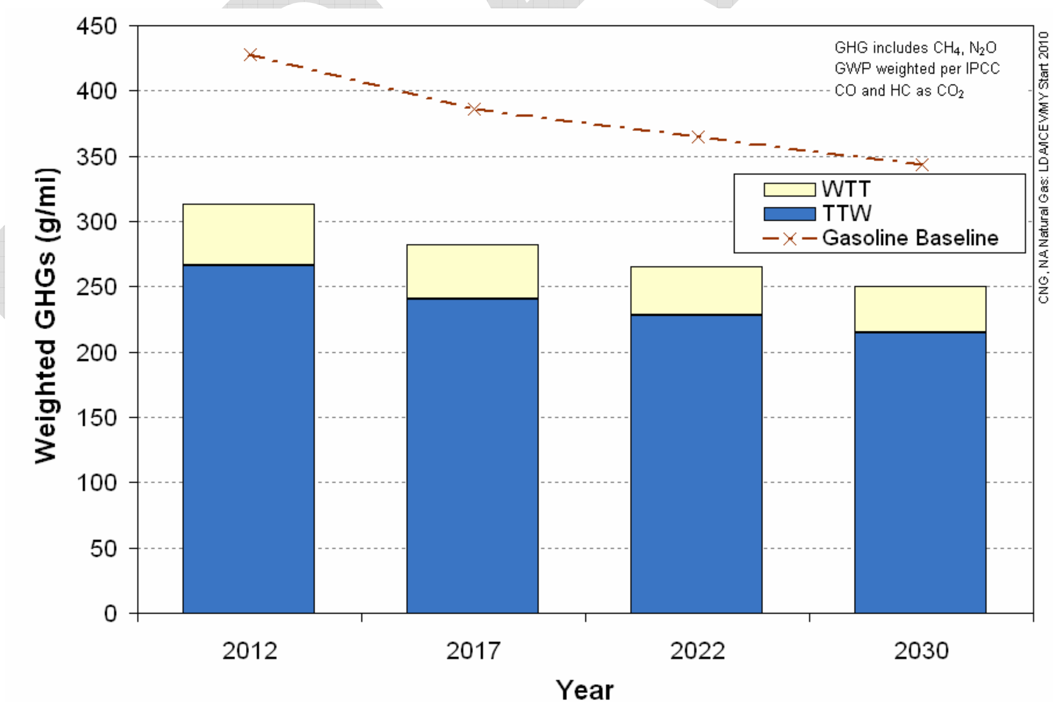

Figure 4-6. WTW GHG Emissions for CNG Passenger Cars (g/mi)

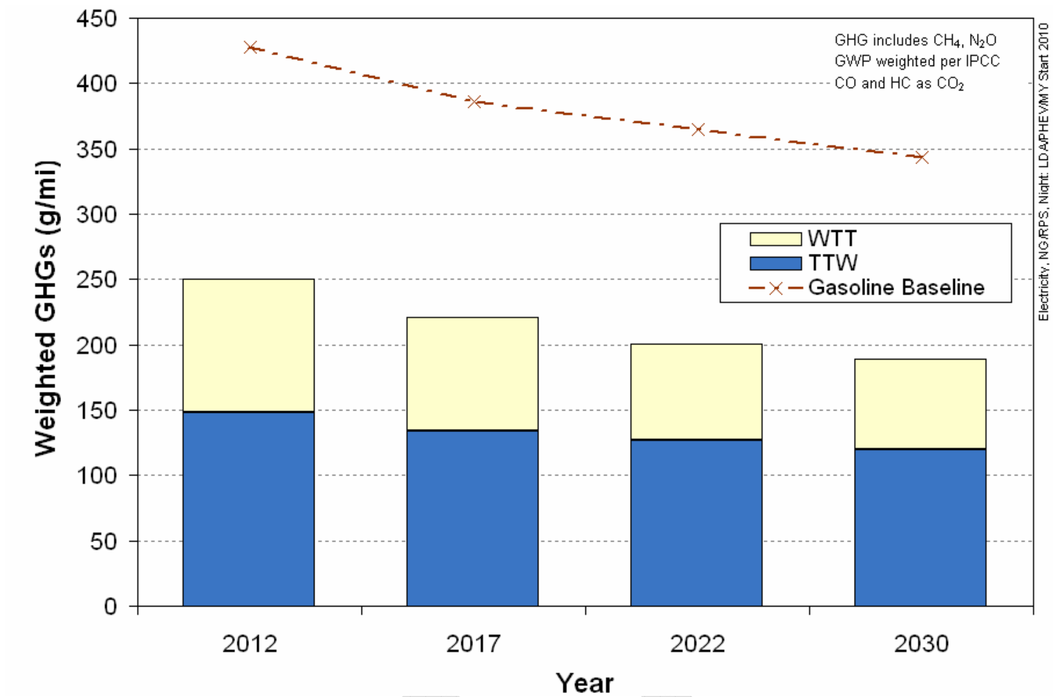

Figure 4-7. WTW GHG Emissions for PHEV Passenger Cars (g/mi)

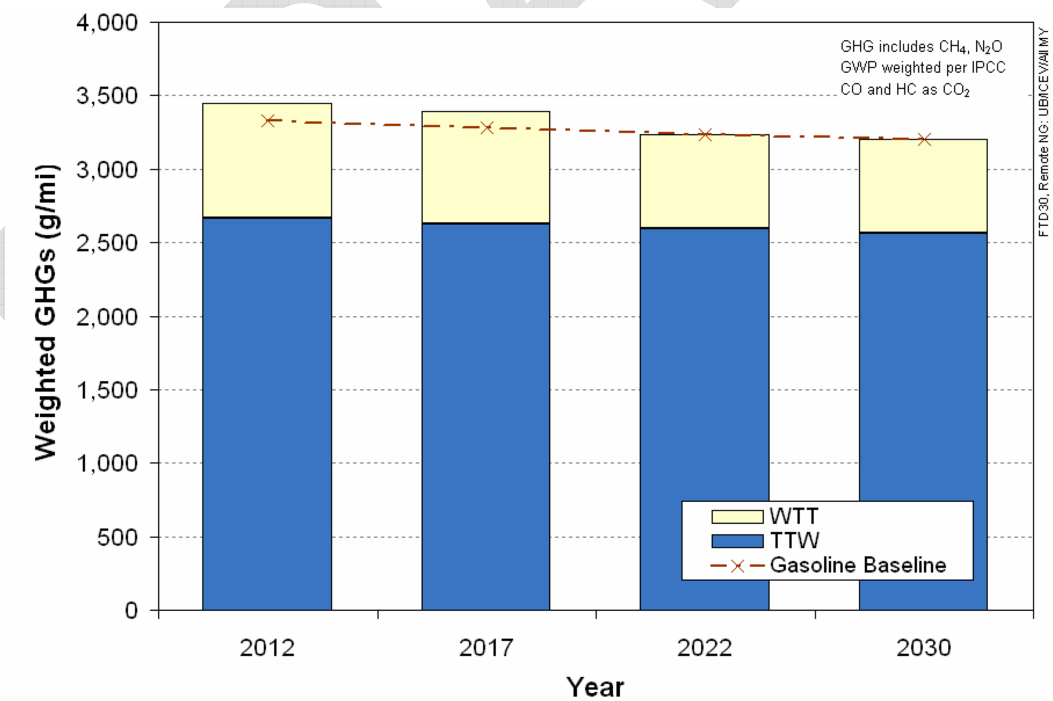

Figure 4-8. WTW GHG Emissions for Natural Gas Derived FTD30 Buses (g/mi)

4.6 Multimedia Impacts

Multimedia impacts result from a wide range of potential discharges to the environment that could ultimately contaminate surface water, ground water, and soil. These impacts can include those from agriculture and fuel production, fuel transport, fuel processing, and fuel delivery facilities. Water impacts such as from oil tanker spills or chemical run-off from farming are discussed qualitatively for each fuel option in the WTT and TTW reports

Agricultural impacts were not quantified on a per unit of fuel basis because of the wide range of agricultural practices, uncertainty over which fuels are displaced, and complex rules governing agricultural activity.

Tanker ship, rail, truck, and pipeline spills are a source of hydrocarbons and other chemicals entering waterways. The fates of the spills are very site specific and, again, it can be difficult to provide an integrated assessment of the impact of these spills. Clearly, hydrocarbon based fuels have the greatest potential for water impacts. Alcohols and biodiesel are more biodegradable and can are eliminated from the environment more quickly than hydrocarbons. However the interaction between alcohols and hydrocarbons in the soil may impact how hydrocarbon spills affect the environment.

The potential release of fuel during delivery or storage represents the dominant potential environmental impacts. The second order full fuel cycle impacts of diesel fuel spills are significantly less for fuels such as LNG, methanol, DME, hydrogen, and LPG that are delivered by diesel truck. The diesel component for these fuels is less than 5 percent of the total fuel cycle energy.

Therefore, in California, the most significant multimedia impacts correspond to the use of hydrocarbon fuels. Engine oil spills and drips can contribute as much to water impacts as fuels spills. Fuels that contain no petroleum hydrocarbons do not have a substantial multimedia impact associated with their use in California.

SECTION 5. CONCLUSIONS

This report provides an analysis of the impacts of transportation fuels on a full fuel cycle basis. The analysis includes energy, GHG, criteria pollutant, air toxics, and multimedia impacts. The analysis reflects fuels used, as well as the production of new fuel conversion facilities in California subject to prevailing emission constraints. Energy inputs and emissions correspond to vehicle technologies and fuel production assumptions corresponding to timeframes ranging from 2012 through 2030.

WTW emissions were evaluated in the context of marginal emissions associated with marginal alternative fuel consumption or petroleum fuel displacement. A moderate use of alternative fuels would displace finished petroleum fuels that would be imported to California. Increments of alternative fuel use would displace emissions from fuel transportation, vehicle fueling, and the use of marine vessels to import refinery blending components into the state. Many alternative fuels would be produced outside of California, so the marginal treatment of fuel production is consistent with that applied to finished petroleum fuels.

Marginal emissions correspond largely to transportation and distribution impacts associated with marine vessel activity, rail transport, fuel trucking, or distribution and local vehicle fueling. New fuel production facilities and power plant emissions attributable to incremental fuel production and use also contribute to the fuel cycle impacts.

Vehicle emissions depend on vehicle energy consumption combined with the carbon intensity of the fuel and emission factors for processes in the fuel cycle. The emission estimates shown here are consistent with ARBs projection for the existing vehicle stock for blend fuel strategies and 2010 and beyond vehicle stock for new vehicle technologies.

5.1 Energy Input and GHG Emissions Conclusions

The energy inputs and GHG emissions are determined by the conversion efficiency and carbon intensity of fuels. The study results are driven by the dominant assumptions regarding vehicle efficiency and fuel production process energy inputs. These results are consistent with others in terms of tracking the impacts of energy use and GHG emissions. The key conclusions regarding GHG emissions are:

1. GHG emissions from fossil fuels depend on both the carbon content of the fuel and process energy inputs. For fossil fuels, GHG emissions ranked from highest to lowest on a percent change in g/mi emission basis (taking vehicle efficiency into account) are:

Light Duty Applications (Gasoline Baseline)

- Hydrogen (FCVs) from electrolysis using the marginal natural gas/RPS mix
- RFG with 5.7 percent ethanol
- E10
- California ULSD in light duty vehicles
- LPG from petroleum or natural gas
- CNG
- Hydrogen (FCVs) from natural gas reforming technologies
- Hydrogen (FCVs) from electrolysis with at least 70 percent renewable power
- Hydrogen from coal with CO_2 sequestration

Heavy Duty Applications (Diesel Baseline)

- Synthetic fuels from coal without CO_2 sequestration
- Hydrogen (FCVs) from electrolysis using the marginal natural gas/RPS mix
- FT diesel from natural gas with current technology
- California ULSD, FTD with advanced technology, DME
- LNG with modern boil off management practices
- CNG from North American natural gas
- Methanol (Fuel Cell Bus)
- Hydrogen (FCVs) from natural gas reforming technologies
- Synthetic fuels from coal with CO_2 sequestration

2. The effect the use of alternative fuels on GHG emissions from off road equipment equipped with internal combustion engines is comparable to the effect for on 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. An electric generation mix based on natural gas combined cycle power combined with California's RPS constraint is an appropriate mix for electric transportation and the electricity inputs for fuel production. The use of renewable power allows for the mitigation of GHG emissions from other processes, which is an option for all fuel providers.

5. The results of the analysis show reductions in GHG emissions for electric transportation on the order of 50 percent or greater for battery electric, plug in hybrid, and forklift applications. These results are the result of the high energy efficiency for electric drive technologies and the improvement in gasoline vehicle energy consumption for plug in hybrid applications.

6. Hydrogen technologies result in a wider range of GHG emission reductions that depend on the range of production pathways and feedstocks that can be used for hydrogen production.

7. GHG emissions from biofuels production and use depend on agricultural inputs, allocation to byproducts, and the level and carbon intensity of process energy inputs. For biofuels, GHG emissions ranked from highest to lowest on a percent change basis (taking vehicle efficiency into account) are:

   Light-Duty Vehicles (Gasoline Baseline)

   - Ethanol from corn with process heat input from a coal fired boiler
   - Ethanol from corn with process heat input from a natural gas fired boiler
   - Ethanol from corn with reduced energy input by providing wet DGS byproduct
   - Ethanol from cellulose and sugar cane with no fossil fuel input for fuel production
   - Ethanol from waste materials (depending on the displaced use of waste material)

   Diesel Vehicles (Light- and Heavy-Duty Baseline)

   - Soybean based biodiesel (depending on N_2O emissions and byproduct credits)
   - Vegetable oil from crops with low agricultural inputs (assuming no change in land use such as use of prairie land or deforestation)
   - FT diesel and DME from biomass via gasification
   - Vegetable oils from yellow grease (depending on the displaced use of waste material)

The GHG emissions from biofuels production and use depend on many other factors. Most important are changes in land use that vary with substantially with scenario assumptions.

The analysis here provides only the vehicle emissions and WTT process inputs employed. Impacts associated with changes in land use can be added to these values. 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. These economic impacts are consistent with producing 5 billion gallons of ethanol per year in the U.S. To the extent that this assumption holds true, the impact of differing agricultural land uses represents a small portion of the WTW impact.

The issue of deforestation needs to be examined with several biofuel options. In the case of Brazilian ethanol, the sugar cane feedstock is not grown in the Amazon. However, agricultural displacement effects should be documented. A large fraction of the palm oil produced in the world is from areas with extensive tropical deforestation and the sustainable use of this fuel needs to be addressed.

5.2 Criteria Pollutant and Air Toxics Emissions

The WTW analysis takes into account vehicle and fuel production emissions consistent with vehicle operation in California. Vehicle emissions were based on ARB's EMFAC model for existing and new vehicle stocks. Fuel cycle emissions were calculated for California urban areas based on emission limits that apply to California stationary sources and fuel delivery equipment. The key conclusions regarding criteria pollutant and air toxics emissions are:

- California emission requirements are resulting in reduced emissions from vehicles as new vehicle technologies are introduced. The relative importance of fuel cycle emissions grows as vehicle emissions decline on a per mile basis.

- 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 fuel cycle.

- Some fuel blends such as biodiesel and FT diesel result in a decrease in criteria pollutant emissions in today's vehicles. The effect on future vehicles is being examined by ARB and others.

- 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 increase for fuels that are produced in the state. However, emissions outside of California are generally larger for imported fuels.

- Emissions of NO_x, VOC, and in some cases PM would need to be offset from new fuel production facilities in California. Obtaining permits and offsets, and installing emission control equipment will play an important role in the construction of new fuel production facilities.

- 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. Truck delivery requires shorter transportation distances and trucks are subject to more stringent emission controls. 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.

- Diesel PM is the major contributor to weighted toxics emissions in California for the marginal fuel production analyses. Therefore, fuels that are delivered by ship or rail have the highest weighted toxics impact.

- Criteria pollutant emissions for electric transportation are comparable to, or lower than, those from conventional fuels use, except for power plant PM. The lower emission levels result from requirements for new power plants to offset criteria pollutant emissions combined with RPS requirements. Power plant emissions associated with the average statewide generation mix are much higher, but these emissions are declining. Interestingly, emission factors for natural gas combined cycle power plants are greater than those for gasoline cars. However, power plant emissions are determined using different test methods than those for vehicle emissions, so the resulting emission factor values may not be directly comparable.

- 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.

- Fugitive losses and fuel spills are a source of benzene and 1-3 butadiene emissions associated with gasoline as well as PAHs from diesel. These emissions from fuel transport and delivery are largely eliminated with alternative fuels use. The weighted impact of these fugitive and fuel spill losses is lower than that of diesel PM associated with fuel delivery.

5.3 Multimedia Impacts

Fuel production and vehicle operations can result in significant impacts on rivers, oceans, groundwater, and other water media. The significant sources of multimedia impacts from vehicle operation include:

- Engine oil leaks and illegal discharges
- Tanker ship spills
- Fuel spills from delivery trucks and vehicle fueling
- Underground storage tank leaks
- Agricultural runoff
- Oil and gas production

The following multimedia impact conclusions are based on the analyses in this study:

- Multimedia impacts are difficult to compare in a unified manner because of the wide range of release scenarios and impacted environments
- While agricultural activities are subject to oversight from environmental agencies, the impacts are difficult to quantify in an integrated manner

- Oil and gas production results in significant potential multimedia impacts. These impacts are subject to stringent regulation in the U.S.
- The potential for hydrocarbon releases are significantly reduced with the use of non-hydrocarbon alternative fuels.
- Electric drive systems can reduce or eliminate engine oil losses, a significant source of potential multimedia impacts as noted above

SECTION 6. RECOMMENDATIONS

Based on the information found in this study, the following are recommendations to support the requirements of AB1007 and further advance efforts in performing full fuel cycle analyses. The recommendations include those regarding analysis methods, data collection, and system boundary considerations.

6.1 Analysis Methods

1. The GREET model served as a suitable tool to assess the transportation logistics for conventional and alternative fuels production and distribution in California. The GREET model was well suited for identifying the emissions associated with agricultural, transportation, and electric power generation processes. The version of the GREET model employed in this project should be maintained to support continued investigations of criteria pollutant and GHG emissions impacts. The analysis would be more transparent if emissions from California fuel production facilities are treated as separate inputs to the model.

2. One study observation was that the WTT energy inputs and GHG emissions for petroleum fuels use and electric power generation do not depend on the WTT analysis for biofuels production and use (unless large scale economic impacts occur). Recursive second order fuel cycle impacts are not an issue with typical biofuel chains (fuel to make the fuel to make the fuel). The analysis of energy and GHG emissions can be accomplished with simple tools that allow for a more detailed examination of agricultural systems and boundaries. Therefore, static WTT parameters from the GREET model or other fuel cycle models for diesel, electricity, uncompressed natural gas, gasoline, and LPG production and vehicle fuel use, combined with process data for alternative fuel production, agriculture, and chemical inputs can be incorporated into a simple database. A simple database approach can be used when only energy and GHG emissions are of interest.

3. Vehicle N_2O and methane emissions are treated as fixed g/mi values. This approach is neither convenient in terms of assessing the GHG intensity of a fuel nor strongly supported by emission test data. Future efforts should be devoted to developing GHG analysis metrics that incorporate the benefits of treating these pollutants on a g/MJ basis, thereby enabling an assessment of a fuel's GHG potential directly from WTT estimates.

4. Vehicle CO_2 emissions are directly linked to the carbon content of the fuel. For biofuels, this CO_2 was recently removed from the atmosphere. CO_2 emissions from biofuels should not be attributed to vehicle operation unless the analysis procedures demonstrate that the CO_2 capture from the atmosphere is also accounted for. This issue applies to the attribution of emissions for GHG inventory and accounting protocols rather than fuel cycle analyses.

5. The analysis in this study provides information to assess the emission impacts of different fuel production pathways. The emissions both inside and outside California, as well as the location of marine vessel emissions should be taken into account when assessing the impacts of criteria pollutant and and toxics emissions.

6.2 Data Collection

6. WTT results should continue to be reported with carbon in fuel as CO_2. This reporting method provides an overview of the potential GHG impact from all fuels and prevents confusion when comparing fuels with varying carbon contents.

7. Even though CO_2 is a pollutant, the emissions are often not included in reports on stationary equipment testing. The lack of CO_2 data makes further data analysis challenging when the goal is to develop fuel specific emission factors. (For example, some source test data only show mass emission rates such as lb/hr). Analysts for this project and many others must then estimate the fuel consumption (bsfc) of equipment and the carbon content of the fuel. ARB should require emission testing performed for stationary sources to include reporting of CO_2 emissions.

8. PM emissions associated with natural gas combined cycle power plants persist throughout the fuel cycle. Needs are to measure emissions or summarize source test data from new combined cycle power plants to better quantify the range in particulate source attribution (combustion product or other), hydrocarbon emissions, and hydrocarbon speciation. Also needed is an assessment of the effect that background emissions have on measured and net power plant emissions.

9. Data on emissions associated with hydrogen and synthetic fuel production facilities should be further examined to better determine the emissions impact of these facilities. In particular, source test results should be examined rather than using inventory estimates.

6.3 Boundary Considerations

10. Displacement effects are a key aspect of a fuel cycle analysis. The assumptions of a marginal analysis, California emission regulations, and offset requirements define the outcome for criteria pollutants. The assumptions on emission boundaries should always be identified.

11. Displacement effects also impact the use of energy avoided by using an alternative fuel. In the case of fuels and feedstocks with relatively small volumes in common use as fuels (e.g., digester gas, LPG, residential solar power), the attribution of feedstocks to alternative fuels production and use should be carefully examined in order to understand the best use of fuel feedstocks and displacement effects. Representing the fuel cycle analysis with a well defined system boundary for each

feedstock and its significant displacement effects is a favorable approach. The alternative uses of farmland in particular should be identified and evaluated.

12. Changes in agricultural land use has a dominant impact on biofuel pathways evaluation. The potential land use impacts should be quantified and shown as a separate component of the WTT and WTW analysis. There is a need to provide measurements to support sustainable agricultural practices, and the prevention of tropical deforestation associated with fuel production need to be incorporated into efforts to promote the use of fuels.

APPENDIX A. CALCULATION RESULTS

The following tables document the GREET model and other calculation results that are shown in the figures included in Section 3 of this report. Tables that detail the energy inputs, GHG emissions, criteria pollutant emissions, and air toxics emissions in the year 2012 are included for each conventional and alternative fuel evaluated and discussed in the report: gasoline, ethanol, biodiesel, natural gas, electricity, GTL fuels, hydrogen, synthetic fuels, and LPG. Following the 2012 results tables for each fuel are tables that document the effects of the scenario years on energy inputs and emissions results for the fuel and vehicle combinations discussed in Section 4 of the report. Scenario year effects tables are given for gasoline passenger cars, E85 passenger cars, CNG passenger cars, PHEV passenger cars, diesel buses, and natural gas derived FTD30 buses.

Each table contains columns of results data for the vehicle/ fuel/ fuel production pathways illustrated in the bar chart figures in the main body of the report. Each vehicle/ fuel/ production pathway given in the results tables is identified by an identifier termed the WTT Case ID. The initial table in the following represents the key that associates each WTT Case ID with the vehicle/ fuel/ production pathway description given in the bars comprising the bar charts that summarize analysis results and discussion in Sections 3 and 4 of the report.

WTT Case ID	Region Code	Description
BD23	1	BD20, MW SoyBean
C1	3	CNG, NA Natural Gas
C2	4	CNG, LNG, Remote NG
D1	4	Diesel, CA ULSD
D6	1	E-Diesel, MW EtOH
DM1	4	DME, Remote NG
e1	3	Electricity, NG/RPS
e2	3	Electricity, Renewable, No Combustion
e3	3	Electricity, Renewable Mix
e4	3	Electricity, H_2 Pet Coke
e10	3	Electricity, NG/RPS, Night
e11	3	Electricity, CA Average
e12	3	Electricity, CA NG CC
E10	4	E10, Corn, MW EtOH
E71	1	E85, Corn, MW mix/BR
E72	1	E85, Corn, MW Coal
E73	1	E85, Corn, MW NG
E74	1	E85, Corn, MW NG, Wet Feed
E75	3	E85, CA Corn, Wet Feed
E76	3	E85, CA Corn, Wet Digester
E78	3	E85, CA Poplar, Cellulose
E79	3	E85, CA Forest Residue
E81	3	E85, CA Switch Grass
E84	3	E85, Brazil Sugar Cane
E98	1	E90, MW mix/BR
F31	4	FTD30, Remote NG
F33	3	FTD30, CA Poplar
F34	3	FTD30, CA Coal
F35	4	FTD100, Remote NG
G0	4	RFG, 0 Oxygen
G1	4	RFG, CA Marginal
G5	4	RFG, Tar Sands
H1	3	H_2, NG SR, LH_2
H2	3	H_2, NG SR, LH2, Ren Power
H3	3	H_2, Coal, Sequestration
H4	3	H_2, NG SR, Pipeline
H5	3	H_2, Pet Coke, Pipeline
H6	3	H_2, Biomass, Pipeline
H7	3	H_2, Onsite NG SR
H8	3	H_2, Onsite NG SR, 700 bar
H9	3	H_2, Onsite NG SR, Ren Power
H10	3	H_2, Grid Electrolysis
H11	3	H_2, 70% Renewable, Electrolysis
L1	3	LNG, NA NG, Pipeline Liquefier
L3	4	LNG, Remote NG
M1	4	Methanol, Remote NG
M2	3	Methanol, LFG
P1	4	LPG, Petroleum
P2	1	LPG, Natural Gas

Region Code: 1=U.S., 2=N.E., 3=CA, 4=ROW (nNA)

Gasoline Fueled Vehicles

Scenario Year 2012: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		**G1**	**E10**	**G5**	**G1**	**E10**	**G5**	**G1**	**D1**
Vehicle Type		G new	G new	G new	G HEV	G HEV	G HEV	G new	ULSD
Vehicle Technology		ICEV	ICEV	ICEV	HEV	HEV	HEV	ICEV	ICEV
Fossil	MJ/mi	5.67	5.49	5.77	4.20	4.07	4.27	5.67	4.47
Petroleum	MJ/mi	5.00	4.77	5.02	3.70	3.53	3.72	5.00	4.07
Natural Gas	MJ/mi	0.67	0.63	0.75	0.49	0.47	0.55	0.67	0.40
Coal	MJ/mi	0.00	0.09	0.00	0.00	0.07	0.00	0.00	0.00
Non Fossil	MJ/mi	0.21	0.33	0.19	0.15	0.25	0.14	0.21	0.01
WTT	MJ/mi	1.28	1.23	1.37	0.95	0.91	1.01	1.28	0.80
TTW	MJ/mi	4.59	4.59	4.59	3.40	3.40	3.40	4.59	3.68
GHGs (weighted)									
WTT	g/mi	86	79	149	64	58	111	86	63
TTW	g/mi	342	340	342	256	255	256	342	283
TOTAL	g/mi	428	419	491	319	313	366	428	346
Criteria, Total								WTT Only	
VOC	g/mi	0.087	0.085	0.090	0.071	0.070	0.073	0.061	0.040
CO (/10)	g/mi	0.046	0.048	0.054	0.044	0.045	0.049	0.102	0.062
NO_x	g/mi	0.315	0.263	0.290	0.240	0.202	0.222	0.289	0.208
PM_{10}	g/mi	0.046	0.055	0.054	0.041	0.047	0.046	0.221	0.151
Criteria, Urban								WTT Only	
VOC	g/mi	0.048	0.046	0.048	0.042	0.041	0.042	0.022	0.013
CO (/10)	g/mi	0.036	0.036	0.036	0.036	0.036	0.036	0.002	0.002
NO_x	g/mi	0.035	0.031	0.035	0.032	0.030	0.032	0.009	0.005
PM_{10}	g/mi	0.025	0.024	0.025	0.025	0.024	0.025	0.004	0.002
Urban Toxics, (weighted)									
Benzene	g/mi	2.3E-03	2.1E-03	2.1E-03	2.2E-03	2.1E-03	2.1E-03	2.3E-03	1.9E-05
1-3 Butadiene	g/mi	2.6E-03	2.2E-03	2.2E-03	2.5E-03	2.2E-03	2.2E-03	2.6E-03	1.1E-05
Formaldehyde	g/mi	5.2E-04	2.1E-04	2.1E-04	4.4E-04	2.1E-04	2.1E-04	5.2E-04	2.9E-05
Acetaldehyde	g/mi	8.3E-05	1.6E-05	1.6E-05	6.6E-05	1.6E-05	1.6E-05	8.3E-05	6.6E-06
Diesel PM	g/mi	2.6E-02	0.0E+00	0.0E+00	1.9E-02	0.0E+00	0.0E+00	2.6E-02	4.5E-03

G02/SC1

Ethanol

Scenario Year 2012: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		**G1**	**E71**	**E72**	**E73**	**E74**	**E75**	**E76**	**E78**	**E79**	**E81**	**E84**	**E98**
Vehicle Type		G FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV	E85 FFV
Vehicle Technology		FFV	FFV	FFV	FFV	FFV	FFV	FFV	FFV	FFV	FFV	FFV	FFV
Fossil	MJ/mi	6.23	4.16	4.08	4.15	3.53	3.43	2.23	1.27	2.07	1.59	0.88	4.00
Petroleum	MJ/mi	5.50	1.52	1.53	1.52	1.51	1.45	1.44	1.45	1.65	1.35	1.39	1.19
Natural Gas	MJ/mi	0.73	2.18	0.47	2.01	1.65	1.96	0.76	-0.20	0.39	0.21	-0.53	2.32
Coal	MJ/mi	0.00	0.46	2.08	0.62	0.37	0.02	0.02	0.02	0.02	0.02	0.02	0.48
Non Fossil	MJ/mi	0.23	3.98	3.99	3.98	3.97	3.92	3.91	10.88	7.35	7.80	7.80	4.31
WTT	MJ/mi	1.41	3.24	3.16	3.23	2.59	2.44	1.23	7.24	4.52	4.49	3.78	3.40
TTW	MJ/mi	5.05	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
GHGs (weighted)													
WTT	g/mi	95	11	80	18	-32	-55	-128	-298	-250	-206	-285	4
TTW	g/mi	375	358	358	358	358	358	358	358	358	358	358	358
TOTAL	g/mi	470	369	438	376	327	303	231	61	108	152	74	362
Criteria, Total													
VOC	g/mi	0.349	0.423	0.425	0.423	0.418	0.415	0.408	0.414	0.379	0.429	0.397	0.429
CO (/10)	g/mi	0.274	0.320	0.327	0.321	0.318	0.327	0.313	0.310	0.314	0.298	0.294	0.324
NO_x	g/mi	0.541	0.818	0.975	0.833	0.774	0.485	0.479	0.923	0.962	0.765	0.726	0.845
PM_{10} (x10)	g/mi	0.575	1.741	5.801	2.147	1.571	0.990	0.946	1.462	1.056	1.253	1.220	1.814
Criteria, Urban													
VOC	g/mi	0.306	0.311	0.311	0.311	0.311	0.311	0.311	0.307	0.308	0.307	0.307	0.311
CO (/10)	g/mi	0.263	0.263	0.263	0.263	0.263	0.268	0.268	0.268	0.263	0.268	0.263	0.263
NO_x	g/mi	0.233	0.236	0.236	0.237	0.237	0.229	0.229	0.236	0.237	0.235	0.234	0.237
PM_{10} (x10)	g/mi	0.337	0.335	0.336	0.336	0.336	0.464	0.457	0.444	0.332	0.450	0.336	0.335
Urban Toxics, (weighted)													
Benzene	g/mi	2.3E-02	2.3E-02	2.3E-02	2.3E-02	2.3E-02	2.3E-02	2.3E-02	2.2E-02	2.2E-02	2.2E-02	2.2E-02	2.2E-02
1-3 Butadiene	g/mi	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02
Formaldehyde	g/mi	2.5E-03	2.6E-03	2.6E-03	2.6E-03	2.6E-03	2.6E-03	2.6E-03	2.1E-03	2.1E-03	2.1E-03	2.1E-03	2.2E-03
Acetaldehyde	g/mi	2.8E-04	3.1E-04	3.1E-04	3.1E-04	3.1E-04	3.1E-04	3.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.2E-04
Diesel PM	g/mi	2.8E-02	2.9E-02	2.9E-02	2.9E-02	2.9E-02	2.0E-02	2.0E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.5E-02

G06

Biodiesel

Scenario Year 2012: LDA/UB Vehicle Class: All Model Years (blend)

WTT Case ID		**D1**	**BD23**	**D1**	**BD23**
Vehicle Type		ULSD	BD20	ULSD	BD20
Vehicle Technology		LDA ICEV	LDA ICEV	UB ICEV	UB ICEV
Fossil	MJ/mi	4.92	4.44	43.94	39.65
Petroleum	MJ/mi	4.48	3.80	40.05	33.96
Natural Gas	MJ/mi	0.44	0.53	3.89	4.77
Coal	MJ/mi	0.00	0.10	0.00	0.92
Non Fossil	MJ/mi	0.01	0.78	0.05	6.93
WTT	MJ/mi	0.88	1.17	7.87	10.47
TTW	MJ/mi	4.04	4.04	36.12	36.12
GHGs (weighted)					
WTT	g/mi	70	31	623	275
TTW	g/mi	310	313	2704	2726
TOTAL	g/mi	380	343	3327	3002
Criteria, Total					
VOC	g/mi	0.221	0.301	1.202	2.086
CO (/10)	g/mi	0.082	0.108	0.427	0.689
NO_x	g/mi	1.690	1.821	20.935	22.220
PM_{10} (x10)	g/mi	1.552	1.668	4.898	6.627
Criteria, Urban					
VOC	g/mi	0.191	0.153	0.934	0.761
CO (/10)	g/mi	0.076	0.068	0.367	0.330
NO_x	g/mi	1.467	1.509	18.942	19.432
PM_{10} (x10)	g/mi	1.388	1.278	3.433	3.151
Urban Toxics, (weighted)					
Benzene	g/mi	1.7E-02	1.3E-02	7.8E-02	6.2E-02
1-3 Butadiene	g/mi	9.5E-03	7.5E-03	4.4E-02	3.4E-02
Formaldehyde	g/mi	2.6E-02	2.0E-02	1.2E-01	9.4E-02
Acetaldehyde	g/mi	5.8E-03	4.6E-03	2.7E-02	2.1E-02
Diesel PM	g/mi	5.7E+00	5.1E+00	1.6E+01	1.4E+01

G05

Natural Gas

Scenario Year 2012: LDA/UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		**G1**	**C1**	**C2**	**D1**	**C1**	**C2**	**L3**	**L1**
Vehicle Type		G new	CNG	CNG	ULSD	CNG	CNG	LNG	LNG
Vehicle Technology		LDA ICEV	LDA ICEV	LDA ICEV	UB ICEV	UB ICEV	UB ICEV	UB ICEV	UB ICEV
Fossil	MJ/mi	5.67	4.96	5.60	43.50	42.28	47.73	47.31	45.69
Petroleum	MJ/mi	5.00	0.02	0.08	39.65	0.16	0.67	1.54	0.24
Natural Gas	MJ/mi	0.67	4.94	5.52	3.85	42.11	47.05	45.76	45.45
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.21	0.01	0.01	0.05	0.10	0.10	0.02	0.13
WTT	MJ/mi	1.28	0.51	1.15	7.79	4.33	9.79	8.87	7.37
TTW	MJ/mi	4.59	4.46	4.46	35.76	38.04	38.04	38.45	38.45
GHGs (weighted)									
WTT	g/mi	86	47	94	617	404	800	764	723
TTW	g/mi	342	266	266	2678	2206	2206	2209	2209
TOTAL	g/mi	428	313	360	3295	2609	3006	2973	2932
Criteria, Total									
VOC	g/mi	0.087	0.044	0.050	0.433	0.305	0.362	0.392	0.344
CO (/10)	g/mi	0.046	0.040	0.044	0.149	0.123	0.158	0.167	0.131
NO_x	g/mi	0.315	0.054	0.363	2.686	0.902	3.540	3.854	0.956
PM_{10}	g/mi	0.046	0.028	0.036	0.213	0.095	0.163	0.176	0.114
Criteria, Urban									
VOC	g/mi	0.048	0.014	0.013	0.168	0.049	0.046	0.049	0.055
CO (/10)	g/mi	0.036	0.036	0.036	0.090	0.091	0.089	0.090	0.095
NO_x	g/mi	0.035	0.029	0.031	0.713	0.687	0.707	0.741	0.712
PM_{10}	g/mi	0.025	0.025	0.024	0.068	0.071	0.067	0.069	0.086
Urban Toxics, (weighted)									
Benzene	g/mi	2.1E-03	4.6E-06	0.0E+00	4.3E-03	4.0E-05	0.0E+00	3.4E-04	3.1E-04
1-3 Butadiene	g/mi	2.2E-03	1.9E-06	0.0E+00	2.4E-03	1.6E-05	0.0E+00	1.4E-04	1.4E-04
Formaldehyde	g/mi	2.4E-04	2.6E-04	2.1E-04	6.5E-03	6.7E-03	6.2E-03	8.4E-03	8.0E-03
Acetaldehyde	g/mi	2.5E-05	1.8E-05	1.6E-05	1.5E-03	1.4E-03	1.4E-03	1.5E-03	1.5E-03
Diesel PM	g/mi	5.7E-03	9.9E-05	0.0E+00	2.2E+00	2.1E+00	2.1E+00	2.2E+00	2.2E+00

G04/G04b

Electricity

Scenario Year 2012: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		G1	e10	e10	e1	e12	e2
Vehicle Type		G new	PHEV	EV	EV	EV	EV
Vehicle Technology		ICEV	PHEV	EV	EV	EV	EV
Fossil	MJ/mi	5.67	1.88	2.50	2.52	2.98	0.00
Petroleum	MJ/mi	5.00	0.60	0.01	0.01	0.01	0.00
Natural Gas	MJ/mi	0.67	1.28	2.49	2.51	2.97	0.00
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.21	0.20	0.27	0.27	0.00	1.28
WTT	MJ/mi	1.28	1.15	1.50	1.51	1.70	0.00
TTW	MJ/mi	4.59	0.93	1.28	1.28	1.28	1.28
GHGs (weighted)							
WTT	g/mi	86	102	164	165	188	0
TTW	g/mi	342	148	0	0	0	0
TOTAL	g/mi	428	250	164	165	188	0
Criteria, Total							
VOC	g/mi	0.087	0.043	0.018	0.018	0.020	0.000
CO (/10)	g/mi	0.046	0.019	0.004	0.004	0.005	0.000
NO_x	g/mi	0.315	0.139	0.015	0.015	0.017	0.000
PM_{10}	g/mi	0.046	0.035	0.030	0.030	0.031	0.020
Criteria, Urban							
VOC	g/mi	0.048	0.020	0.002	0.002	0.002	0.000
CO (/10)	g/mi	0.036	0.014	0.002	0.002	0.002	0.000
NO_x	g/mi	0.035	0.014	0.001	0.001	0.002	0.000
PM_{10}	g/mi	0.025	0.025	0.028	0.028	0.029	0.020
Urban Toxics, (weighted)							
Benzene	g/mi	2.3E-03	8.5E-04	6.1E-05	6.2E-05	7.3E-05	0.0E+00
1-3 Butadiene	g/mi	2.6E-03	9.6E-04	1.3E-05	1.3E-05	1.5E-05	0.0E+00
Formaldehyde	g/mi	5.2E-04	5.1E-04	7.5E-04	7.6E-04	8.9E-04	0.0E+00
Acetaldehyde	g/mi	8.3E-05	4.2E-05	1.9E-05	1.9E-05	2.3E-05	0.0E+00
Diesel PM	g/mi	2.6E-02	1.1E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00

G07

Gas-to-Liquids

Scenario Year 2012: UB Vehicle Class: All Model Years (blend)

WTT Case ID		D1	F35	F31	F33	F34
Vehicle Type		ULSD	FTD 30	FTD 30	FTD 30	FTD 30
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	43.94	61.75	49.28	32.17	51.50
Petroleum	MJ/mi	40.05	0.80	28.67	28.86	28.48
Natural Gas	MJ/mi	3.89	60.95	20.60	3.31	2.86
Coal	MJ/mi	0.00	0.00	0.00	0.00	20.16
Non Fossil	MJ/mi	0.05	0.01	0.04	18.34	0.05
WTT	MJ/mi	7.87	25.64	13.19	14.39	15.43
TTW	MJ/mi	36.12	36.12	36.12	36.12	36.12
GHGs (weighted)						
WTT	g/mi	623	1146	786	-200	1900
TTW	g/mi	2704	2630	2665	2665	2665
TOTAL	g/mi	3327	3777	3451	2465	4565
Criteria, Total						
VOC	g/mi	1.202	1.161	1.021	1.002	1.028
CO (/10)	g/mi	0.427	0.380	0.373	0.403	0.384
NO_x	g/mi	20.935	21.820	20.137	19.542	19.057
PM_{10} (x10)	g/mi	4.898	4.316	4.532	4.593	36.490
Criteria, Urban						
VOC	g/mi	0.934	0.698	0.722	0.724	0.723
CO (/10)	g/mi	0.367	0.309	0.309	0.310	0.310
NO_x	g/mi	18.942	18.023	18.005	18.012	18.007
PM_{10} (x10)	g/mi	3.433	3.191	3.181	3.202	3.202
Urban Toxics, (weighted)						
Benzene	g/mi	7.8E-02	5.9E-02	5.9E-02	5.9E-02	5.9E-02
1-3 Butadiene	g/mi	4.4E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02
Formaldehyde	g/mi	1.2E-01	8.9E-02	8.9E-02	8.9E-02	8.9E-02
Acetaldehyde	g/mi	2.7E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02
Diesel PM	g/mi	1.6E+01	1.5E+01	1.5E+01	1.5E+01	1.5E+01

G5b

Hydrogen

Scenario Year 2012: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		**G1**	**H1**	**H2**	**H3**	**H4**	**H6**	**H7**	**H8**	**H9**	**H10**	**H11**
Vehicle Type		G new	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	5.67	6.43	3.52	4.40	3.81	0.65	4.09	4.22	3.46	6.28	2.21
Petroleum	MJ/mi	5.00	0.04	0.03	0.02	0.01	0.11	0.02	0.02	0.01	0.03	0.01
Natural Gas	MJ/mi	0.67	6.39	3.49	0.62	3.79	0.54	4.07	4.21	3.45	6.25	2.20
Coal	MJ/mi	0.00	0.00	0.00	3.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.21	0.19	1.55	0.04	0.02	4.45	0.04	0.05	0.33	0.50	1.61
WTT	MJ/mi	1.28	4.32	2.77	2.14	1.53	2.81	1.83	1.97	1.50	4.49	1.52
TTW	MJ/mi	4.59	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
GHGs (weighted)												
WTT	g/mi	86	400	216	110	239	17	248	256	208	491	168
TTW	g/mi	342	0	0	0	0	0	0	0	0	0	0
TOTAL	g/mi	428	400	216	110	239	17	248	256	208	491	168
Criteria, Total												
VOC	g/mi	0.087	0.043	0.023	0.035	0.024	0.013	0.026	0.027	0.021	0.053	0.018
CO (/10)	g/mi	0.046	0.008	0.003	0.003	0.004	0.004	0.004	0.004	0.003	0.012	0.005
NO_x	g/mi	0.315	0.044	0.027	0.010	0.022	0.036	0.023	0.024	0.019	0.044	0.015
PM_{10}	g/mi	0.046	0.035	0.025	0.624	0.026	0.024	0.026	0.026	0.023	0.048	0.030
Criteria, Urban												
VOC	g/mi	0.048	0.003	0.000	0.001	0.001	0.001	0.009	0.001	0.000	0.006	0.002
CO (/10)	g/mi	0.036	0.002	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.006	0.002
NO_x	g/mi	0.035	0.004	0.002	0.001	0.001	0.012	0.005	0.002	0.002	0.004	0.001
PM_{10}	g/mi	0.025	0.029	0.021	0.022	0.022	0.022	0.024	0.024	0.021	0.043	0.028
Urban Toxics, (weighted)												
Benzene	g/mi	2.3E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E-05	0.0E+00	0.0E+00	1.8E-04	6.5E-05
1-3 Butadiene	g/mi	2.6E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.9E-06	0.0E+00	0.0E+00	3.9E-05	1.4E-05
Formaldehyde	g/mi	5.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-04	0.0E+00	0.0E+00	2.3E-03	8.0E-04
Acetaldehyde	g/mi	8.3E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E-06	0.0E+00	0.0E+00	5.7E-05	2.0E-05
Diesel PM	g/mi	2.6E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.1E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00

G10

Synthetic Fuels

Scenario Year 2012: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		**D1**	**M1**	**M2**	**DM1**
Vehicle Type		ULSD	Methanol	Methanol	DME
Vehicle Technology		ICEV	FCV	FCV	ICEV
Fossil	MJ/mi	43.50	44.49	30.39	55.56
Petroleum	MJ/mi	39.65	1.09	27.80	1.09
Natural Gas	MJ/mi	3.85	43.40	2.58	54.47
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.05	0.01	2.04	0.01
WTT	MJ/mi	7.79	17.00	4.92	19.81
TTW	MJ/mi	35.76	27.51	27.51	35.76
GHGs (weighted)					
WTT	g/mi	617	818	-3174	997
TTW	g/mi	2678	1890	1957	2420
TOTAL	g/mi	3295	2708	-1217	3418
Criteria, Total					
VOC	g/mi	0.433	0.488	0.112	2.412
CO (/10)	g/mi	0.149	0.157	-0.129	0.171
NO_x	g/mi	2.686	3.566	0.351	3.250
PM_{10} (x10)	g/mi	2.127	2.413	-7.494	2.116
Criteria, Urban					
VOC	g/mi	0.168	0.190	-0.072	2.070
CO (/10)	g/mi	0.090	0.091	-0.162	0.092
NO_x	g/mi	0.713	0.780	0.195	0.790
PM_{10} (x10)	g/mi	0.677	0.715	-7.672	0.718
Urban Toxics, (weighted)					
Benzene	g/mi	4.3E-03	0.0E+00	0.0E+00	0.0E+00
1-3 Butadiene	g/mi	2.4E-03	0.0E+00	0.0E+00	0.0E+00
Formaldehyde	g/mi	6.5E-03	6.2E-03	6.2E-03	6.2E-03
Acetaldehyde	g/mi	1.5E-03	1.4E-03	1.4E-03	1.4E-03
Diesel PM	g/mi	2.2E+00	0.0E+00	0.0E+00	2.1E+00

G12b

LPG

Scenario Year 2012: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		G1	P1	P2
Vehicle Type		G new	LPG	LPG
Vehicle Technology		ICEV	ICEV	ICEV
Fossil	MJ/mi	5.67	5.16	5.14
Petroleum	MJ/mi	5.00	4.75	0.31
Natural Gas	MJ/mi	0.67	0.41	4.65
Coal	MJ/mi	0.00	0.00	0.19
Non Fossil	MJ/mi	0.21	0.01	0.04
WTT	MJ/mi	1.28	0.71	0.72
TTW	MJ/mi	4.59	4.46	4.46
GHGs (weighted)				
WTT	g/mi	86	58	66
TTW	g/mi	342	301	302
TOTAL	g/mi	428	359	368
Criteria, Total				
VOC	g/mi	0.087	0.448	0.450
CO (/10)	g/mi	0.046	0.043	0.044
NO_x	g/mi	0.315	0.146	0.217
PM_{10} (x10)	g/mi	0.463	0.301	0.655
Criteria, Urban				
VOC	g/mi	0.048	0.420	0.420
CO (/10)	g/mi	0.036	0.036	0.036
NO_x	g/mi	0.035	0.037	0.038
PM_{10} (x10)	g/mi	0.246	0.246	0.246
Urban Toxics, (weighted)				
Benzene	g/mi	2.3E-03	9.4E-05	0.0E+00
1-3 Butadiene	g/mi	2.6E-03	4.2E-04	0.0E+00
Formaldehyde	g/mi	5.2E-04	4.6E-04	2.1E-04
Acetaldehyde	g/mi	8.3E-05	6.9E-05	1.6E-05
Diesel PM	g/mi	2.6E-02	9.0E-03	0.0E+00

G03

Effect of Scenario Years: Gasoline Passenger Cars (new)

Effect of Scenario Years : LDA Vehicle Class: Model Year Start 2010 (new)

	Year	**2012**	**2017**	**2022**	**2030**
	WTT Case ID	G1	G1	G1	G1
	Vehicle Type/Tech	RFG5.7/ICEV	RFG5.7/ICEV	RFG5.7/ICEV	RFG5.7/ICEV
Fossil	MJ/mi	5.67	5.10	4.82	4.53
Petroleum	MJ/mi	5.00	4.50	4.26	4.00
Natural Gas	MJ/mi	0.67	0.60	0.56	0.53
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.21	0.18	0.17	0.16
WTT	MJ/mi	1.28	1.15	1.08	1.01
TTW	MJ/mi	4.59	4.14	3.91	3.67
GHGs (weighted)					
WTT	g/mi	86	77	73	68
TTW	g/mi	342	309	292	275
TOTAL	g/mi	428	386	365	344
Criteria, Total					
VOC	g/mi	0.087	0.088	0.096	0.106
CO (/10)	g/mi	0.046	0.053	0.059	0.064
NO_x	g/mi	0.315	0.285	0.271	0.261
PM_{10} (x10)	g/mi	0.463	0.466	0.477	0.490
Criteria, Urban					
VOC	g/mi	0.048	0.054	0.064	0.076
CO (/10)	g/mi	0.036	0.044	0.050	0.056
NO_x	g/mi	0.035	0.037	0.039	0.043
PM_{10} (x10)	g/mi	0.246	0.278	0.303	0.326
Urban Toxics, (weighted)					
Benzene	g/mi	2.3E-03	2.7E-03	3.3E-03	4.1E-03
1-3 Butadiene	g/mi	2.6E-03	2.6E-03	3.0E-03	3.6E-03
Formaldehyde	g/mi	5.2E-04	2.4E-04	2.8E-04	3.3E-04
Acetaldehyde	g/mi	8.3E-05	2.0E-05	2.3E-05	2.8E-05
Diesel PM	g/mi	2.6E-02	0.0E+00	0.0E+00	0.0E+00

tLDA 1

Effect of Scenario Years: Gasoline Passenger Cars (blend)

Effect of Scenario Years : LDA Vehicle Class: All Model Years (blend)

	Year	2012	2017	2022	2030
	WTT Case ID	G1	G1	G1	G1
	Vehicle Type/Tech	RFG5.7/ICEV	RFG5.7/ICEV	RFG5.7/ICEV	RFG5.7/ICEV
Fossil	MJ/mi	6.23	5.65	5.07	4.54
Petroleum	MJ/mi	5.50	4.98	4.48	4.02
Natural Gas	MJ/mi	0.73	0.66	0.59	0.53
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.23	0.20	0.18	0.16
WTT	MJ/mi	1.41	1.27	1.14	1.02
TTW	MJ/mi	5.05	4.58	4.12	3.69
GHGs (weighted)					
WTT	g/mi	95	86	77	69
TTW	g/mi	375	341	307	276
TOTAL	g/mi	470	426	384	345
Criteria, Total					
VOC	g/mi	14.202	13.227	7.626	0.150
CO (/10)	g/mi	8.653	7.793	3.759	0.089
NO_x	g/mi	5.353	4.937	2.816	0.281
PM_{10} (x10)	g/mi	1.127	0.937	0.525	0.507
Criteria, Urban					
VOC	g/mi	14.160	13.189	7.592	0.119
CO (/10)	g/mi	8.642	7.783	3.750	0.081
NO_x	g/mi	5.045	4.663	2.571	0.063
PM_{10} (x10)	g/mi	0.889	0.729	0.342	0.342
Urban Toxics, (weighted)					
Benzene	g/mi	1.5E+00	1.5E+00	7.8E-01	6.8E-03
1-3 Butadiene	g/mi	1.9E+00	1.9E+00	9.7E-01	6.2E-03
Formaldehyde	g/mi	2.3E-01	2.3E-01	1.2E-01	5.4E-04
Acetaldehyde	g/mi	2.5E-02	2.5E-02	1.3E-02	4.8E-05
Diesel PM	g/mi	2.8E-02	0.0E+00	0.0E+00	0.0E+00

tLDA 4

Effect of Scenario Years: Biomass Based E85 Passenger Cars

Effect of Scenario Years : LDA Vehicle Class: All Model Years (blend)

Year		**2012**	**2017**	**2022**	**2030**
WTT Case ID		E78	E78	E78	E78
Vehicle Type/Tech		E85 FFV/FFV	E85 FFV/FFV	E85 FFV/FFV	E85 FFV/FFV
Fossil	MJ/mi	1.27	1.15	1.03	0.93
Petroleum	MJ/mi	1.45	1.31	1.18	1.06
Natural Gas	MJ/mi	-0.20	-0.19	-0.17	-0.15
Coal	MJ/mi	0.02	0.02	0.02	0.02
Non Fossil	MJ/mi	10.88	3.30	2.96	2.66
WTT	MJ/mi	7.24	0.00	0.00	0.00
TTW	MJ/mi	4.91	4.45	4.00	3.58
GHGs (weighted)					
WTT	g/mi	-298	-270	-243	-217
TTW	g/mi	358	325	294	264
TOTAL	g/mi	61	56	51	47
Criteria, Total					
VOC	g/mi	0.414	0.321	0.258	0.198
CO (/10)	g/mi	0.310	0.218	0.160	0.115
NO_x	g/mi	0.923	0.774	0.663	0.570
PM_{10} (x10)	g/mi	1.462	1.361	1.261	1.166
Criteria, Urban					
VOC	g/mi	0.307	0.225	0.171	0.120
CO (/10)	g/mi	0.268	0.179	0.125	0.084
NO_x	g/mi	0.236	0.151	0.103	0.068
PM_{10} (x10)	g/mi	0.444	0.438	0.431	0.422
Urban Toxics, (weighted)					
Benzene	g/mi	2.2E-02	1.5E-02	1.1E-02	6.8E-03
1-3 Butadiene	g/mi	2.6E-02	1.6E-02	1.0E-02	6.2E-03
Formaldehyde	g/mi	2.1E-03	1.3E-03	8.9E-04	5.4E-04
Acetaldehyde	g/mi	2.1E-04	1.3E-04	8.3E-05	4.8E-05
Diesel PM	g/mi	0.0E+00	0.0E+00	0.0E+00	0.0E+00

tLDA 5

Effect of Scenario Years: CNG Passenger Cars

Effect of Scenario Years : LDA Vehicle Class: Model Year Start 2010 (new)

	Year	2012	2017	2022	2030
	WTT Case ID	C1	C1	C1	C1
	Vehicle Type/Tech	CNG/ICEV	CNG/ICEV	CNG/ICEV	CNG/ICEV
Fossil	MJ/mi	4.96	4.45	4.18	3.93
Petroleum	MJ/mi	0.02	0.02	0.02	0.02
Natural Gas	MJ/mi	4.94	4.43	4.17	3.91
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.01	0.02	0.03	0.02
WTT	MJ/mi	0.51	0.45	0.41	0.39
TTW	MJ/mi	4.46	4.02	3.80	3.57
GHGs (weighted)					
WTT	g/mi	47	42	38	36
TTW	g/mi	266	240	228	215
TOTAL	g/mi	313	282	266	250
Criteria, Total					
VOC	g/mi	0.044	0.043	0.043	0.045
CO (/10)	g/mi	0.040	0.048	0.053	0.059
NO_x	g/mi	0.054	0.055	0.056	0.059
PM_{10} (x10)	g/mi	0.277	0.304	0.327	0.349
Criteria, Urban					
VOC	g/mi	0.014	0.016	0.018	0.022
CO (/10)	g/mi	0.036	0.044	0.050	0.056
NO_x	g/mi	0.029	0.034	0.037	0.041
PM_{10} (x10)	g/mi	0.248	0.280	0.305	0.328
Urban Toxics, (weighted)					
Benzene	g/mi	4.6E-06	0.0E+00	0.0E+00	0.0E+00
1-3 Butadiene	g/mi	1.9E-06	0.0E+00	0.0E+00	0.0E+00
Formaldehyde	g/mi	2.6E-04	2.4E-04	2.8E-04	3.3E-04
Acetaldehyde	g/mi	1.8E-05	2.0E-05	2.3E-05	2.8E-05
Diesel PM	g/mi	9.9E-05	0.0E+00	0.0E+00	0.0E+00

tLDA 3

Effect of Scenario Years: PHEV Passenger Cars

Effect of Scenario Years : LDA Vehicle Class: Model Year Start 2010 (new)

	Year	**2012**	**2017**	**2022**	**2030**
	WTT Case ID	e10	e10	e10	e10
	Vehicle Type/Tech	G PHEV/PHEV	G PHEV/PHEV	G PHEV/PHEV	G PHEV/PHEV
Fossil	MJ/mi	1.88	1.68	1.52	1.45
Petroleum	MJ/mi	0.60	0.58	0.56	0.55
Natural Gas	MJ/mi	1.28	1.11	0.96	0.90
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.20	-0.31	-0.21	-0.20
WTT	MJ/mi	1.15	0.49	0.46	0.43
TTW	MJ/mi	0.93	0.88	0.85	0.82
GHGs (weighted)					
WTT	g/mi	102	87	74	69
TTW	g/mi	148	134	127	119
TOTAL	g/mi	250	221	201	189
Criteria, Total					
VOC	g/mi	0.043	0.041	0.043	0.046
CO (/10)	g/mi	0.019	0.021	0.023	0.024
NO_x	g/mi	0.139	0.124	0.117	0.112
PM_{10} (x10)	g/mi	0.349	0.342	0.339	0.341
Criteria, Urban					
VOC	g/mi	0.020	0.022	0.025	0.029
CO (/10)	g/mi	0.014	0.017	0.019	0.021
NO_x	g/mi	0.014	0.014	0.015	0.016
PM_{10} (x10)	g/mi	0.251	0.257	0.261	0.268
Urban Toxics, (weighted)					
Benzene	g/mi	8.5E-04	9.8E-04	1.2E-03	1.5E-03
1-3 Butadiene	g/mi	9.6E-04	9.4E-04	1.1E-03	1.3E-03
Formaldehyde	g/mi	5.1E-04	3.6E-04	3.6E-04	3.6E-04
Acetaldehyde	g/mi	4.2E-05	1.4E-05	1.5E-05	1.6E-05
Diesel PM	g/mi	1.1E-02	0.0E+00	0.0E+00	0.0E+00

tLDA 2

Effect of Scenario Years: Diesel Buses

Effect of Scenario Years : UB Vehicle Class: All Model Years (blend)

Year		**2012**	**2017**	**2022**	**2030**
WTT Case ID		D1	D1	D1	D1
Vehicle Type/Tech		ULSD/ICEV	ULSD/ICEV	ULSD/ICEV	ULSD/ICEV
Fossil	MJ/mi	43.94	43.28	42.73	42.25
Petroleum	MJ/mi	40.05	39.46	38.97	38.54
Natural Gas	MJ/mi	3.89	3.82	3.75	3.71
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.05	0.05	0.05	0.05
WTT	MJ/mi	7.87	7.74	7.63	7.54
TTW	MJ/mi	36.12	35.59	35.15	34.76
GHGs (weighted)					
WTT	g/mi	623	613	603	597
TTW	g/mi	2704	2665	2632	2603
TOTAL	g/mi	3327	3278	3235	3200
Criteria, Total					
VOC	g/mi	1.202	1.141	1.078	0.973
CO (/10)	g/mi	0.427	0.387	0.358	0.294
NO_x	g/mi	20.935	18.982	17.425	14.262
PM_{10} (x10)	g/mi	4.898	4.534	4.270	3.835
Criteria, Urban					
VOC	g/mi	0.934	0.882	0.826	0.724
CO (/10)	g/mi	0.367	0.329	0.301	0.238
NO_x	g/mi	18.942	17.037	15.515	12.374
PM_{10} (x10)	g/mi	3.433	3.134	2.913	2.493
Urban Toxics, (weighted)					
Benzene	g/mi	7.8E-02	7.4E-02	6.8E-02	5.9E-02
1-3 Butadiene	g/mi	4.4E-02	4.1E-02	3.8E-02	3.3E-02
Formaldehyde	g/mi	1.2E-01	1.1E-01	1.0E-01	8.9E-02
Acetaldehyde	g/mi	2.7E-02	2.5E-02	2.3E-02	2.0E-02
Diesel PM	g/mi	1.6E+01	1.5E+01	1.4E+01	1.2E+01

tUB 1

Effect of Scenario Years: Natural Gas Derived FTD30 Buses

Effect of Scenario Years : UB Vehicle Class: All Model Years (blend)

	Year	2012	2017	2022	2030
	WTT Case ID	F31	F31	F31	F31
	Vehicle Type/Tech	FTD 30/ICEV	FTD 30/ICEV	FTD 30/ICEV	FTD 30/ICEV
Fossil	MJ/mi	49.28	48.27	47.39	46.87
Petroleum	MJ/mi	28.67	28.25	27.90	27.59
Natural Gas	MJ/mi	20.60	20.02	19.49	19.27
Coal	MJ/mi	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.04	0.04	0.04	0.04
WTT	MJ/mi	13.19	12.72	12.28	12.14
TTW	MJ/mi	36.12	35.59	35.15	34.76
GHGs (weighted)					
WTT	g/mi	786	765	644	636
TTW	g/mi	2665	2626	2594	2565
TOTAL	g/mi	3451	3391	3338	3301
Criteria, Total					
VOC	g/mi	1.021	0.970	0.920	0.840
CO (/10)	g/mi	0.373	0.338	0.314	0.260
NO_x	g/mi	20.137	18.271	16.783	13.776
PM_{10} (x10)	g/mi	4.532	4.199	3.957	3.556
Criteria, Urban					
VOC	g/mi	0.722	0.682	0.640	0.563
CO (/10)	g/mi	0.309	0.276	0.253	0.200
NO_x	g/mi	18.005	16.194	14.748	11.764
PM_{10} (x10)	g/mi	3.181	2.904	2.699	2.312
Urban Toxics, (weighted)					
Benzene	g/mi	5.9E-02	5.5E-02	5.1E-02	4.4E-02
1-3 Butadiene	g/mi	3.3E-02	3.1E-02	2.8E-02	2.4E-02
Formaldehyde	g/mi	8.9E-02	8.4E-02	7.8E-02	6.7E-02
Acetaldehyde	g/mi	2.0E-02	1.9E-02	1.7E-02	1.5E-02
Diesel PM	g/mi	1.5E+01	1.3E+01	1.3E+01	1.1E+01

tUB 2