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

STATE PLAN TO INCREASE THE USE OF NON-PETROLEUM TRANSPORTATION FUELS
AB 1007 (Pavley) Alternative Transportation Fuels Plan Proceeding

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NOTATION

Acronyms and Abbreviations

AB 1493	Assembly Bill 1493
AP-42	EPA document on emission factors
API	American Petroleum Institute
ARB	California Air Resources Board
atm	1 atmosphere = 14.7 psi
bbl	barrel of crude oil (42 gal)
Bcf	billion standard cubic feet
BD	biodiesel
bhp-hr	brake horsepower hour (dynamometer measurement)
bsfc	brake specific fuel consumption
BTL	biomass-to-liquid
Btu	British thermal unit = 1.055 kJ
bu	bushel
CA	California
CARBOB	California Reformulated Gasoline Blendstocks for Oxygenate Blending
CCCT	Combined Cycle Combustion Turbine
CCS	Carbon Capture and Sequestration
CEC	California Energy Commission
cH_2	compressed hydrogen[1]
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DME	dimethyl ether
DOE	United States Department of Energy
DWT	dead weight ton
E-10	Ethanol, 10 percent blended in gasoline
E-85	Ethanol, 85 percent blended in gasoline
E100	ethanol, 100 percent with no blending components
EER	Energy Economy Ratio
EIA	Energy Information Administration
EMA	Engine Manufacturers Association
EMFAC	Emissions Factors Model (ARB vehicle emissions factor model)
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator
EtOH	Ethanol
EUCAR	European Council for Automotive Research & Development
EV	electric vehicle

[1] The lower case c is used to prevent confusion with hydrocarbon radicals.

FCC	fluid catalytic cracker
FCV	Fuel Cell Vehicle
FE	Fuel economy
FFV	flexible fuel vehicle
FT	Fischer Tropsch
FTD	Fischer Tropsch diesel
g	gram
g/bhp-hr	grams per brake horsepower-hour
g/GJ	grams per giga joule
g/mi	grams per mile
g/Mj	grams per mega joule
gal	gallon = 3.7854 Liter
gal/yr	gallons per year
GHG	greenhouse gas
GREET	Greenhouse gases Regulated Emissions and Energy in Transportation Model
GRI	Gas Research Institute
GTL	gas-to-liquid
GVW	gross vehicle weight
GWh	gigaWatt hour = 1,000,000 kWh
GWP	global warming potential
H_2	hydrogen
HC	hydrocarbon
HEV	hybrid electric vehicle
HHV	higher heating value of fuel or feedstock
hp-hr	shaft horsepower hour
IC	internal combustion
ICEV	IC engine vehicle
IGCC	Integrated Gasification Combined Cycle
J	Joule
kg	kilogram
kJ	kilo Joule
kn	nautical mile, 2000 yards
kWh	kilo-Watt hour = 3.6 MJ = 3,412 Btu
lb	pound mass = 453.53 g
LEM	Life cycle Emissions Model
LEV	low emission vehicle
LH2	liquid hydrogen
LHV	lower heating value, HHV less heat of vaporization of water vapor in combustion products
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LUST	Leaking Underground Storage Tank
M100	methanol, 100 percent with no blending components
mi	mile
MJ	Mega Joule = 3.6 kWh
MMBtu	million Btu

MMscf	million scf
mpg	miles per gallon
MTBE	methyl tertiary butyl ether
MW	molecular weight
MWh	megaWatt hour
NERD	Non-esterified renewable diesel
NG	natural gas
NGV	natural gas vehicle
NMOG	non-methane organic gases
NO_x	oxides of nitrogen
NREL	National Renewable Energy Laboratory
NSPS	new source performance standards
O_3	ozone
OEM	original equipment manufacturer
ORVR	Onboard Refueling Vapor Recovery
PADD	Petroleum Administration Defense District
PAH	polycyclic aromatic hydrocarbons
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PM_{10}	particulate matter of ten micron diameter
psi	pressure, lb/in^2, 14.7 psi = 1 atm
RECLAIM	Regional Clean Air Incentive Market
RFG	reformulated gasoline
RFG3	reformulated gasoline, current California requirement
RNG	remote natural gas, produced outside North America
ROW	rest of world
RPS	renewable portfolio standard
RVP	Reid vapor pressure
SCAQMD	South Coast Air Quality Management District
SCCT	Simple Cycle Combustion Trubine
SCE	Southern California Edison
scf	standard cubic feet of gas, at 60°F and 1 atm
scfm	standard cubic feet per minute
SCR	selective catalytic reduction
SoCAB	South Coast Air Basin
SO_x	oxides of sulfur
SR	steam reformer
SRWC	short rotation woody crops
T&D	Transmission and Distribution
t/d	tons/day
TEOR	thermally enhanced oil recovery
THC	total hydrocarbons
TOG	total organic gases
ton	United States short ton, 2000 lb
tonne	Metric ton, 1000 kg
TTW	Tank-To-Wheels

TVP	true vapor pressure
UCD	University of California Davis
ULSD	ultra low sulfur diesel
U.S. EPA	United States Environmental Protection Agency
UG	underground
V_E	equilibrium vapor
VOC	volatile organic compounds
WTT	Wheel-To-Tank
WTW	Well-To-Wheels
ZEV	Zero Emission Vehicle

ABSTRACT

As mandated by Assembly Bill 1007, this study assesses the energy inputs, greenhouse gas emissions, criteria pollutant emissions, air toxics emissions, and multimedia impacts from the production and use of a variety of conventional and alternative fuels that are considered options for on-road vehicle and off-road equipment applications in California on a full fuel cycle basis through 2030 to determine their "net material" impact. Seventeen different vehicle/fuel combinations with more than 50 fuel production pathways are evaluated. Possible uses of the results of the analysis are identified. Criteria pollutant emission calculations are determined for vehicle operation and emissions within California. Total global greenhouse gas emissions are quantified. The results are presented in three separate volumes. The fuel cycle, or "well-to-tank," impacts evaluate feedstock production, processing, fuel production, and fuel delivery. Vehicle energy use, or "tank-to-wheels," emissions were analyzed separately. The fuel cycle and vehicle impacts were combined and results are reported on a "well-to-wheels" basis in this report. The approach to the full fuel cycle analysis and the key assumptions are discussed. Results are presented for well-to-wheels emissions for selected feedstock/fuel/vehicle cases. Emissions associated with the production or decommissioning of facilities or vehicles are not in the scope of this project. The executive summary highlights the findings of the three-volume set that present the assumptions, method, and results of the full fuel cycle analysis prepared to support the development of the alternative transportation fuels plan as directed by AB 1007.

KEY WORDS

Criteria Pollutants, Full Fuel Cycle, Greenhouse Gas, Multi-media Impacts, Tank-to-Wheels, Well-to-Tank, Well-to-Wheels

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EXECUTIVE SUMMARY

OVERVIEW

California's transportation energy demand is rising due to population growth, economic activity and increasing vehicle miles traveled. At the same time, traditional supplies of conventional transportation fuels are uncertain. In-state production of crude oil has declined by 60 percent over the last 10 years. California's import of crude oil from Alaska, a dominant domestic source, has also fallen. Increasing competition for crude oil internationally and price volatility limits California's import options of unrefined and refined petroleum products.

Assembly Bill 1007 (Pavley), Chapter 371, Statutes of 2005, responds to California's rising transportation energy demand and the uncertainties related to conventional petroleum products by requiring development of a plan for increased use of alternative, non-petroleum fuels by California's consumers through designated milestone years, 2012, 2017, 2022. The California Energy Commission (Energy Commission) and the California Air Resources Board (ARB) extended analysis for the State Alternative Fuels Plan (SAFP) to 2030 and 2050. The additional periods allow an assessment of alternative non-petroleum transportation fuels and technologies with longer development time frames.

The 2003 *Joint Agency Report on Reducing California's Petroleum Dependence*[2] identified alternative fuels as one of five options to meet California's future transportation energy demand and set important non-petroleum transportation fuel goals. By 2020, 20 percent of California's transportation energy use would come from alternative fuels. By 2030, the Joint Agency Report specified that 30 percent of the state's transportation fuel needs would be met by non-petroleum fuels. The Energy Commission's 2003 and 2005 *Integrated Energy Policy Reports* reaffirmed these goals.

For AB 1007, the Energy Commission and the ARB conducted a full fuel cycle assessment of the possible combination of more than 50 feasible non-petroleum fuel/vehicle technologies (Pathway). The full fuel cycle analysis examines feedstock production and processing, fuel production and delivery, and fuel use in vehicles. For fuel/vehicle pathway, the analysis assesses the energy inputs, greenhouse gas emissions, criteria pollutant emissions and multimedia impacts to determine their net material impact. The agencies identified the following possible uses of this analysis:

- Determining and understanding the emissions footprint and other multi-media impacts of alternative fuels/vehicles on a full fuel cycle basis.

[2] The Joint Agency Report on Reducing California's Petroleum Dependence was published by the California Energy Commission and the California Air Resources Board in August 2003, as directed by AB 2076 (Reducing California's Petroleum Dependence - Assembly Bill 2076, Shelley, Chapter 936, Statutes of 2000). The full report identified conservation, efficiency, non-petroleum fuels, land-use planning as measures to meet mismatched supply and demand in California through 2030.

- Determining whether there is a "net material increase in emissions" for a particular fuel/feedstock and vehicle technology combination. (For example, a slight increase in emissions occurred for some fuel/feedstock and vehicle technology combination pathways, namely, selected Midwest corn ethanol.) If an increase is identified, knowing where in the fuel production and use cycle the increase occurs – that is, the Well-To-Tank or Tank-To-Wheel portion. As applied in the SAFP, determining what remedies, research and development focus, and investments are required for the fuel/feedstock and vehicle technology combination to satisfy the AB 1007 "No Net Material Increase in Emissions" standard.

- As applied to the SAFP, the magnitude of change in emissions that advances other state policies such as the AB 32[3] Transportation Sector greenhouse gas reduction targets, on a full fuel cycle basis, as a function of the AB 1007 fuel use volumes in the milestone years.

- As a foundation for potential alternative compliance mechanisms in the low carbon fuels standard (LCFS) and AB 32 policy frameworks.

- As applied to the SAFP, the magnitude of the change in emissions that promotes achieving the low carbon fuels standard LCFS targets through 2020, and maintains the standard post 2020, as determined by the Average Fuel Carbon Intensity (AFCI), and as a function of the AB 1007 fuel use volumes in the milestone years (or other schedule).

- Identifying areas of future work where time, resource, and data availability constraints prevented this full fuel cycle assessment from capturing the breadth of issues such as agricultural impacts, displacement effects, and sustainability impacts related to the increased use of biofuels.

ASSESSMENT APPROACH

AB 1007 specifically requires the Energy Commission, in partnership with the ARB to “develop and adopt a state plan to increase the use of alternative transportation fuels” in California. It directs the Energy Commission to consult with the State Water Resources Control Board, Department of Food and Agriculture, and other relevant state agencies in developing an Alternative Fuels Plan. One requirement of AB 1007 is to assess emissions on a full fuel cycle basis. This report is the assessment of the full fuel cycle emissions for alternative fuels use as required by AB 1007.

[3] The AB 32 (Global Warming Solutions Act - Assembly Bill 32 (Nunez), Chapter 488, Statutes of 2006) directs the Air Resources Board to adopt measures to reduce 175 million metric tons of CO2 emissions from California activities by 2020. The state's transportation sector accounts for an estimated 43 percent of the reduction target.

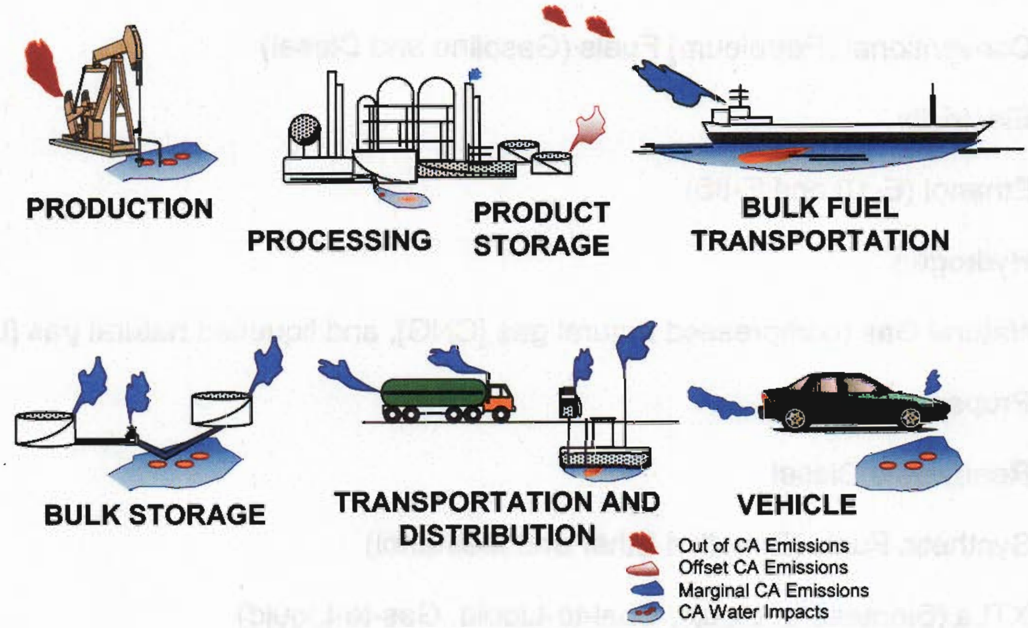
Full fuel cycle emissions from the production and use of 10 fuels were assessed:

1. Biodiesel
2. Conventional (Petroleum) Fuels (Gasoline and Diesel)
3. Electricity
4. Ethanol (E-10 and E-85)
5. Hydrogen
6. Natural Gas (compressed natural gas [CNG], and liquefied natural gas [LNG])
7. Propane
8. Renewable Diesel
9. Synthetic Fuels (Dimethyl Ether and Methanol)
10. XTLs (Biomass-to-Liquid, Coal-to-Liquid, Gas-to-Liquid)

The emissions were analyzed on a well-to-wheels (WTW) basis (Figure ES-1). WTW emissions are divided into two components: the fuel cycle, or well-to-tank (WTT) emissions and the vehicle cycle, or tank-to-wheels (TTW). The analysis is separated in this way because the tank to wheels emissions are already regulated and better known. WTT impacts include all emission events from fuel production to final transport and vehicle fueling. TTW impacts include vehicle exhaust and evaporative emissions. The WTT and TTW emissions and energy consumption for each fuel/feedstock combination are provided in two separate reports. The combined WTW results are presented here.

This report explains the WTW results. Energy inputs, emissions of greenhouse gases (GHG), criteria pollutants and air toxic contaminants, and multimedia impacts are provided. GHG emissions from the fuel cycle processes and vehicle operation include carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). All WTW emission results are provided on a gram per mile (g/mi) basis. Emissions associated with the production of materials for vehicles or facilities typically fall into the category of life cycle analysis, and are not covered in the full fuel cycle analysis presented in this report.

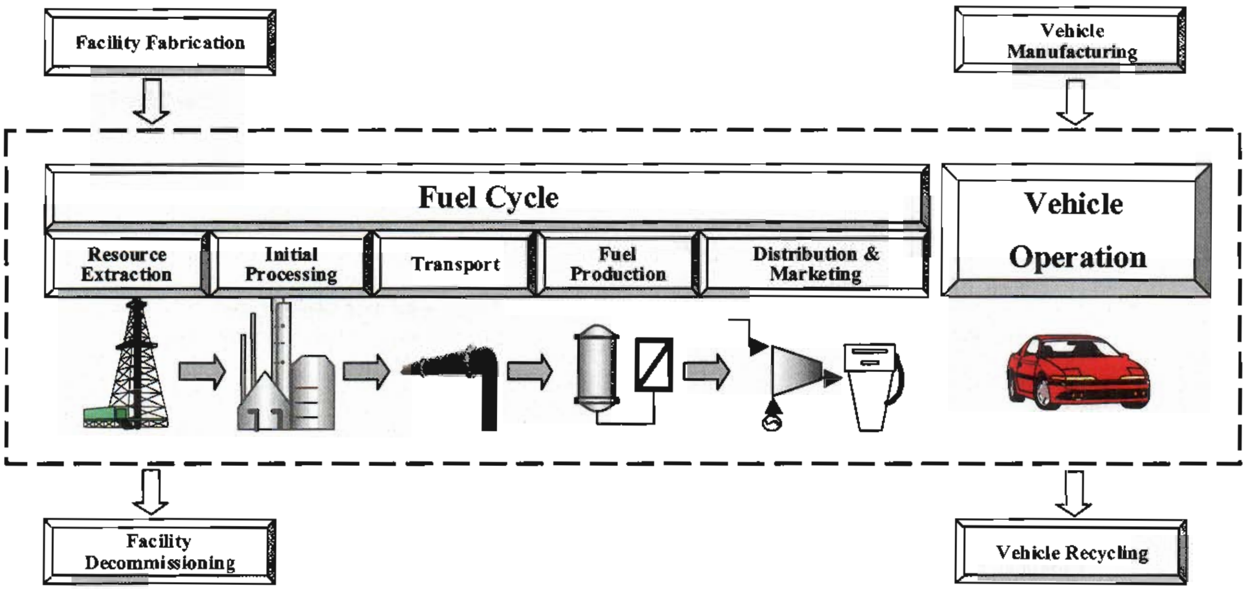
Figure ES-1. Emission Events Included in a Full Fuel Cycle Assessment



WTT emissions include those associated with feedstock production, fuel refining, transport, and local delivery (Figure ES-2). Overarching assumptions were made in two areas: geographic boundaries for emission quantification, and marginal fuel production. GHGs were quantified on a global basis while criteria and air toxic pollutant emissions were quantified both globally and within California (including California waters). The WTT analysis was completed using the latest version of the GHGs Regulated Emissions and Energy in Transportation (GREET) Model 1.7 as the platform. The primary parameters and key assumptions that affected the WTT analysis include:

- Natural gas/ renewable power electricity mixes for vehicle and fuel production applications in California.
- Transportation modes and distances that reflect transit to California and allow for separate accounting of emissions within California (assuming ozone non-attainment).
- Fuel production technologies and energy inputs that are consistent with the assessment scenario timeframe.
- Fuel delivery truck and agricultural equipment emissions declining as lower emitting engines are introduced.
- California emission control requirements and offset requirements for stationary equipment and fueling stations applicable in the state.

Figure ES-2. Total Vehicle Well-to-Wheels Energy Cycle



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

For the TTW portion of the fuel cycle, two separate calculation steps were performed. First, baseline and alternative fueled vehicle efficiencies were determined. Baseline vehicle fuel consumption was assumed to comply with AB1493[4] and these values on a fleet-wide basis for each analysis year and vehicle class were provided by ARB. Fuel consumption estimates for the alternative fueled mid-size vehicles are shown in Figure ES-3 and are consistent with the comparative performance of conventional and alternative fueled vehicles. Figure ES-4 shows the Energy Economy Ratio (EER) for alternative fueled urban buses as compared to the conventional fueled urban bus. The TTW report provides the exact energy consumption ratios used for each alternative fuel vehicle.

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

[4] AB 1493 Vehicular Emissions: Greenhouse Gases – (Assembly Bill 1493 (Pavley), Chapter 200, Statutes of 2002) directs the Air Resources Board to begin regulating carbon dioxide emissions from passenger vehicles.

Figure ES-3. Summary of Light-Duty Vehicle Fuel Economy

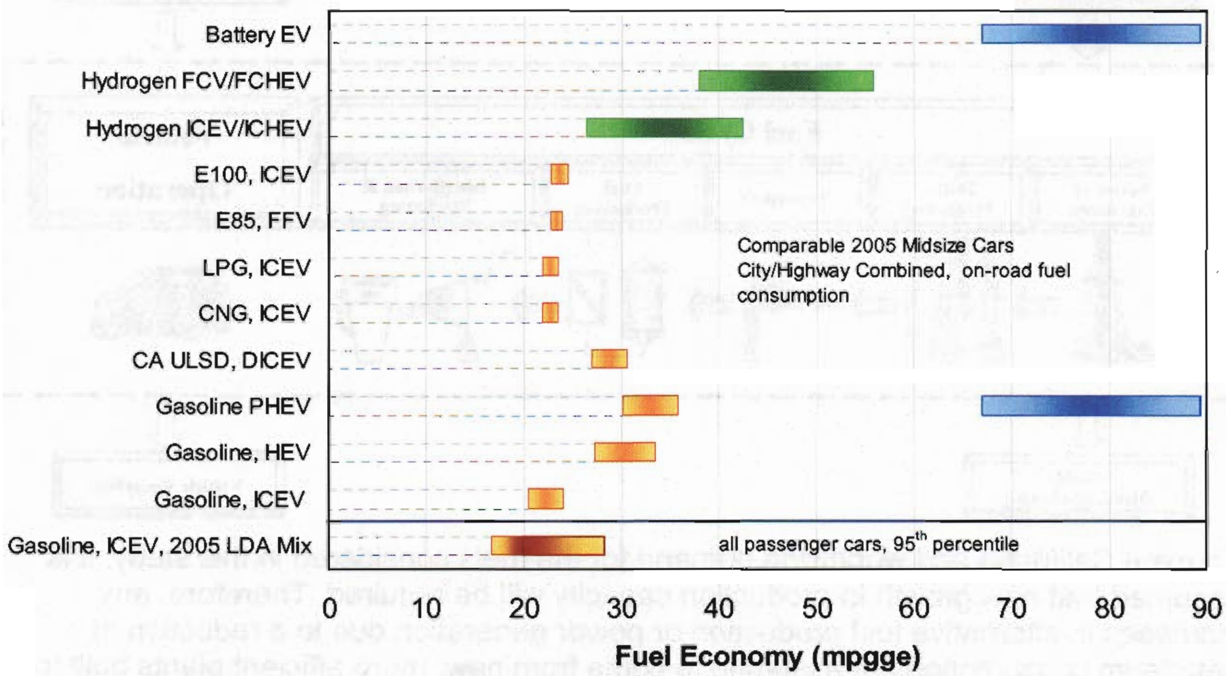
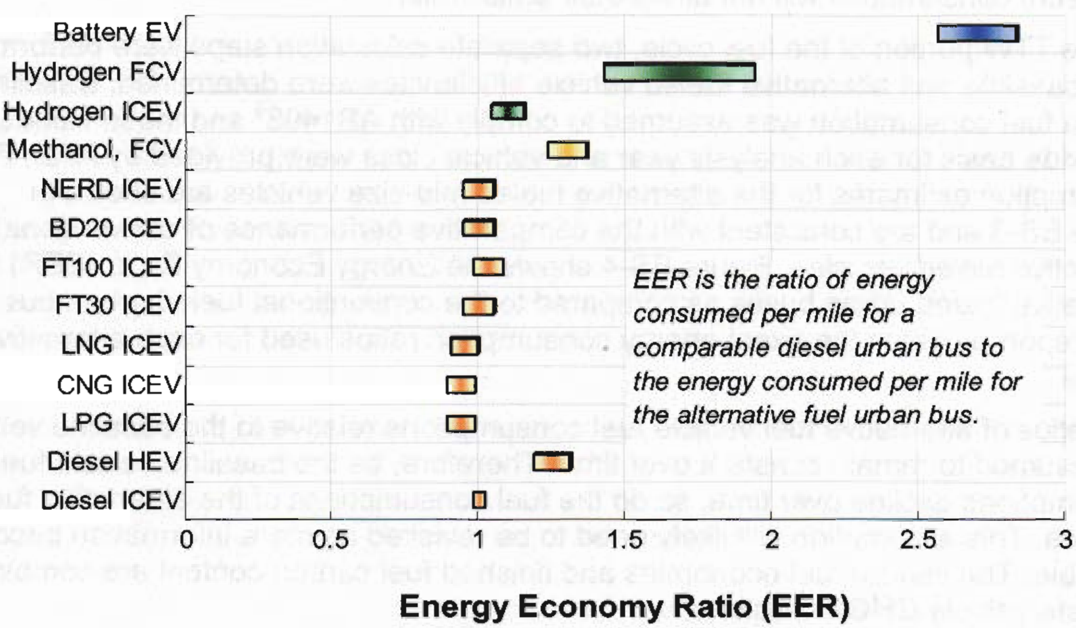


Figure ES-4. Summary of Urban Bus EERs Utilized in TTW Analysis



The second TTW calculation step is estimation of criteria pollutant and air toxic contaminant emissions. The ARB's Emission Factors (EMFAC) 2007 model was used to determine vehicle criteria and air toxic pollutant emissions for conventional gasoline and diesel vehicles for different scenario years on a g/mi basis. These results reflect the impact of vehicle retirement and mileage assumptions for the entire California vehicle fleet.

Two different sets of criteria and toxic pollutant emission factors for each scenario year were assembled. The first set is referred to as "new vehicle stock" and includes only model year 2010 and newer vehicles. This set of data was used to evaluate alternative fuels that require new vehicle technologies to be deployed. The second set of data, referred to as "existing vehicle stock" includes all model years in the California motor vehicle inventory and is used for fuel blend strategies, since blends can be used by the entire fleet as they are introduced at the fueling station. The key difference between the new technology strategy and the blend strategy is that an extended period of time is required for the new technology vehicles to roll into the inventory, and then only a fraction of the fleet will correspond to this technology. With blend strategies, essentially all vehicles in the inventory are affected as soon as the blend is available.

The criteria pollutant emissions for the base case vehicles decline significantly over the scenario years evaluated (2012, 2017, 2022, and 2030). An interesting artifact of the "new vehicle stock" methodology is that the pool of vehicles in 2012 is two-years old and newer while the pool of vehicles in 2030 is up to 20 years old. The 10 micron size of particulate matter (PM_{10}) deterioration rates in the ARB EMFAC model have the effect of increasing the "new vehicle stock" PM_{10} emission factor significantly from 2012 to 2030.

An overriding assumption in determining the criteria pollutant emissions for the alternative fuels was that blend fuels must meet petroleum fuel emission standards for NO_x; hydrocarbons (HC), with a carbon monoxide (CO) credit; and weighted air toxics emissions as determined by ARB's Predictive Model. Further, alternative fuel vehicles (namely, liquefied petroleum gas [LPG] and compressed natural gas [CNG]) must meet prevailing fuel-specific California emission standards. While an extensive review of the criteria emissions reduction potential of each alternative fuel vehicle type was not performed, the effect of alternative fuels on criteria pollutant emissions was estimated from published adjustment factors. The adjustment factors are applied to the baseline EMFAC values. Please refer to the TTW volume of the report for specific adjustment factors for each alternative fuel.

WELL-TO-WHEELS SELECTED RESULTS

GHG Emissions

The WTW GHG emissions for selected feedstock/fuel/vehicle combinations are presented in this section. Five key conclusions can be made regarding GHG emissions from the full fuel cycle assessment of transportation fuels:

- GHG emissions from fossil fuels depend on both the carbon content of the fuel and process energy inputs. In all cases except hydrogen and electricity, the vehicle GHG emissions dominate WTW emissions.
- The effect of alternative fuel use in off-road equipment with internal combustion (IC) engines on GHG emissions is comparable to the effect for on road vehicles.
- A wide range of GHG emission reductions 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.
- Electricity pathways are highly dependent upon generation mix assumptions. An electric generation mix based on natural gas combined cycle power plants combined with California's Renewable Portfolio Standard (RPS) constraint is the most likely future marginal generation mix. The figures indicate that coal fired IGCC plants utilized carbon capture and sequestration (CCS) also provide low WTW GHG emissions. It is important to note that some generation technologies, such as CCS, that apply to coal power plants are emerging (may not be operational by 2012) and could also be applied to the natural gas fired generators resulting in significantly lower GHG emissions. The use of renewable power also allows for the mitigation of GHG emissions.
- GHG emissions from biofuels production and use depend on agricultural inputs, allocation to byproducts, and the level and carbon intensity of process energy inputs.

Figures ES-5 and ES-6 provide midsize passenger car results for 2012 and 2022, respectively. Corresponding results for urban buses are shown in Figures ES-7 and ES-8. Many other combinations of results are discussed later in this report.

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

The issue of deforestation also 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.

Figure ES-5. 2012 GHG Emissions for Spark Ignited Passenger Car Options (new stock)

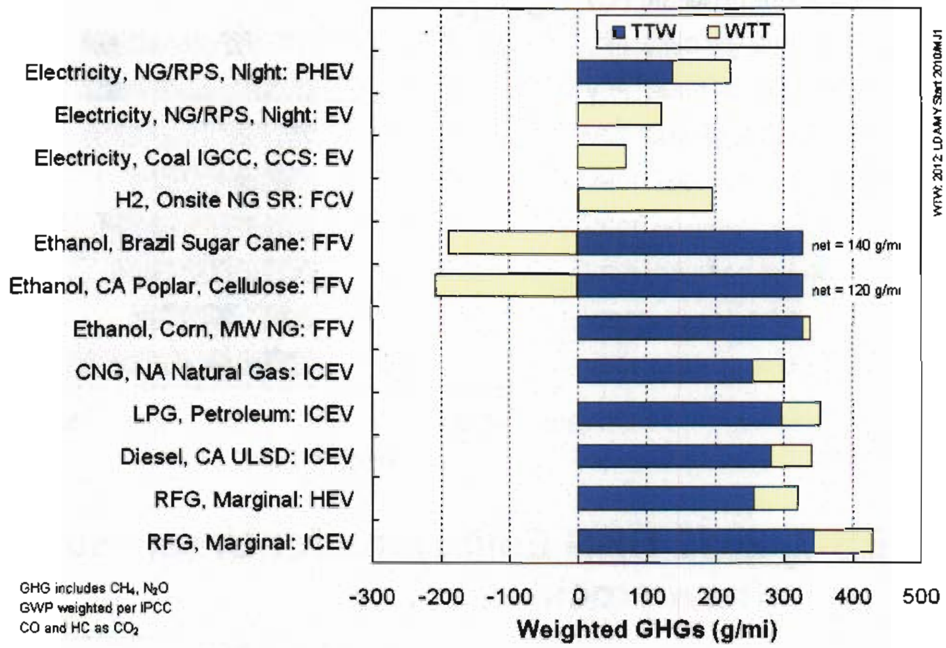


Figure ES-6. 2022 GHG Emissions for Spark Ignited Passenger Car Options (new stock)

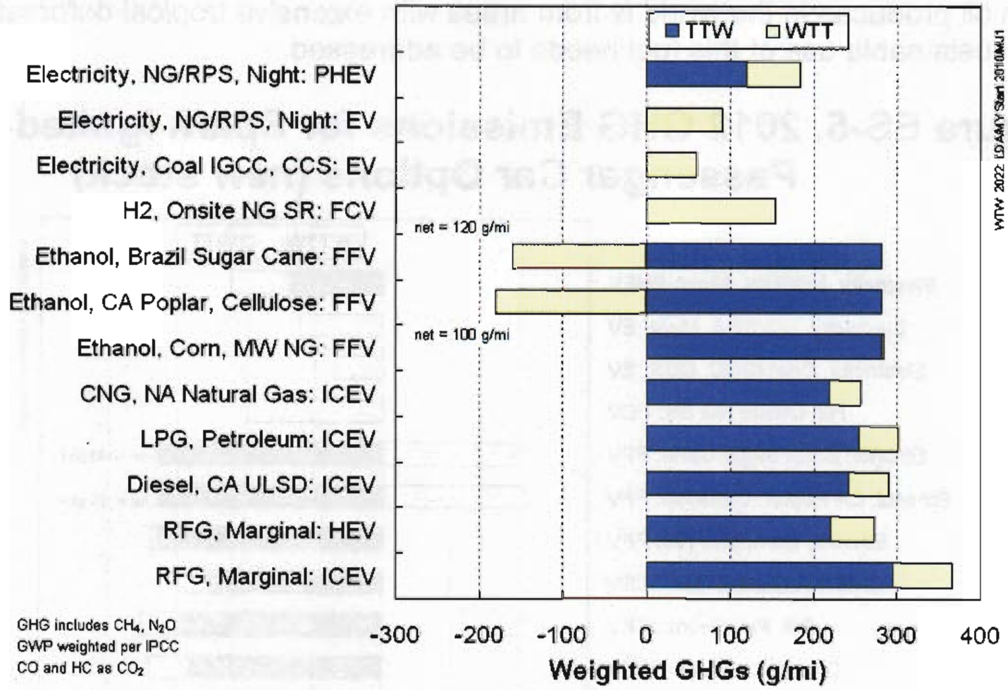


Figure ES-7. 2012 GHG Emissions for Urban Bus Options (new stock)

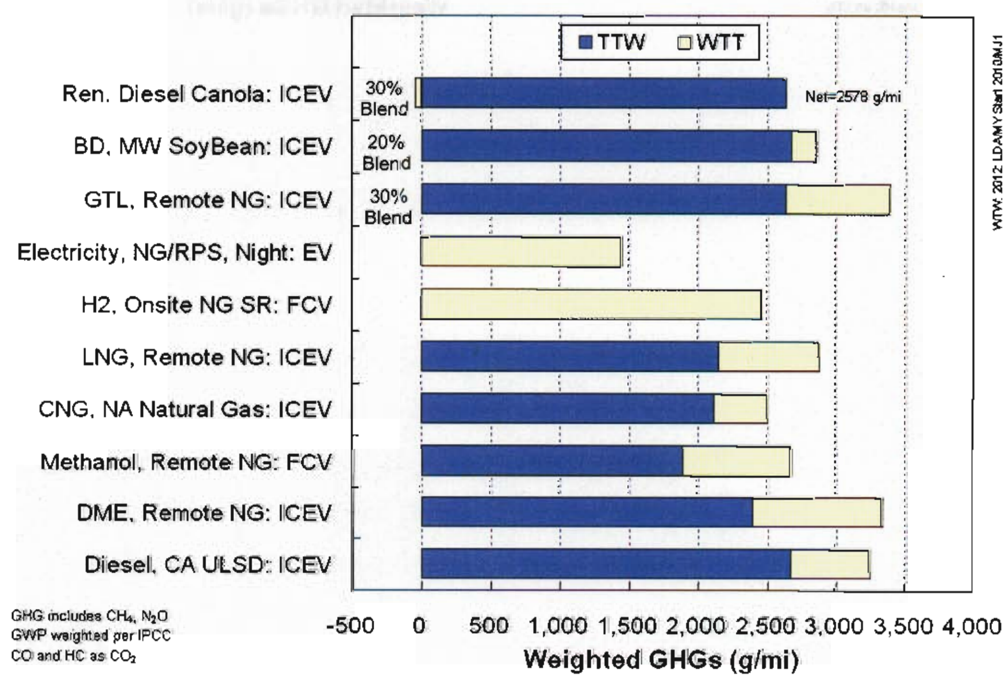
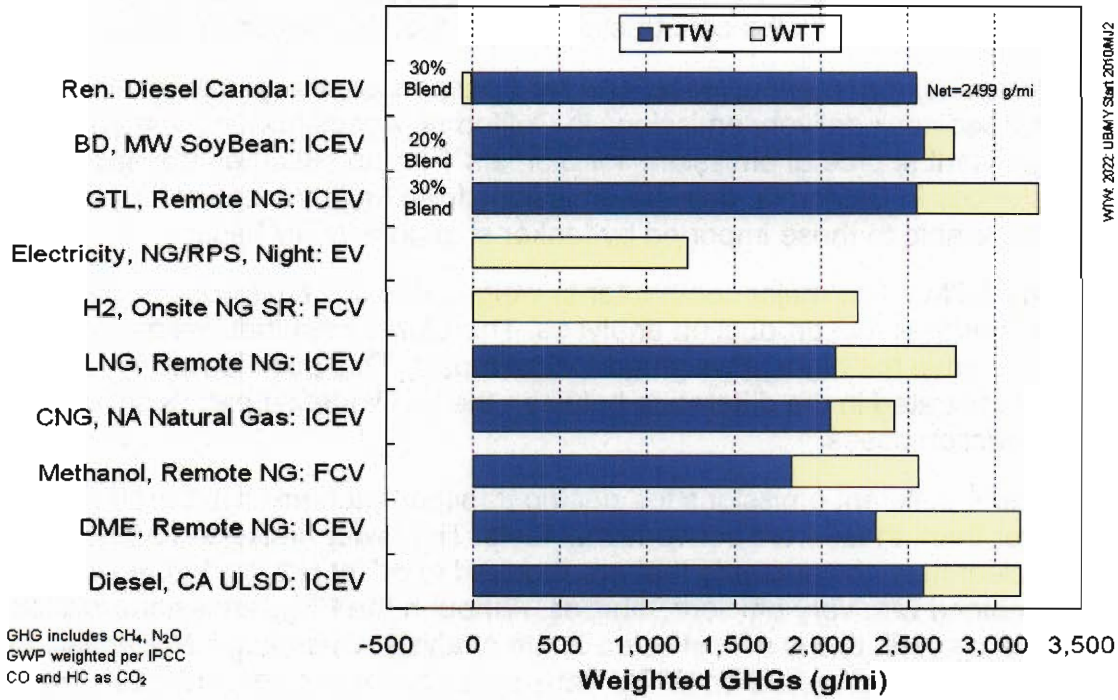


Figure ES-8. 2022 GHG Emissions for Urban Bus Options (new stock)



Criteria Pollutant and Air Toxics Emissions

The WTW analysis takes into account vehicle and fuel production emissions consistent with vehicle operation in California.

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

- California places stringent requirements on vehicle emissions and fuels properties. ARB requires that changes in fuel blends result in no increase in emissions. Therefore, the primary change in criteria pollutant emissions is expected to occur in the WTT portion of the fuel cycle.
- Some fuel blends such as biodiesel and Fischer Tropsch (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. It is not clear whether the new engines will be optimized to reduce emissions below standards or for fuel economy.
- 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 local emission standards or regulations. In general criteria pollutant emissions in California tend to decrease for fuels that are produced in the state. However, emissions outside of California are generally greater for imported fuels. Fuel production facilities outside of California are assumed to comply with the prevailing environmental regulations where such facilities are located.

- Emissions of NO_x, volatile organic compounds (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. 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. This point is clearly demonstrated in the difference between the two liquefied petroleum gas (LPG) production cases.

- Criteria pollutant emissions for electric transportation are comparable to, or lower than, those from conventional fuels. The lower emission levels result from efficient new power plants that are required to offset NO_x and VOC emissions combined with very efficient vehicles. Although the PM_{10} emissions will likely be offset as well, this is not reflected in the analysis. Offsetting PM_{10} emissions will have a minimal impact on WTW PM_{10} emissions since tire and brake emissions are much larger than WTT emissions. Emissions associated with the average statewide generation mix are higher than the marginal mix, but are still below the baseline vehicle.

- 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 Carbon Monoxide (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 polycyclic aromatic hydrocarbons (PAH) 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.

Figures ES-9 and ES-10 provide estimated WTW criteria pollutant emissions for selected light duty vehicle cases for 2012 and 2022, respectively. Figures ES-11 and ES-12 provide the corresponding urban bus results for criteria pollutant emissions.

Figure ES-9. 2012 WTW Criteria Pollutant Emissions from Passenger Cars (new stock)

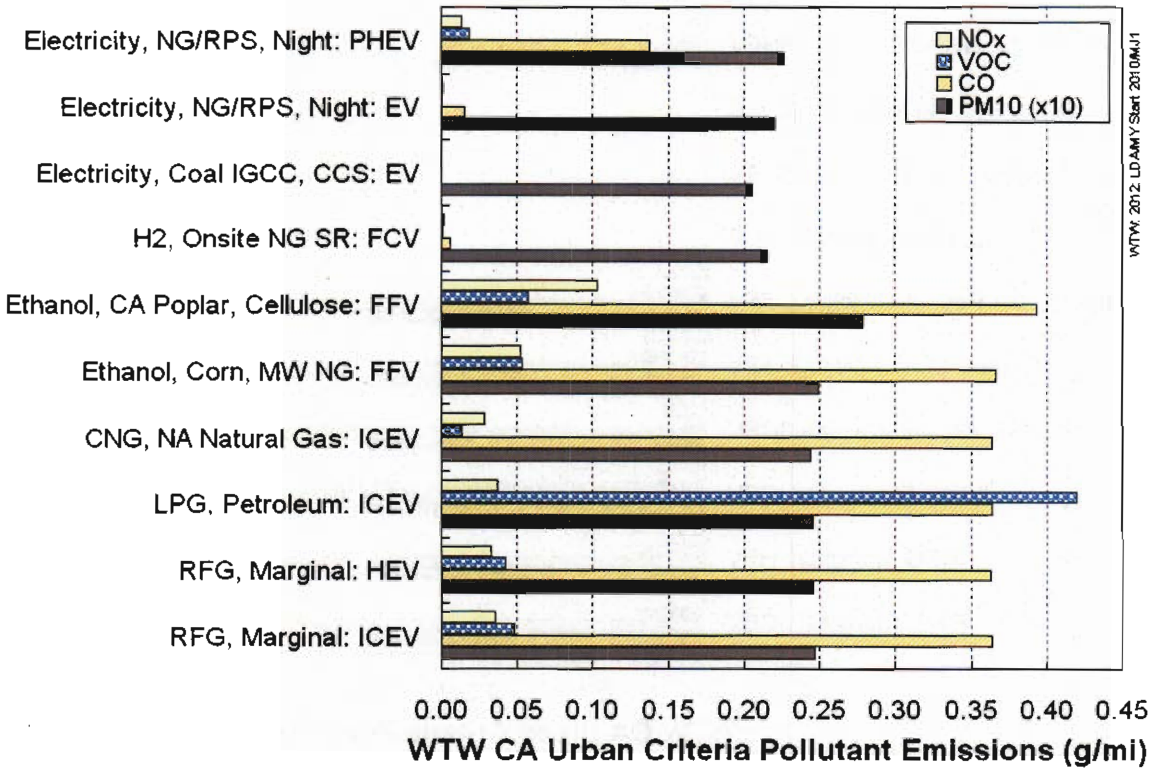


Figure ES-10. 2022 WTW Criteria Pollutant Emissions from Passenger Cars (new stock)

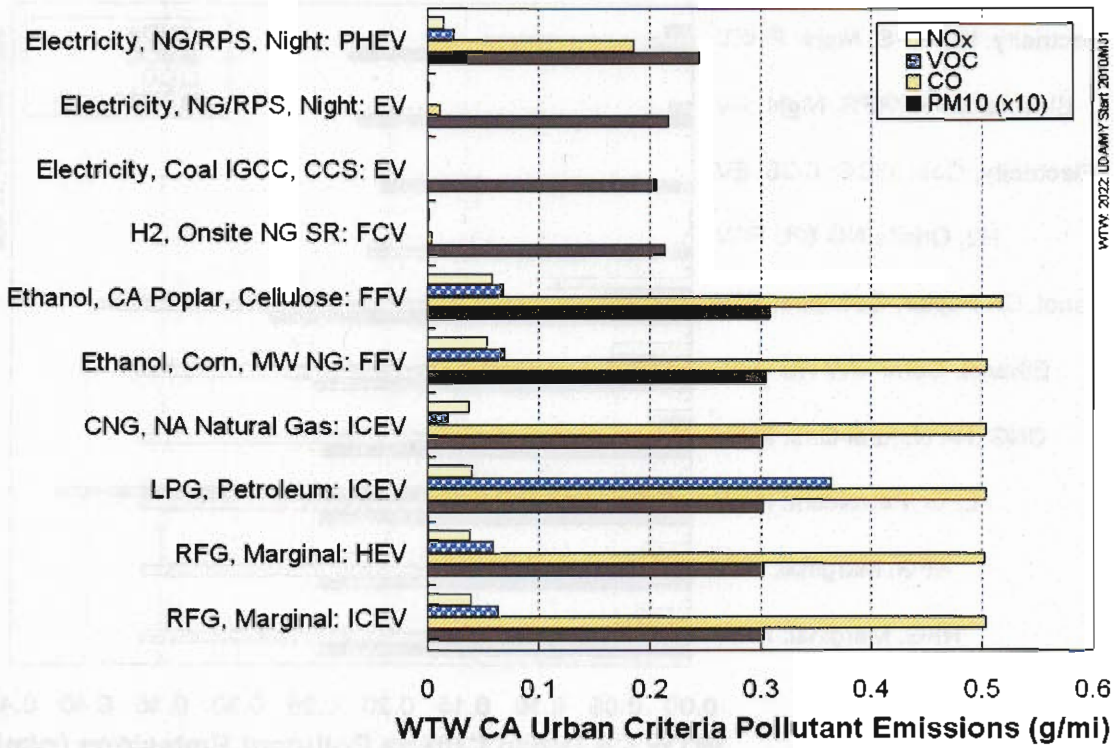


Figure ES-11. 2012 WTW Criteria Pollutant Emissions from Urban Buses (new stock)

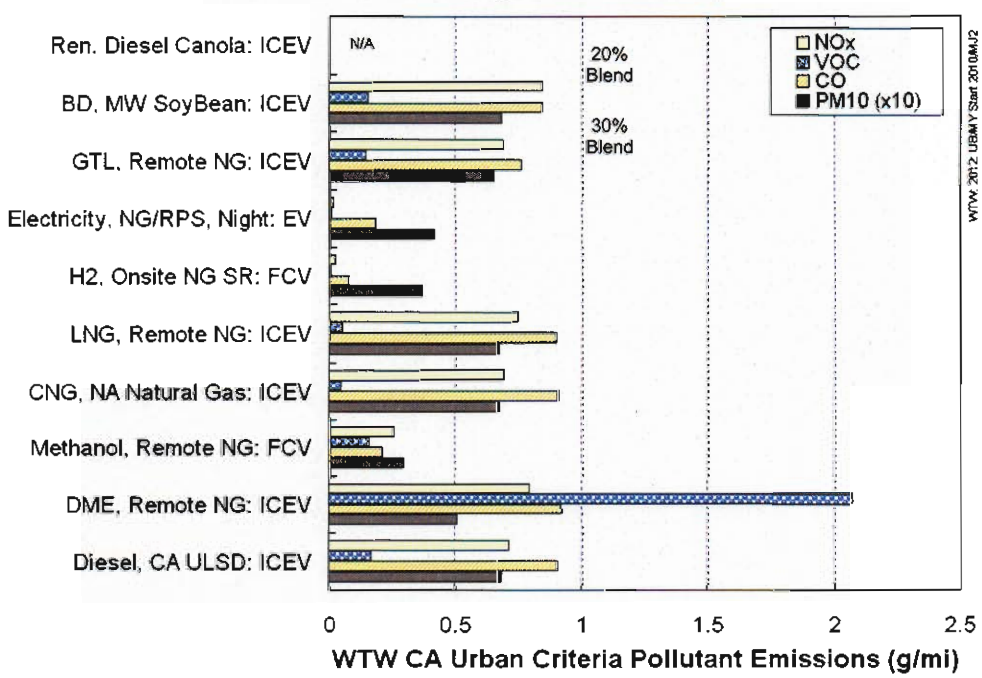
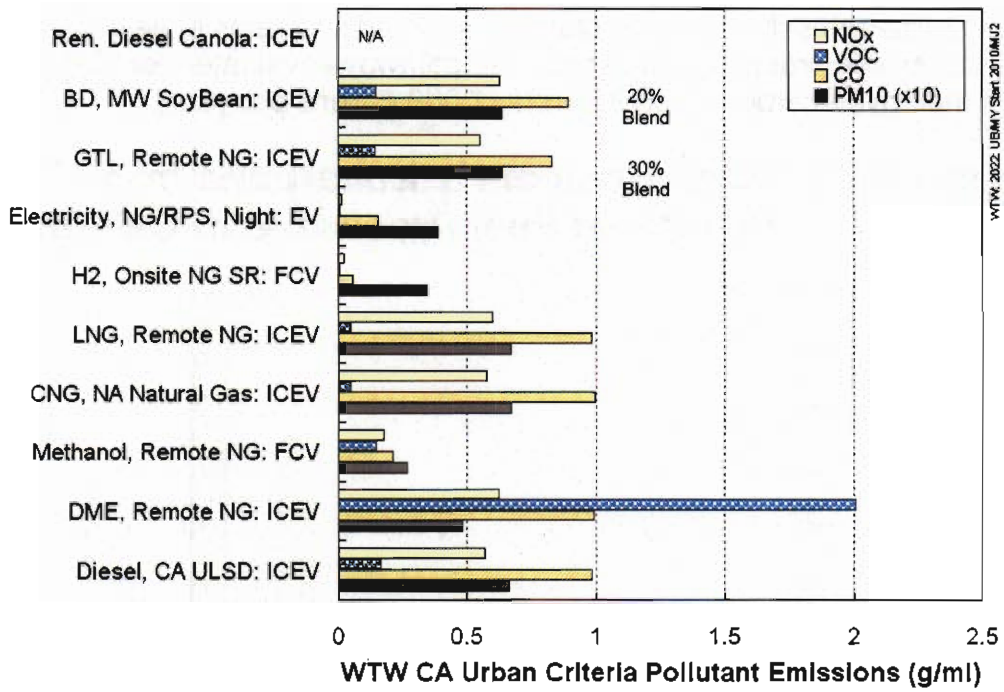


Figure ES-12. 2022 WTW Criteria Pollutant Emissions from Urban Buses (new stock)



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

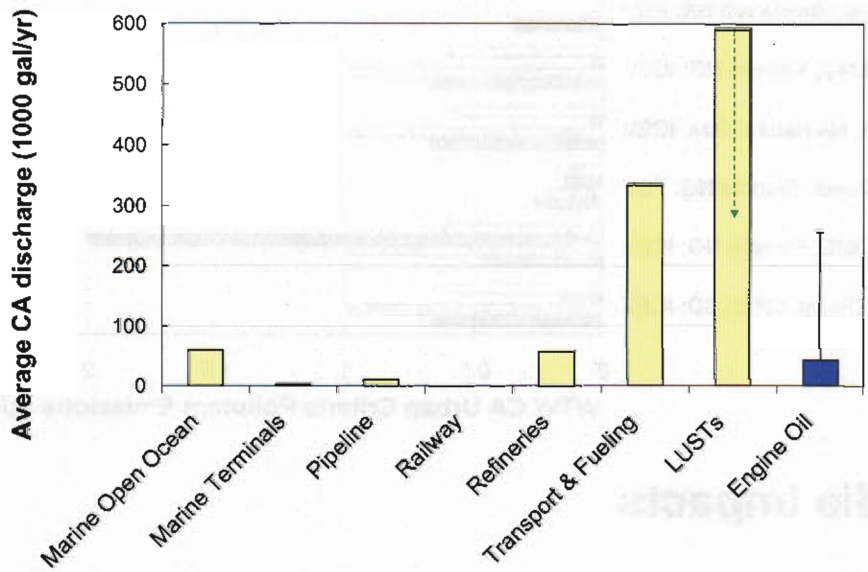
The following multimedia impact conclusions are based on the analyses in this study:

- 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.

Figure ES-13 illustrates the relative potential multimedia impacts of several of the transport, production process, and vehicle use pathways evaluated for petroleum fuels in terms of their hydrocarbon discharge rate (1,000 gallons per year).

Figure ES-13. Discharges of Hydrocarbons from Petroleum Fuel Processes in California



FINDINGS AND RECOMMENDATIONS

The results of this full fuel cycle assessment using the GREET Model 1.7 modified for California can be used to satisfy the requirements of AB 1007. The analysis and the results and key findings summarized below, adequately serve the purposes and possible uses identified, and satisfy the requirements of AB 1007 in developing the state plan to increase the use of alternative non-petroleum transportation fuels.

Findings

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

- Depending on fuel pathway alternative fuels like ethanol, natural gas, LPG, electricity and hydrogen can provide significant reductions in well to wheels GHG emissions when used in midsize autos.
    - Biofuels provide large reductions (~75 percent compared to gasoline) depending on processing intensity because CO_2 emissions are recycled through plant photosynthesis.
    - Low carbon containing fuels like natural gas and LPG also reduce GHG emissions (20 to 30 percent compared to gasoline).
    - Zero carbon fuels and power production options also substantially reduce GHG emissions depending on the specific fuel or power production technology and associated pathways.
    - Hydrogen produced from natural gas using steam reforming provides a 54 percent reduction in GHG emissions in a hydrogen fuel cell vehicle (compared to gasoline).
    - Electricity use reduces GHG emissions compared to gasoline by 68 percent in electric vehicle's (EV) and 44 percent in plug-in hybrid electric vehicle's (plug-in hybrid electric vehicle [PHEV]).
- For urban buses (heavy duty vehicles) many of the fuels provide a GHG benefit, but not as significant a benefit as for light duty vehicles.
    - Electric buses provide the most significant benefit at 55 percent reduction followed by hydrogen fuel cells and CNG at 23-24 percent reduction.
    - A 30 percent renewable diesel blend yields approximately 20 percent reduction while a 20 percent biodiesel blend provides approximately 12 percent reduction.
    - Methanol provides an estimated 18 percent reduction.
    - Dimethyl Ether (DME) and a 30 percent blend of gas-to-liquid (GTL30) (remote natural gas as feedstock) increase GHG emissions. However, utilizing a biomass feedstock provides a 28 percent reduction for the GTL30 and a 94 percent reduction for biomass based DME.

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

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

Recommendations

Based on the information developed in this study, the following recommendations are made to support the requirements of AB1007 and further improve future full fuel cycle analyses.

1. The GREET model served as a suitable tool for assessing the transportation logistics for conventional and alternative fuels production and distribution pathways in California. The model approach should be maintained to accommodate revised analyses and more transparent input assumptions.
2. The analysis in this study provides information to assess the emission impacts of different fuel production pathways. The emissions within and outside of California, as well as the location of marine vessel emissions should be taken into account when assessing the impacts of criteria pollutant and toxics emissions.
3. 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 outcomes for criteria pollutants. The assumptions on emission boundaries should always be identified.
4. Changes in agricultural land use have a dominant impact on the evaluation of biofuel pathways. 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. Prevention of tropical deforestation associated with fuel production needs to be incorporated into efforts to promote alternative fuel use, as a key measure to use non-petroleum fuels sustainably.

CHAPTER 1 INTRODUCTION

The 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[5] 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, AB 1007 requires the Energy Commission to "develop and adopt a state plan to increase the use of alternative transportation fuels" in California. It directs the Energy 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[6].

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 assessment (FFCA) for a variety of alternative transportation fuels. This analysis is one of several ongoing 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 FFCA 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.

FFCA 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

[5] The AB 1007 (Pavley), Chapter 371, Statutes of 2005) directs the Energy Commission to develop a state plan to increase the use of alternative fuels.

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

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 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 alternative fuel operation are included. GHG emissions from the fuel cycle processes and vehicles include CO_2, nitrous oxide (N_2O), and methane (CH_4). WTW emissions on a grams per mile 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 quantification 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:

Full Fuel Cycle Analysis. This section describes the analysis approach and identifies the information sources utilized 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.

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.

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 2012 full fuel cycle analyses to the out years of 2017, 2022, and 2030 are outlined.

Conclusions. This section summarizes key conclusions of the analyses.

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	California emissions evaluated for Southern California Air Basin (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 California emission analysis for near ZEV candidates. Dispatch modeling of power generation for EV charging.
AB 2076 – 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 California instead of SoCAB.
GM/ANL, 2001, 2003, 2005	General Motors (GM)/Argonne National Laboratory (ANL) modeling of comparable vehicles. GREET model for fuel cycle. Average criteria pollutants.
UCD/LEM, 1997-2005	University of California Davis (UCD)/Life cycle Emission Model (LEM) extensive analysis of all fuel pathways, biofuels land use.
EUCAR, 2005	European Council for Automotive Research & Development (EUCAR) analysis. Extensive evaluation of biofuels.

CHAPTER 2 FULL FUEL CYCLE ANALYSIS

This report presents the results of a full fuel cycle assessment (FFCA) of 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 boundaries of the FFCA, 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 included here.

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 represents 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. The term "fuel cycle" is sometimes used for WTT.

TTW – Fuel consumption and emissions from vehicle refueling, evaporation, and operation expressed on a per mile basis. The term "vehicle cycle" is sometimes used for TTW.

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 dependent on assumptions made, particularly in the WTT portion of the analysis. Therefore, researchers made an effort 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 summarize the approaches used for the WTT and TTW analyses.

Figure 2-1. Total Vehicle Energy Cycle

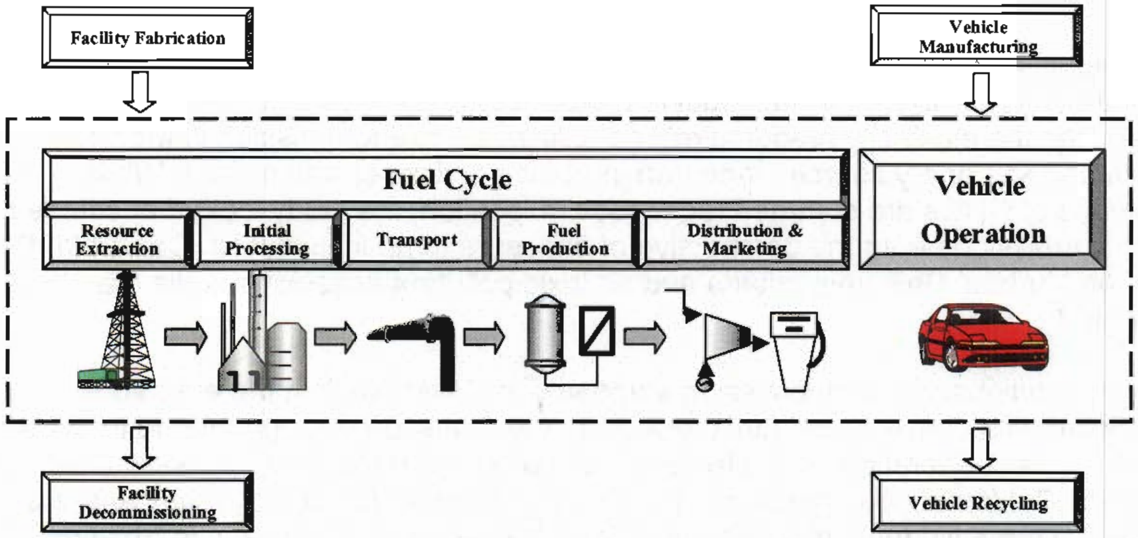


Table 2-1. Effect of Study Parameters on Fuel Cycle Results

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.

Well-to-Tank Analysis Approach

Researchers performed the WTT analysis using the latest version of the GREET1.7, an Excel spreadsheet-based model, as the platform. Many emission factors and transport modes and distances were modified to reflect alternative fuel use in California. These modifications became what is referred to as the modified California GREET model. 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.

Geographic Boundary Assumptions

Geographic location of each pollutant emission event from feedstock extraction to final distribution was tracked for each fuel/feedstock combination. Location of each step determines the electricity resource mix as well as prevailing emission standards for mobile and stationary sources, and transportation distances and modes. While emissions of GHGs are summed regardless of location, the study looked at criteria and air toxic emissions from the perspective of exposure to an individual in California. Both 'total' and 'urban' California criteria and air toxic pollutant emission results are presented[7].

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. Because a significant portion of California does not attain the ambient standard for ozone, it was assumed that new alternative fuel production facilities will be located in ozone non-attainment areas. This assumption requires that combustion equipment installed at these facilities utilize Best Available Control Technology (BACT) and offset their emissions of NO_x and VOC. Therefore, new California combustion equipment NO_x and VOC emissions were set to 0. For operations outside of California, the default GREET emission factors and fuel mixes were utilized with only a few exceptions.

In addition to emissions from fuel production, emissions for fuel or feedstock transportation and distribution were also divided into the geographic 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.

Marginal Emissions

For this analysis, production capacity in California and many other regions involved in the logistics of fuel supply is 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 WTT 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 increases will not be

[7] The GREET model defines 'total emissions' as emissions occurring in all locations covering the well-to-tank and tank-to-wheel stages. 'Urban emissions' are emissions occurring in urban area-metropolitan areas defined in the Energy Policy Act of 1992."

sufficient to meet the increased demand 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 Renewables 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 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 Renewables Portfolio Standard goals.
- Emissions from new stationary sources are consistent with local permitting equipment including BACT for criteria pollutants and NO_x/VOC offsets.
- Emissions from fuel transport vehicles are consistent with ARB requirements.
- Marginal natural gas supplies originate from outside California.
- Displacement and changes in land use for agriculture are complex and evolving issues and will be addressed separately from the present analysis.

Fuel and Feedstock Analysis Matrix

The finished fuel and feedstock combinations considered in the WTT analysis are shown in Tables 2-2 and 2-3. 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 2-2 and 2-3. 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 2-2. Finished Liquid Fuels and Feedstocks Considered

Fuel	Feedstock	Production Location	Existing Pathway	New Application	New Technology
CARBOB/ E5.7	Crude Oil, SE Asia	Singapore	X		
	Heavy Crude Oil	Venezuela	X		
	Tar Sands	Canada	X		
CA RFG0	Crude Oil, SE Asia	Singapore		X	
CA RFG - E-10	Crude Oil, SE Asia	Singapore		X	
Diesel, ULSD (10 ppm S)	Crude Oil, SE Asia	Singapore	X		
LPG	Crude Oil	California	X		
	Natural Gas	Arizona	X		
CNG	Natural Gas	Texas, Canada	X		
	LNG	Indonesia	X		
LNG	Natural Gas	Indonesia	X		
	Pipeline NG	CA	X		
Methanol	Natural Gas	Indonesia	X		
	Biomass (Poplar)	California		X	
	Coal	Wyoming	X		
DME	Natural Gas	Indonesia	X		
	Biomass (Poplar)	CA		X	
	Coal	Wyoming	X		
XTL	Natural Gas	Malaysia	X		
	Biomass (Poplar)	CA		X	
	Coal	Wyoming	X		
Biodiesel (esterified)	Palm Oil	Malaysia	X		
	Soy Bean Oil	Midwest	X		
Renewable Diesel (non-esterified)	Palm Oil	Malaysia	X		
	Canola	CA	X		
E-Diesel	Corn, Midwest	Midwest	X		
Ethanol, E-85	Corn, Midwest	Midwest	X		
	Corn, Midwest	CA	X		
	Sugar Cane	CA, Brazil	X		
	Poplar	CA			X
	Switch Grass	CA			X
	Forest Residue	CA			X

Table 2-3. 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

Tank-to-Wheels Analysis Approach

For the TTW analysis, emissions from on-road and off-road 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 using blended fuels were compared to the California mix of vehicles (existing stock - all model years on the road in a given calendar year), while new alternative fuel vehicle technologies were compared to a new vehicle using the base case petroleum fuel (new vehicle stock – model years 2010 and newer on the road for a given calendar year).

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.

Vehicle Fuel Economy Assumptions

Vehicle and equipment fuel economies were used to convert the TTW emissions per unit energy in the finished fuel into a vehicle grams per mile basis so it can be added to the grams per 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 using 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 used. 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 grams per mile basis and a grams per gallon of finished fuel basis for a wide range of vehicle applications. Figure 2-2 provides a summary of the fuel economies assumed for each of the light duty vehicle options. Table 2-4 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. Summary of Light-Duty Vehicle Fuel Economies Used in TTW Analysis

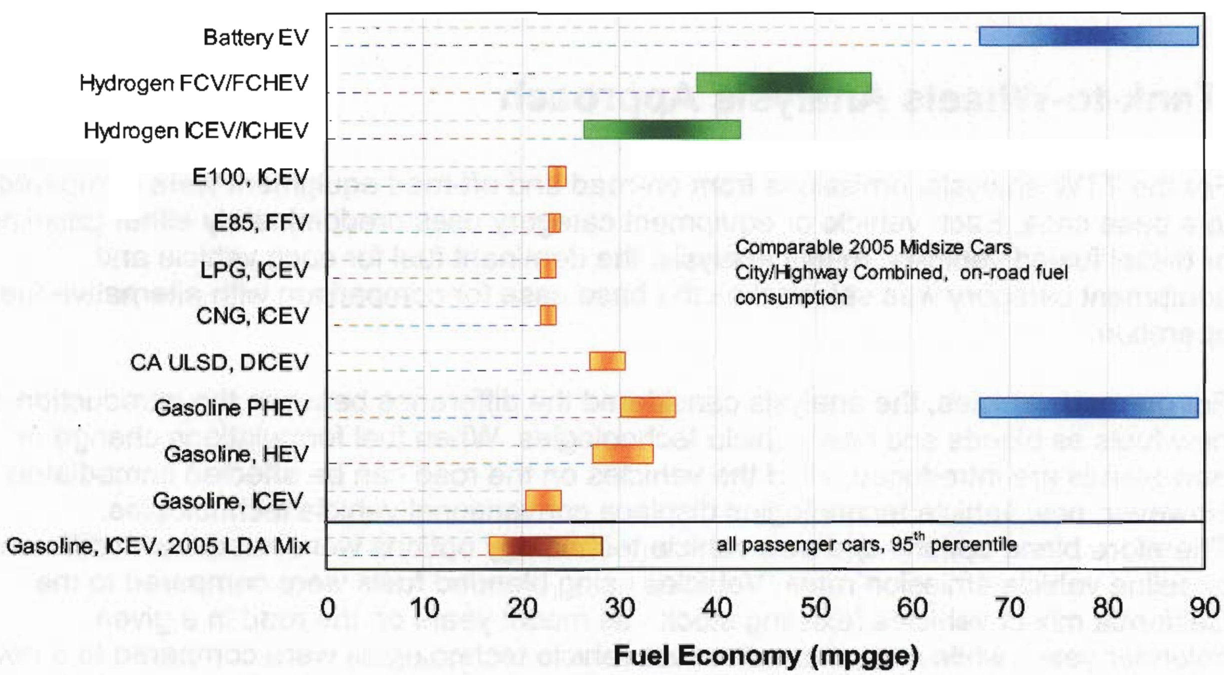


Table 2-4. Baseline Vehicles for Estimating Alternative Fueled Vehicle Emissions

Fuels	Midsize Light-Duty Vehicles			Urban Buses	
	New	Blend Displacing Gasoline	Blend Displacing Diesel	New	Blend Displacing Diesel
RFG — E-0	—	A		—	—
RFG — E-5.7	**N (CAT)**	**A (CAT+NCAT)**	—	—	—
RFG — E-5.7, HEV	N	—	—	—	—
RFG — E-10	N	A	—	—	—
Diesel	—	—	**A (DSL)**	**N (DSL)**	**A (DSL)**
LPG	N	—	—	—	—
CNG	N	—	—	N	—
LNG	—	—	—	N	—
Methanol	—	—	—	N	—
DME	—	—	—	N	—
FT blend (30%)	—	—	A	—	A
FT (100%)	—	—	—	N	—
Ethanol — E-85	—	A	—	—	—
E-diesel	—	—	—	—	A
Biodiesel, BD20	—	—	A	—	A
NERD (30%)	—	—	—	A	—
Electricity	N	—	—	—	—
Hydrogen ICEV	N	—	—	N	—
Hydrogen FCV	N	—	—	N	—

Baseline vehicles shown in bold
A = Average Fleet, all vehicles on-road
N = New technology
CAT = Catalyst
NACT = Non-Catalyst

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. Researchers considered three different classes of pollutants: criteria pollutants, GHGs, and air toxics. The methods used 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. Researchers used the same approach for off-road equipment. The ARB Off-road 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 (for example, 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 used 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 grams per mile 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 used per mile.

Refrigerants from vehicle air conditioning systems are also a source of GHG emissions. Researchers did not include refrigerant emissions 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 ARB's organic speciation factors to the ROG emission factors from the EMFAC and the Off-road models.

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.

Figure 2-3. Summing up Fuel Cycle Emission Components

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

CHAPTER 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. The following sections present the energy and emissions of GHGs, criteria pollutants, and toxic air contaminants for each fuel considered. Multimedia impacts are also 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. All plots are for the 2012 calendar year. Results for other calendar years are tabulated in the appendix.

Conventional (Petroleum) Fuels: Gasoline and Diesel

This subsection presents the results for the new vehicle stock (MY2010 and newer) mid-size passenger vehicles operated on gasoline and diesel fuels. Figures 3-1 and 3-2 present the WTW energy consumption and GHG emission results, respectively, for each of the petroleum fuels considered for both conventional vehicles and HEVs. Results for an ethanol/gasoline blend (E-10) are also shown in the figures. Table 3-1 summarizes the energy and GHG impacts for gasoline fuels and Table 3-2 summarizes the energy and GHG impacts for diesel.

Figures 3-3 and 3-4 illustrate the criteria pollutant and air toxic contaminant emission impacts for the gasoline based vehicles; these results are summarized in Table 3-3. Because the EMFAC model does not have any new light duty diesel vehicles in the 2010+ timeframe in the inventory, we do not show WTW criteria pollutant results for new diesel vehicles. The underlying assumption is that these vehicles will meet the same emission standards as their gasoline counterparts. Diesel vehicle results are summarized in Table 3-4.

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

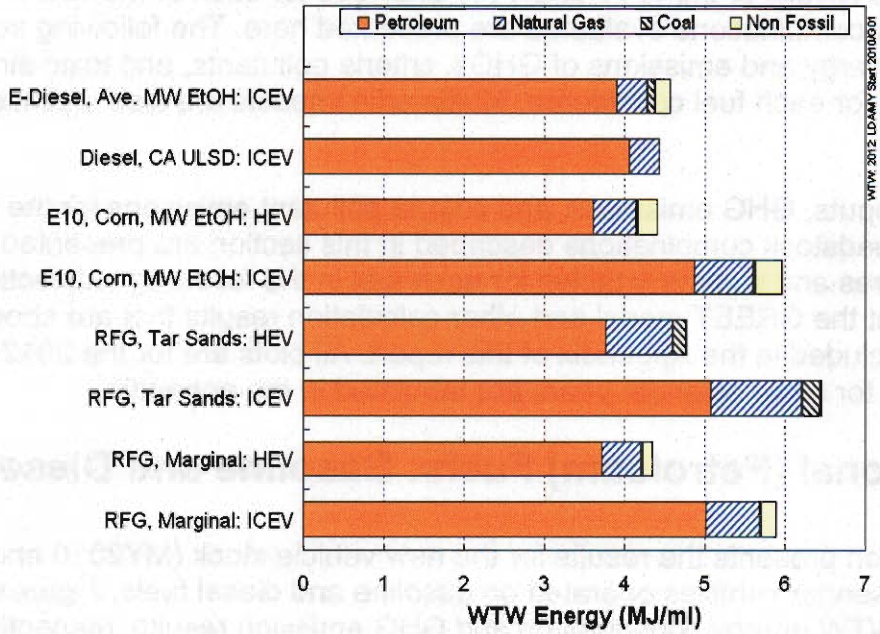


Figure 3-2. WTW GHG Emissions for Petroleum Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

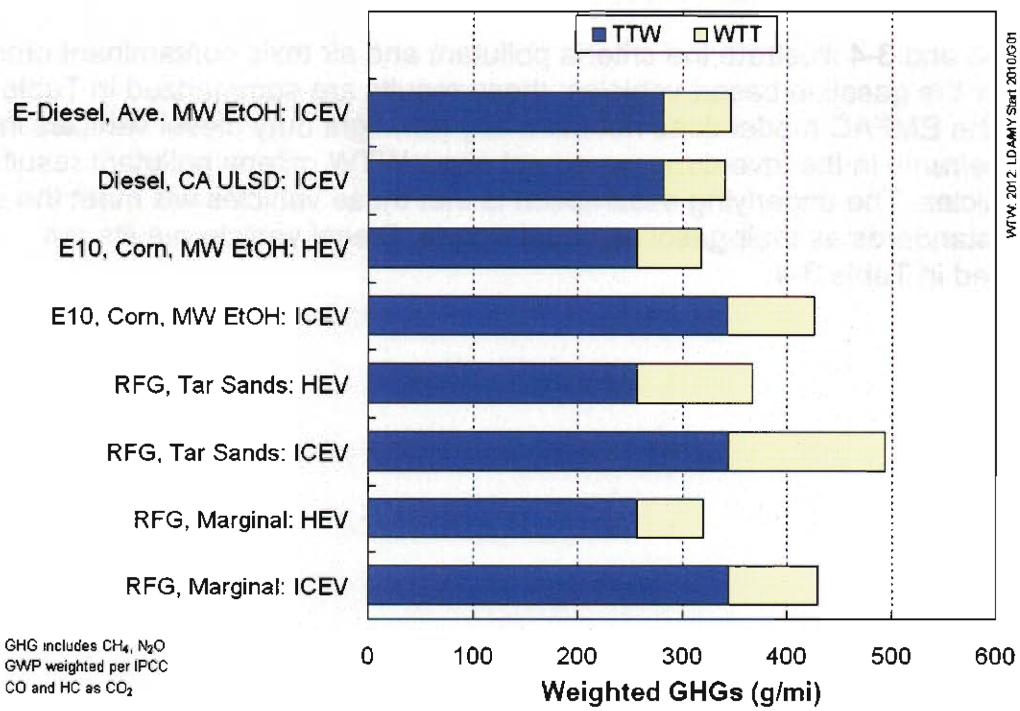


Table 3-1. Energy and GHG Impacts of Gasoline Vehicles

Parameter	Energy and GHG Impact		
Energy Factors	• Advanced gasoline technologies such as HEVs can reduce fuel consumption by ~25 percent. • Requirement for producing reformulated gasoline affects energy inputs and rejected pentanes with related transportation logistics have a small impact on WTT energy. • If E-10 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 (2012) Petroleum Fossil Fuel	**HEV** 25% reduction 25% reduction	**E-10** 3% reduction 1% reduction	**Tar Sands** 1% increase 13% increase
GHG Impact	HEV E-10 Tar Sands	25% reduction 1% reduction 15% increase	

Table 3-2. 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 (better refinery efficiency than gasoline). • Improvement in energy consumption over gasoline vehicles • Increased hydro treating is required to achieve low sulfur specifications
GHG Factors	• Lower WTT energy inputs are partially offset by higher carbon content in the fuel
Comparison	**Passenger Cars**
Energy Impact (2012) Petroleum Fossil Fuel	 19% reduction 22% reduction
GHG Impact	21% reduction

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

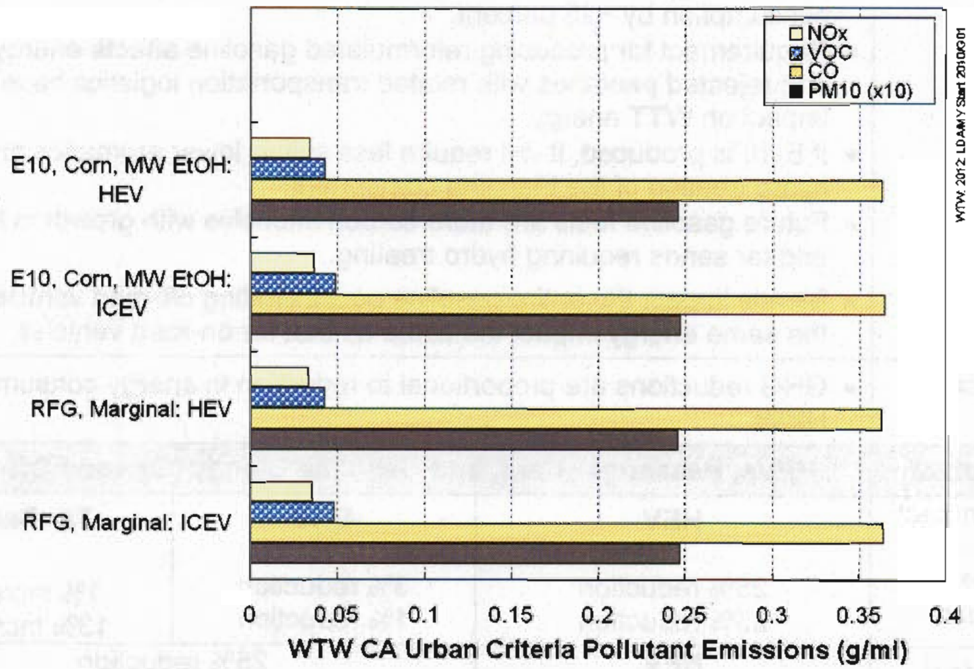


Figure 3-4. WTW Air Toxic Contaminant Emissions for Gasoline Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

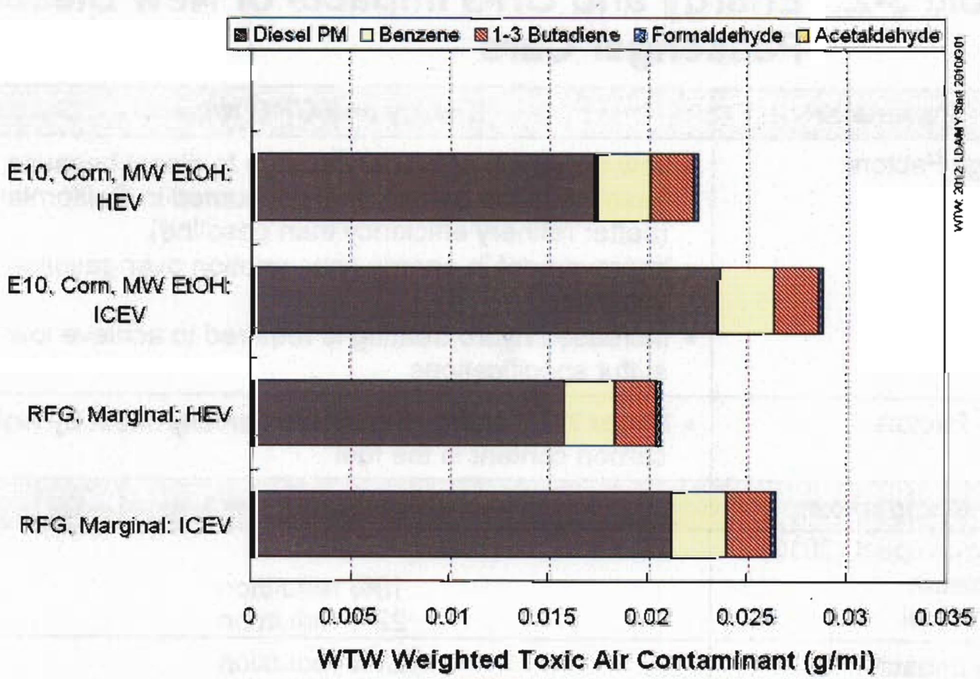


Table 3-3. Pollutant Impacts of Gasoline Vehicles

Parameter	Pollution Impact
Criteria Pollutants	• Reduction in vehicle fuel consumption for HEV results in proportional reduction in WTT criteria pollutants. • Marginal WTT 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 have a minor contribution to WTT 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 WTT 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 CA by train and then to bulk terminals by truck rather than pipeline. The slightly higher diesel PM_{10} emissions are weighted by toxicity, resulting in slightly higher air toxics for E-10.
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	Gasoline HEV	E-10 ICEV	E-10 HEV
CA Criteria Pollutants – 2012	% Reduction	% Reduction	% Reduction
VOC	12%	-1%	12%
CO	0%	0%	0%
NO_x	7%	-2%	6%
PM_{10}	0%	0%	0%
2022 – Benefit diminishes as gasoline vehicles improve			
Weighted Toxics – 2012	21% reduction	9% increase	15% reduction
Multimedia Impacts	Proportional to petroleum reduction		

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

Parameter	Pollution Impact
Criteria Pollutants	• Because the EMFAC inventory shows no diesel vehicles, we are unable to show WTW criteria emissions for light duty ULSD vehicles. • 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	TTW emissions should be similar to gasoline vehicles. WTW emissions should therefore be slightly lower.
Weighted Toxics	The air toxics emissions should be slightly higher than gasoline since diesel PM is accounted for as a toxic.
Multimedia Impacts	Same to slight increase.

Ethanol

The results for ethanol blends (E-85) 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 3-5 and 3-6 present the energy and GHG impacts for E-85. As discussed in the WTT report, the GREET output for the biomass and sugar cane cases, for example WTT case ID E84, includes the portion of the feedstock that actually partitions to the fuel and is not consumed in the fuel production. This has not been subtracted out and is in effect double counted in the WTW plot shown below. A line has been drawn on the plots to indicate approximately the WTW energy consumption. This accounting artifact will be corrected in future analyses. Table 3-5 summarizes the energy and GHG results for corn based ethanol, while Table 3-6 summarizes these results for biomass and sugarcane based ethanol. The accounting is correct for WTT GHG emissions.

Figure 3-7 provides criteria air pollutant emissions for E-85 and Figure 3-8 provides air toxic emissions. Tables 3-7 and 3-8 summarize these results for corn based ethanol and sugarcane/biomass derived ethanol, respectively. Note that all plots are for existing vehicle stock since blend strategies are near-term solutions for existing FFVs. For energy consumption and emissions in new vehicle stock, please refer to Appendix A.

Figure 3-5. WTW Energy Consumption for Ethanol Fuels in Mid-Size Vehicles (2012 Existing Vehicle Stock)

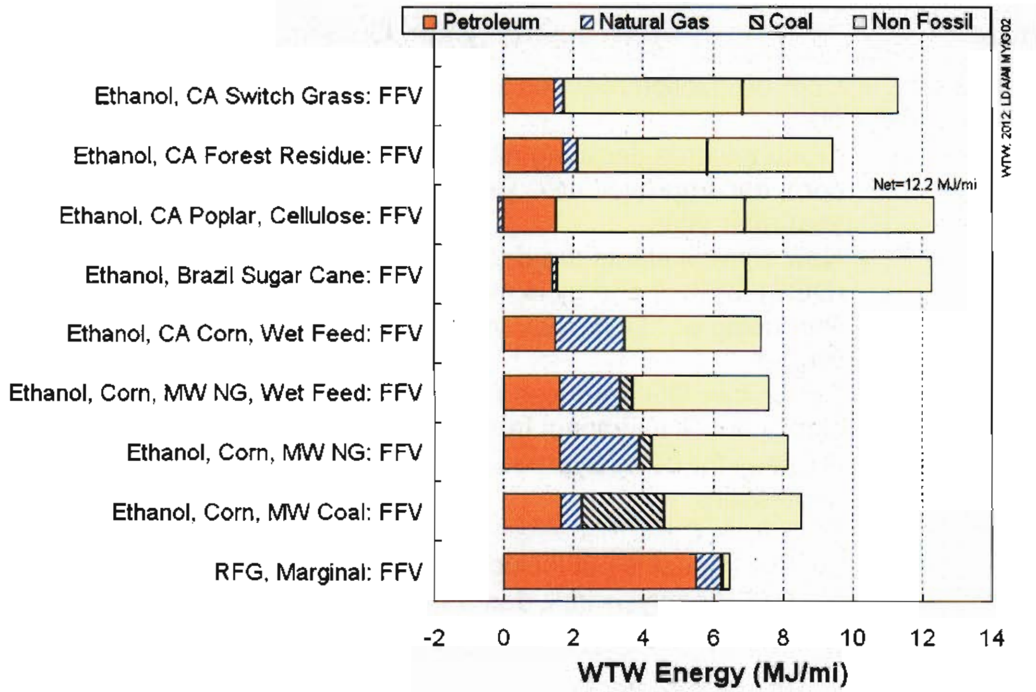


Figure 3-6. WTW GHG Emissions for Ethanol Fuels in Mid-Size Vehicles (2012 Existing Vehicle Stock)

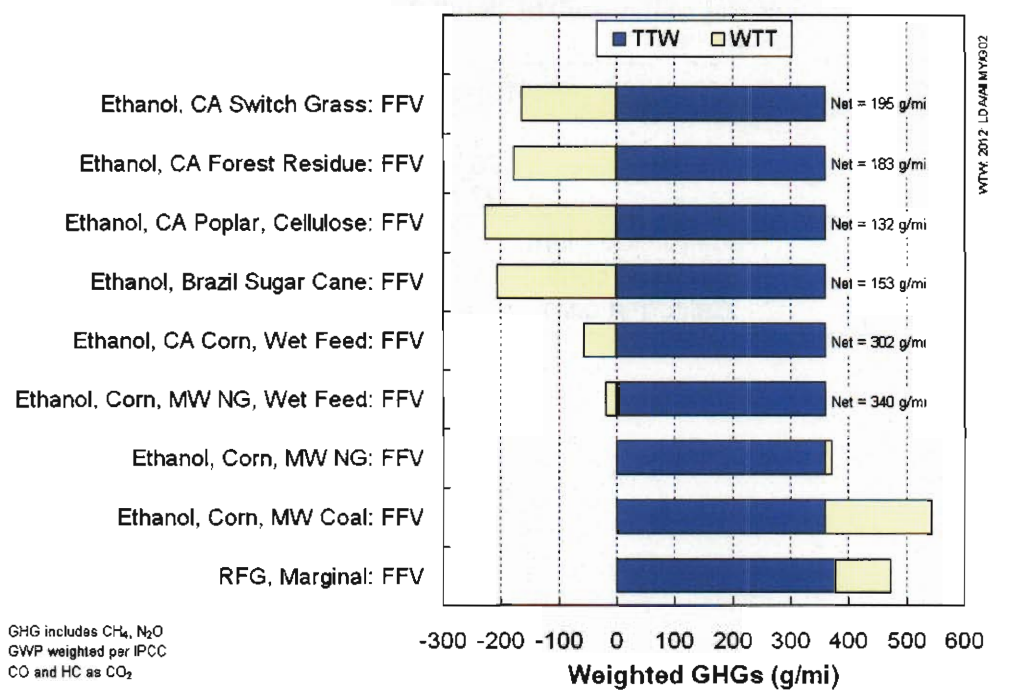


Table 3-5. Energy and GHG Impacts of E-85 Vehicles – Corn Based Ethanol

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 by ~ 10,000 to 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, but this impact is not included in the analysis. • E-85 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 E-85 basis. Similar impact could be achieved with low-level blends without improvement in energy consumption.	
Comparison	**Passenger Cars (E-85 basis)**	
Energy Impact Petroleum Fossil Fuel	 70 to 73% reduction 27 to 45% reduction	
GHG Impact	Coal-based plant Midwest corn California corn	15% increase 15 to 28% reduction 36% reduction

Table 3-6. Energy and GHG Impacts of E-85 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. • Fossil energy input for sugar cane and biomass are relatively low. Biomass residue provides fuel for ethanol plant. • E-85 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 E-85 basis. Similar impact could be achieved with low-level blends without improvement in energy consumption.	
Comparison	**Passenger Cars (E-85 basis)**	
Energy Impact Petroleum Fossil Fuel	 73% to 75% Reduction 72% to 80% Reduction	
GHG Impact	Sugar Cane Cellulose	68% reduction 60% to 72% reduction

Figure 3-7. Criteria Pollutant Emissions for Ethanol Fuels (2012 Existing Vehicle Stock)

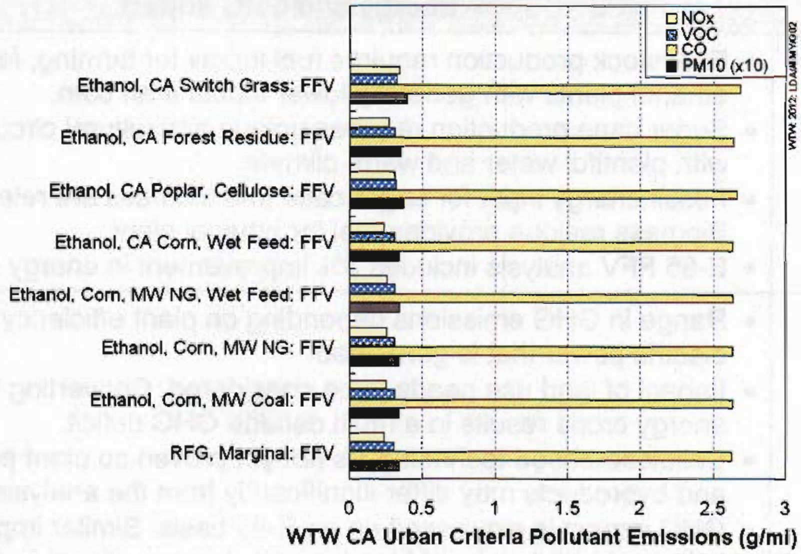


Figure 3-8. Air Toxic Contaminant Emissions for Ethanol Fuels (2012 Existing Vehicle Stock)

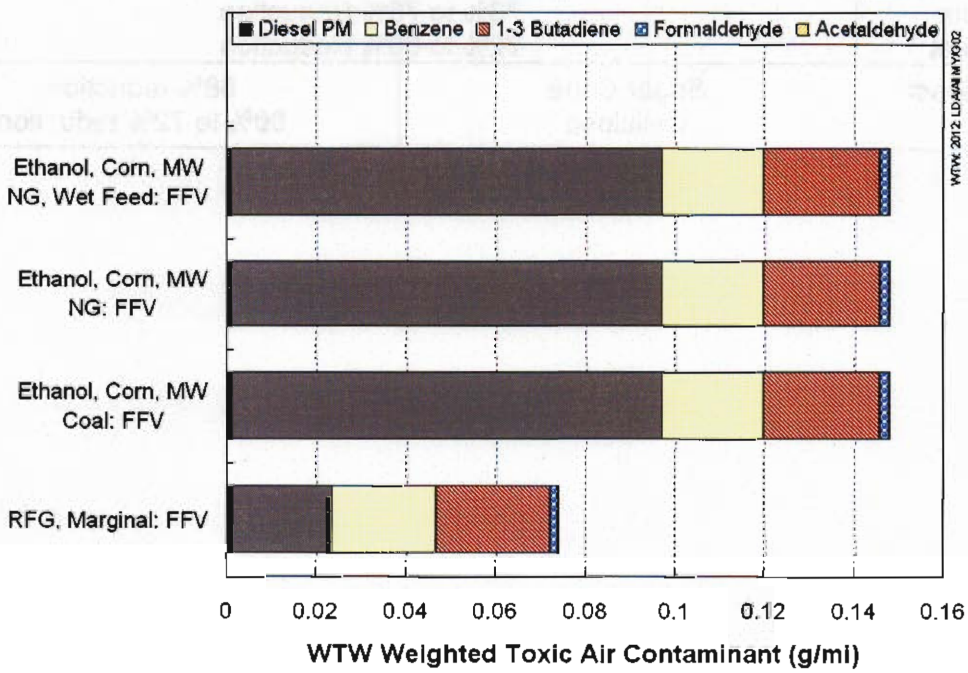


Table 3-7. Pollution Impacts of E-85 Vehicles – Corn Based Ethanol

Parameter	Pollution Impact	
Criteria Pollutants	• 2012 WTW emissions of NO_x and PM_{10} are higher for the ethanol pathways due to WTT impacts. MW corn ethanol has higher transport NO_x and PM_{10} emissions. California energy crop pathways have higher NO_x and PM_{10} due to agriculture equipment. These small differences decrease over time due to emission reductions achieved by agriculture equipment, locomotives and trucks. • Additional pentanes to increase E-85 volatility must be hauled by truck from the refinery to the terminal. This effect was not included here. • 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. • Elevated diesel PM_{10} emissions for E-85 cases due to increased locomotive and truck transport for ethanol relative to RFG for Midwest ethanol. CA biomass ethanol pathways have higher PM_{10} emissions due to the in-state agricultural equipment. • 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 E-85 in underground tank leaks is complex with no likely net impact.	
Comparison	**Passenger Car**	
Criteria Pollutants	VOC CO NO_x PM_{10}	2% increase 0% 8% increase +1 increase
Weighted Toxics	Benzene 1-3 Butadiene Formaldehyde Acetaldehyde Diesel PM	2% decrease 1% increase 8% increase 18% increase 3X increase
Multimedia Impacts	85%reduction in hydrocarbon related transport	

Table 3-8. Pollution Impacts of E-85 Vehicles – Sugarcane and Biomass Based Ethanol

Parameter	Pollution Impact Base	
Criteria Pollutants	• California energy crop pathways have higher NO_x and PM_{10} than RFG due to agriculture equipment and truck transport emissions. These differences decrease over time due to emission reductions achieved by agriculture equipment, locomotives and trucks. • Additional pentanes to increase E-85 volatility must be hauled by truck from the refinery to the terminal. This effect was not included here. • California plants will be required to offset NO_x and VOC 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 WTT 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, however this is a small portion of WTW emissions. Diesel PM emissions for the agriculture equipment are expected to contribute to slightly elevated toxic emissions relative to RFG in the near term, decreasing over time.	
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 E-85 in underground tank leaks is complex with no likely net impact.	
Comparison	**Passenger Car**	
Criteria Pollutants 2012. Impact diminishes over time.	VOC CO NO_x PM_{10}	2% to 5% increase 0% 32% to 45% increase 10% to 17% increase
Weighted Toxics	Likely similar to corn pathways with agriculture equipment PM from biomass pathways ~ locomotive and truck for MW ethanol. Expected to decrease over time.	
Multimedia Impacts	-85% due to reduction in hydrocarbon related transport	

Biodiesel and Renewable Diesel

This subsection presents the results for light duty (mid-size passenger car) and heavy duty (urban bus) diesel vehicles operated on biodiesel fuels. Figures 3-9 and 3-10 present the WTW energy consumption for mid-size vehicles and urban buses while Figures 3-11 and 3-12 present the corresponding GHG emission results. Two different alternative diesel fuels are shown: biodiesel (esterified vegetable oils) and renewable diesel (hydrogenated vegetable oils). A 20 percent blend is shown for biodiesel while a 30 percent blend is shown for renewable diesel (because the properties are close to GTL fuels which are blended at a 30 percent level). All plots are shown for existing vehicle stock since these fuel blends are a near term strategy impacting all existing vehicles. Table 3-9 summarizes the energy and GHG impacts for these fuels.

Figures 3-13 and 3-14 provide the criteria pollutant emission impacts of using biodiesel and renewable diesel fuels in midsize vehicles and urban buses. 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. Note that biodiesel is a blend strategy that can be utilized in existing vehicles; plots show results for all model years, not new vehicles.

Figure 3-9. WTW Energy Consumption for Bio and Renewable Diesel Fueled Midsize Vehicles (2012 Existing Vehicle Stock)

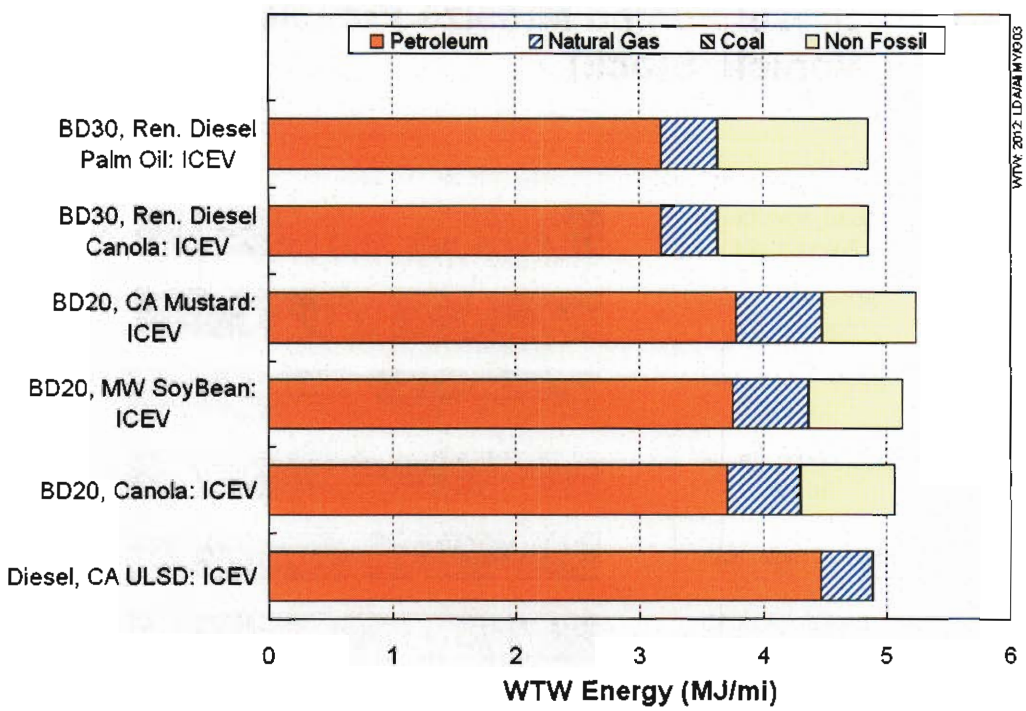


Figure 3-10. WTW Energy Consumption for Bio and Renewable Diesel Fueled Urban Buses (2012 Existing Vehicle Stock)

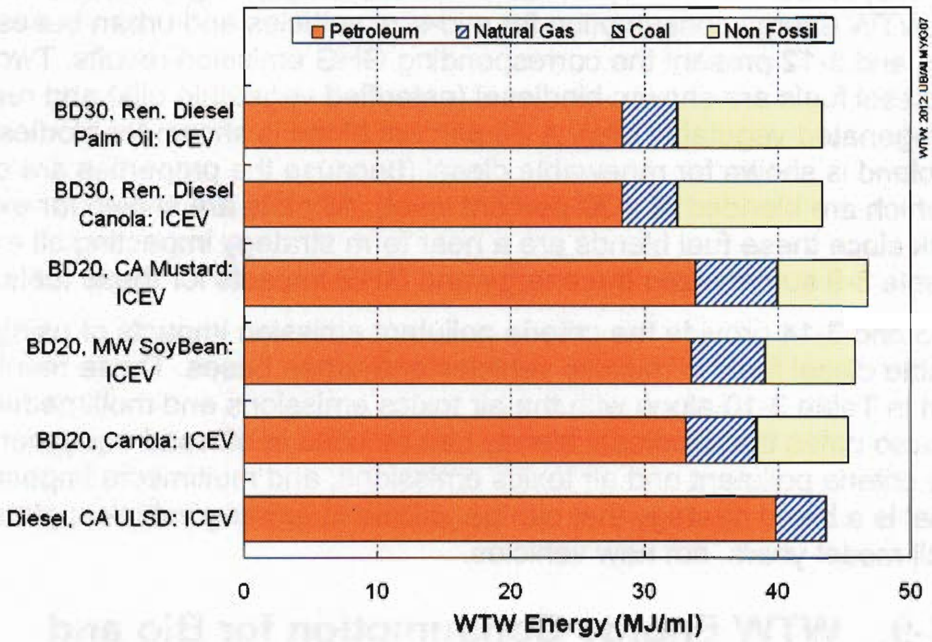


Figure 3-11. WTW GHG Emissions for Bio and Renewable Diesel Fueled Midsize Vehicles (2012 Existing Vehicle Stock)

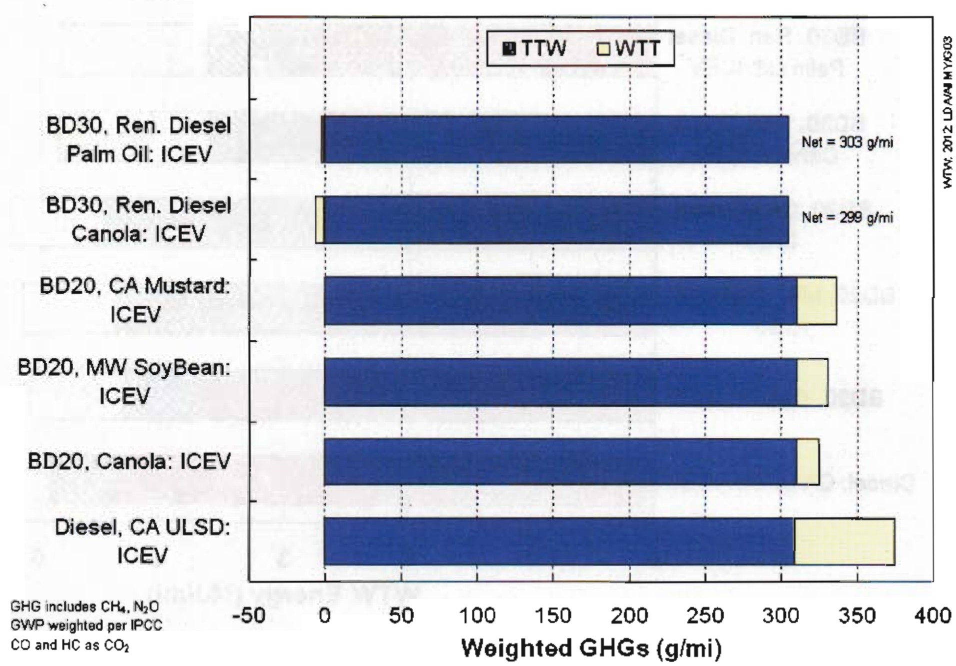


Figure 3-12. WTW GHG Emissions for Bio and Renewable Diesel Fueled Urban Buses (2012 Existing Vehicle Stock)

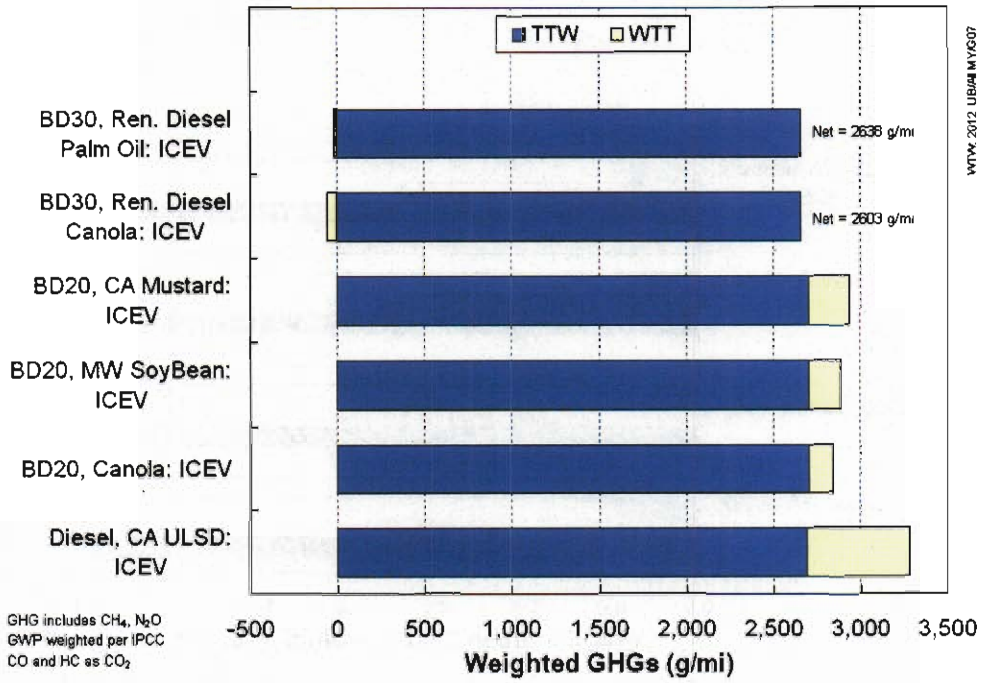


Table 3-9. Energy and GHG Impact of Biodiesel and Renewable Diesel Vehicles

Parameter	Energy and GHG Impact			
Energy Factors	• Petroleum and other fuels are inputs for farming and processing. • 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 United States, converting forest to agricultural use results in an increase in GHG emissions for decades. • Effect of displaced crops needs to be examined. • Need to address sustainable agriculture for tropical oils. • Bulk of the GHGs is from the vehicles. • Diesel hybrid not shown, but results in 20% reduction in GHGs.			
Comparison	**BD20 LDA**	**RD30 LDA**	**BD20 UB**	**RD30 LDA**
Petroleum Reduction	15 to 17%	29%	15 to 17%	29%
GHG Reduction	10 to 13%	20%	10 to 13%	20%

Figure 3-13. Criteria Pollutant Emissions for Bio and Renewable Diesel Fueled Midsize Vehicles (2012 Existing Vehicle Stock)

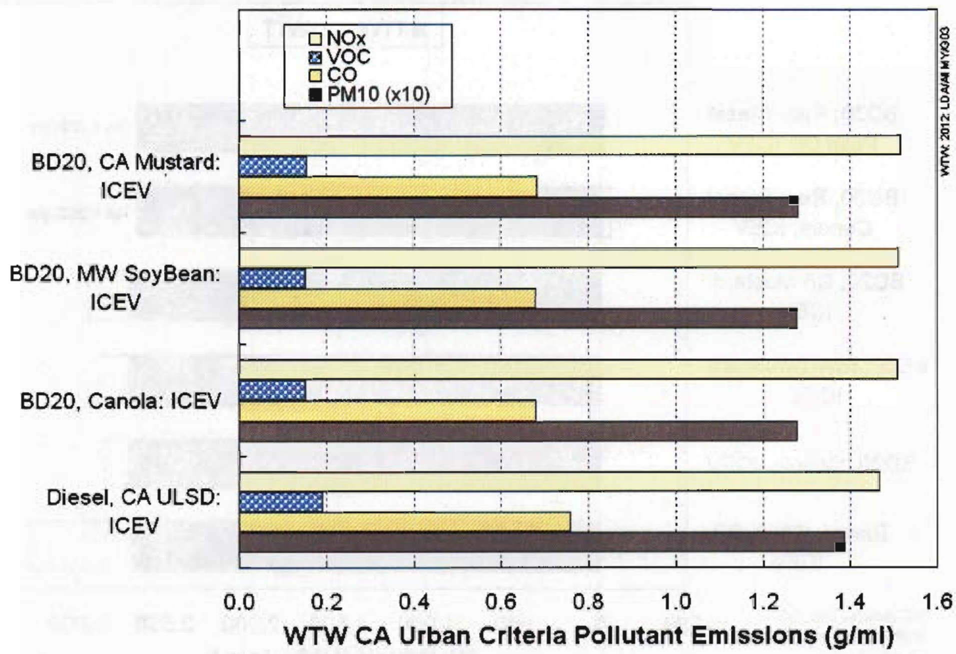


Figure 3-14. Criteria Pollutant Emissions for Bio and Renewable Diesel Fueled Urban Buses (2012 Existing Vehicle Stock)

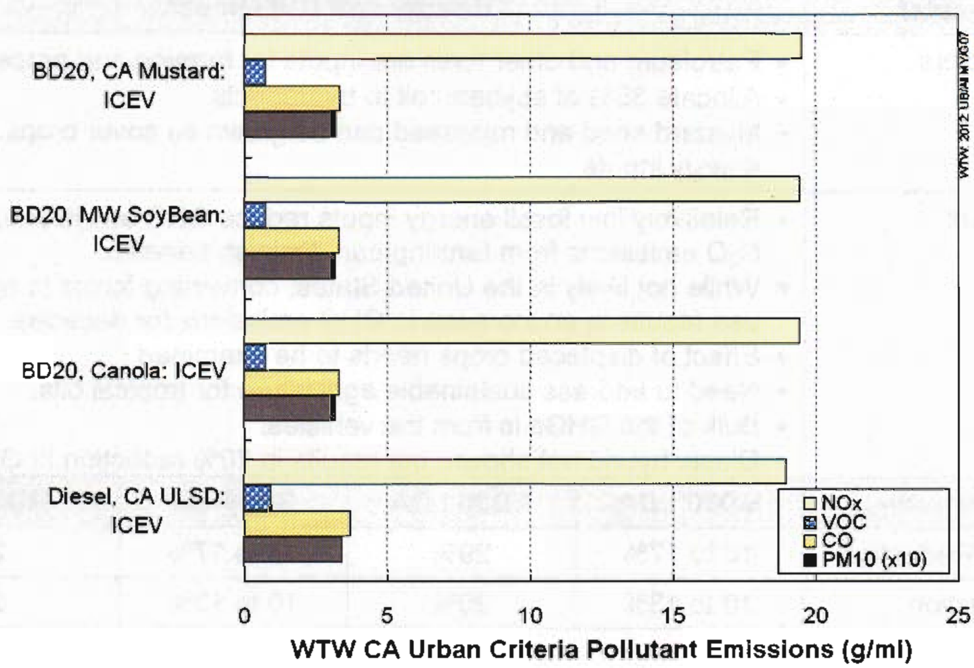


Table 3-10. Pollution Impacts of Biodiesel Vehicles – BD20

Parameter	Pollutant Impact
Criteria Pollutants	• Reduction in HC, CO, and PM for existing vehicles. Slight increase in WTW NO_x emissions. Impact on new technologies is under evaluation. • Need to assure fuel quality to meet stringent future emission standards with new engines. • WTT 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	
VOC	20% reduction relative to diesel
CO	10% reduction relative to diesel
NO_x	3% increase relative to diesel
PM_{10}	8% reduction relative to diesel
2022	Emission impacts could diminish with new diesel engines
Weighted Toxics	Same to small reduction in benzene and diesel PM
Multimedia Impacts	Proportional to % reduction in petroleum use

Natural Gas

This subsection presents the results for vehicles operated on natural gas fuels.[8] Figures 3-15 and 3-16 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 3-17 and 3-18 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 in urban buses.

[8] Future analysis of natural gas will assess the potential benefits from bio-methane which may reduce the WTT GHG emissions and enhance the overall WTW GHG benefit for natural gas.

Figure 3-15. WTW Energy Consumption for CNG Midsize Vehicles (2012 New Vehicle Stock)

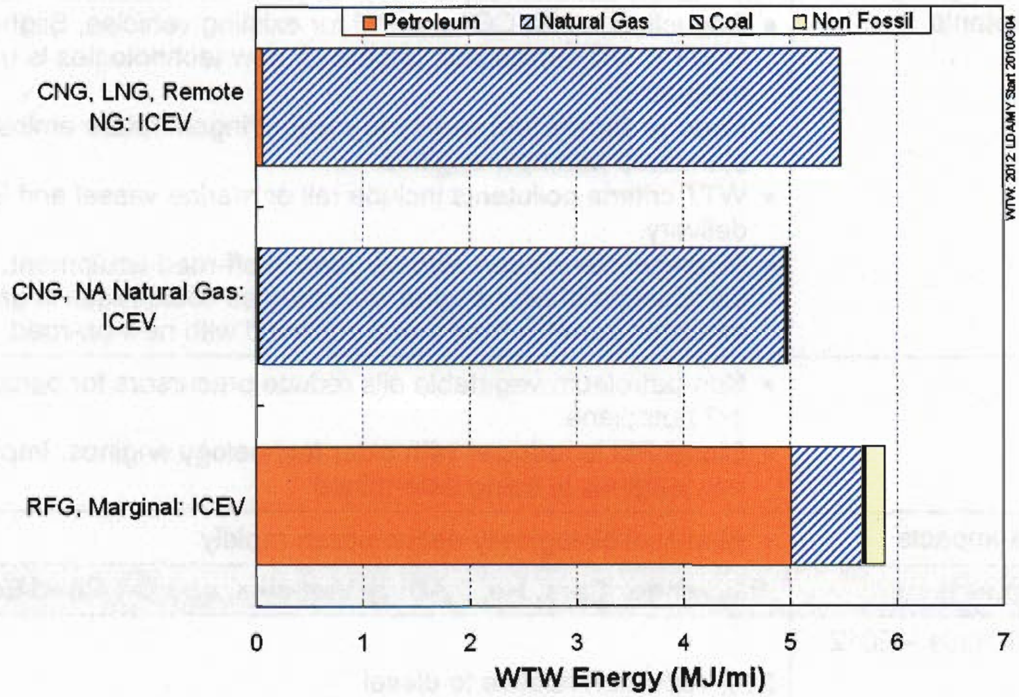


Figure 3-16. WTW GHG Emissions for CNG Midsize Vehicles (2012 New Vehicle Stock)

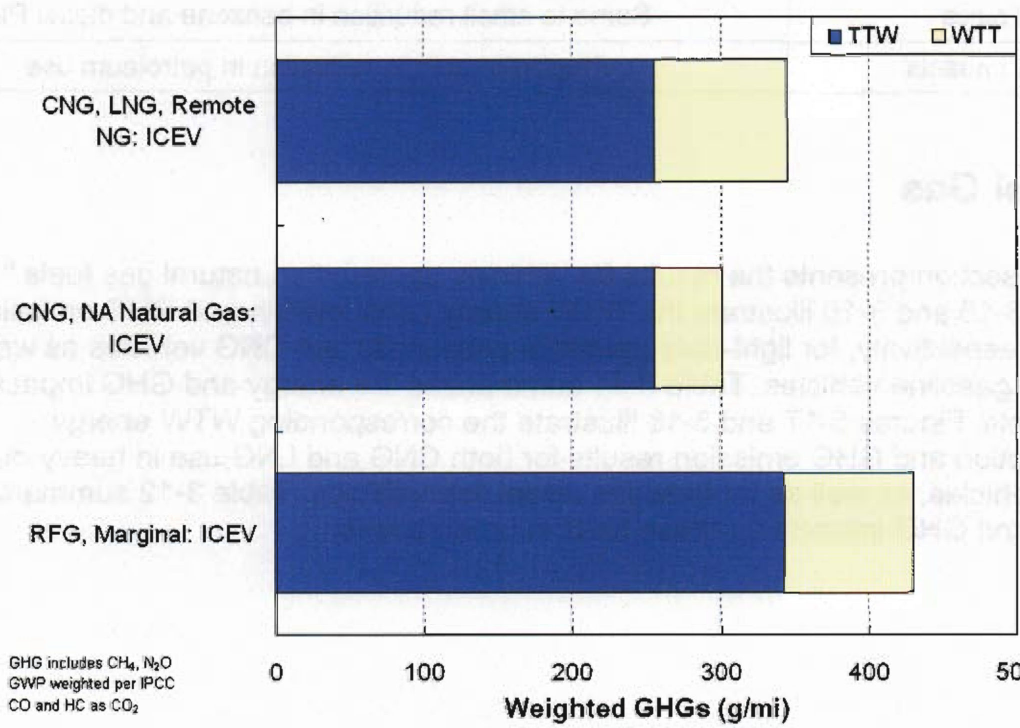


Table 3-11. Energy and GHG Impacts of CNG Vehicles

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 – not taken into account here.	
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 Petroleum Fossil Fuel	 greater than 99% reduction 4% to 13% reduction	 greater than 99% reduction 2% decrease to 8% increase
GHG Reduction	20% to 30% reduction	11% to 23% reduction

Figure 3-17. WTW Energy Consumption for LNG and CNG Heavy Duty Vehicles (2012 New Vehicle Stock)

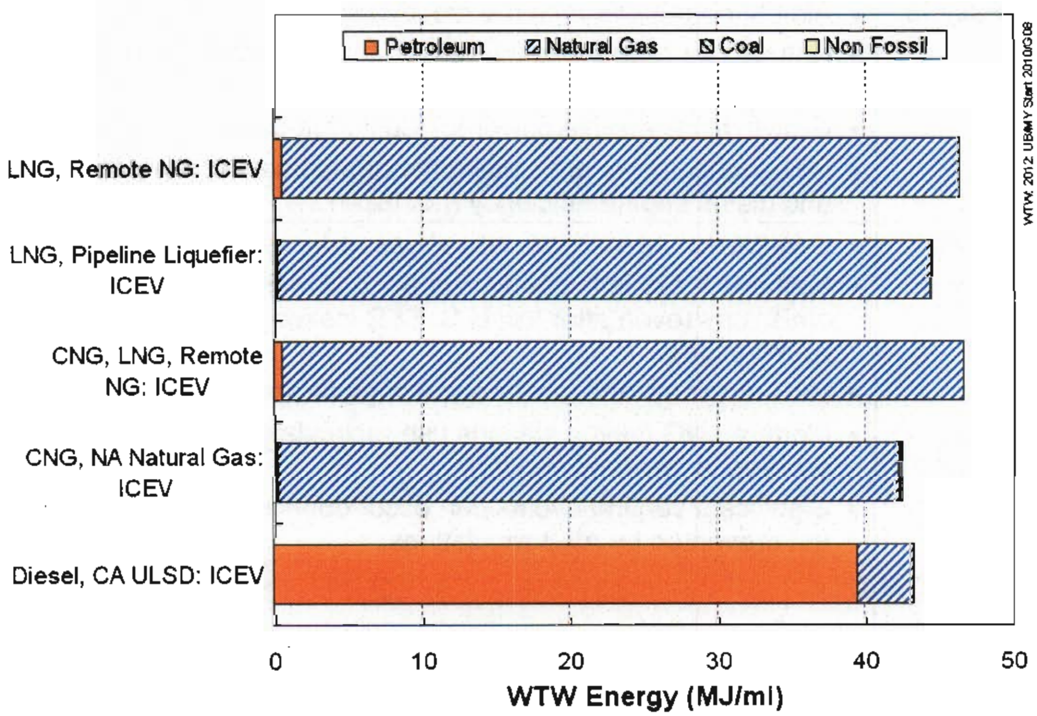


Figure 3-18. WTW GHG Emissions for LNG and CNG Heavy Duty Vehicles (2012 New Vehicle Stock)

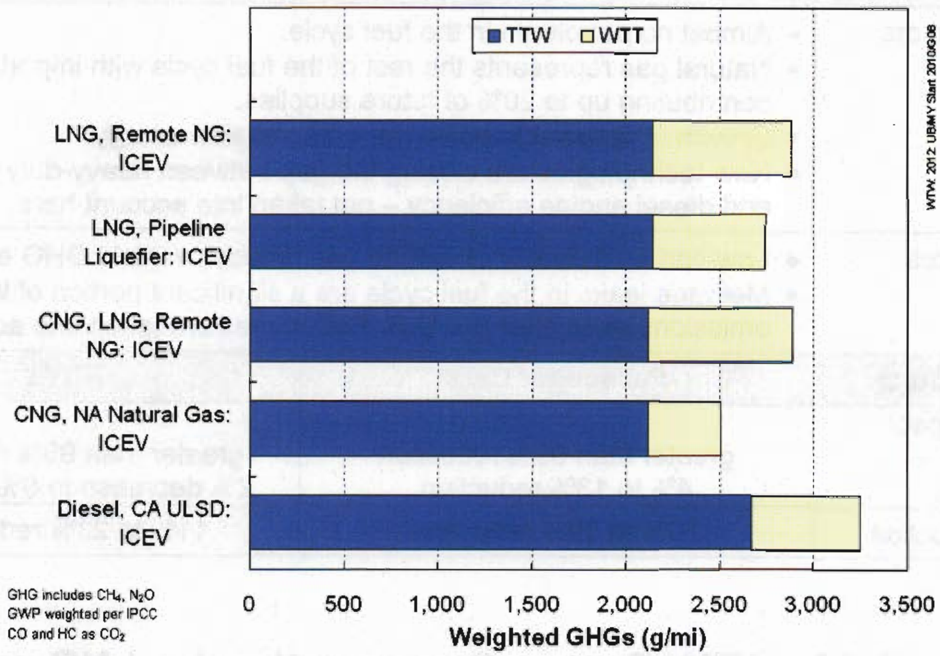


Table 3-12. Energy and GHG Impacts of LNG Vehicles

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 (not taken into account).
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 Petroleum Fossil Fuel	 greater than 99% reduction 3% to 7% increase
GHG Impact 2012 2022	 11% to 16% reduction 12% to 16% reduction

Figure 3-19 provides the criteria pollutant emission impacts of using CNG in light-duty vehicles. Figure 3-20 provides the corresponding criteria pollutant emission impacts of using both CNG and LNG in heavy-duty diesel vehicles. Figures 3-21 and 3-22 provide air toxic emissions for midsize vehicles and urban buses. 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 3-19. Criteria Pollutant Emissions for CNG Vehicles (2012 New Vehicle Stock)

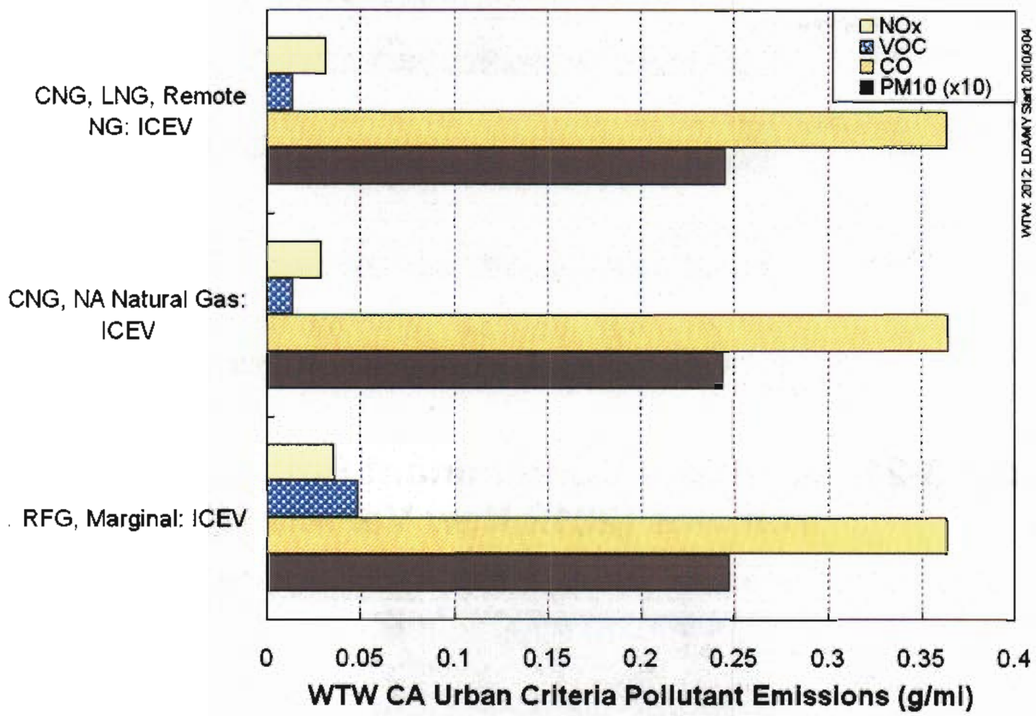


Figure 3-20. Criteria Pollutant Emissions for LNG and CNG Urban Buses (2012 New Vehicle Stock)

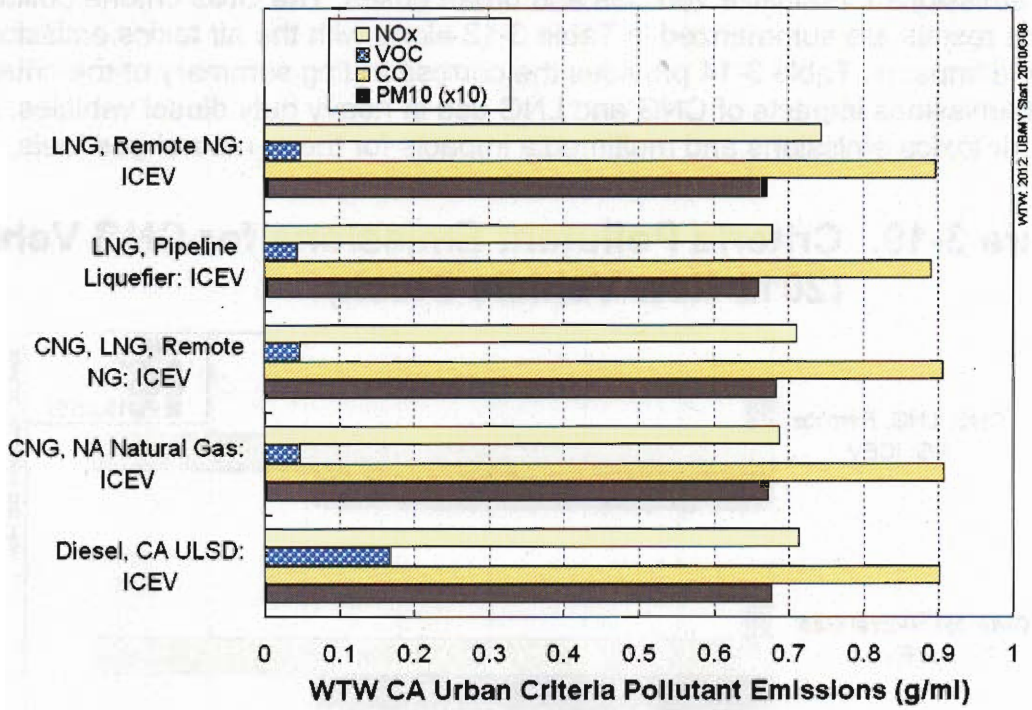


Figure 3-21. Air Toxic Contaminant Emissions for CNG Vehicles (2012 New Vehicle Stock)

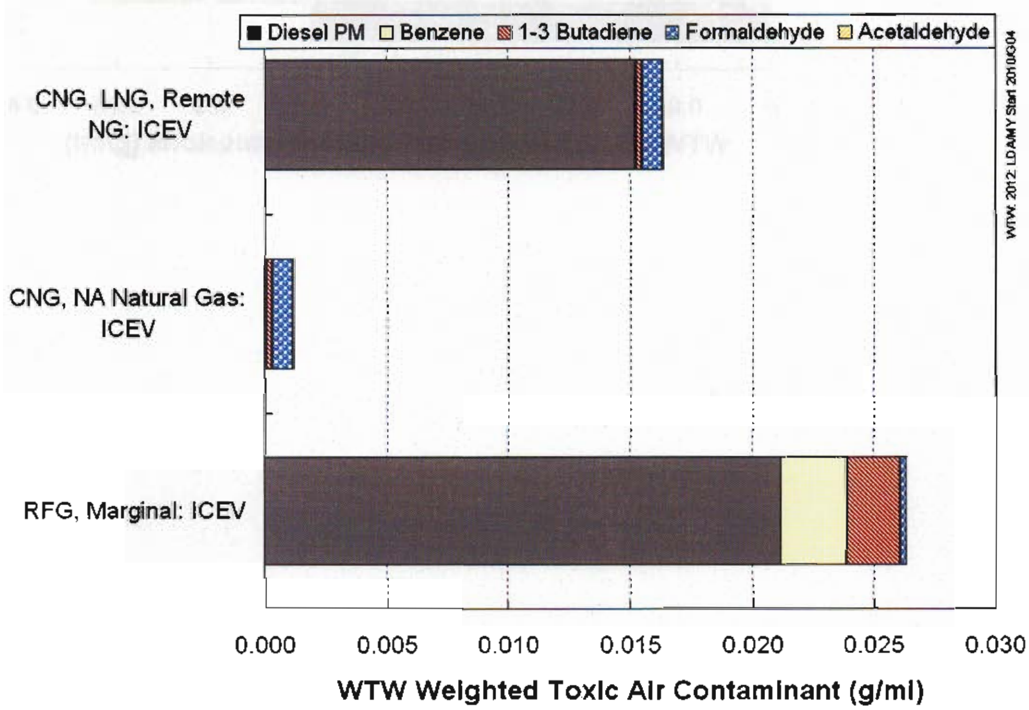


Figure 3-22. Air Toxic Contaminant Emissions for LNG and CNG Urban Buses (2012 New Vehicle Stock)

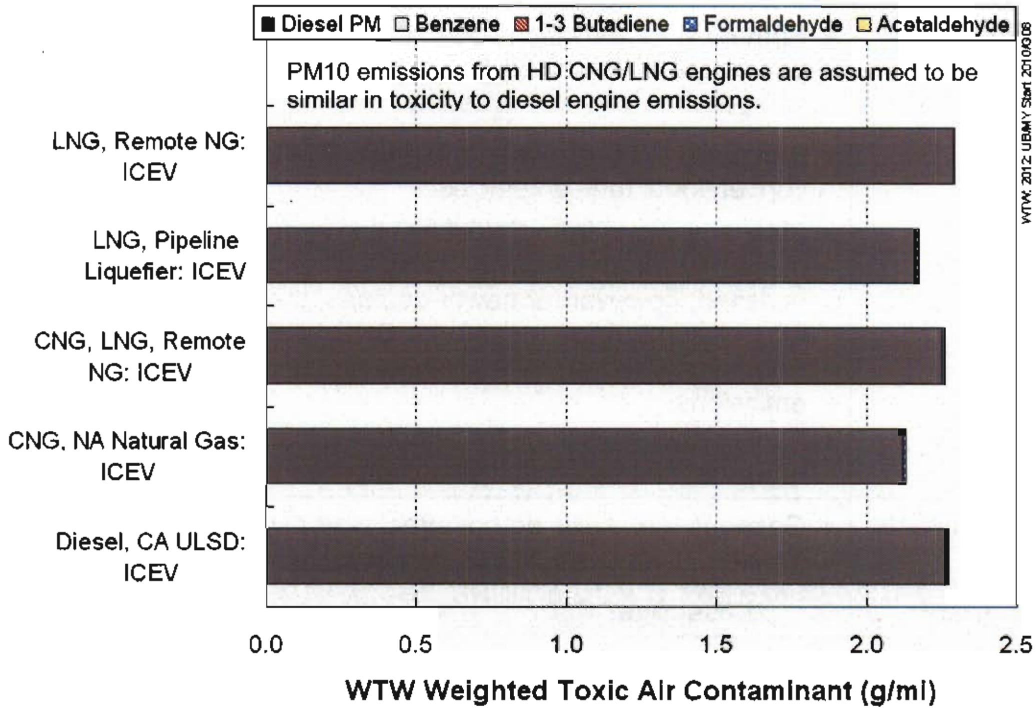


Table 3-13. Pollution Impacts of CNG Vehicles

Parameter	Pollutant Impact	
Criteria Pollutants	• Primary WTT emission sources are natural gas engines and electric power plants for compression, however these are negligible compared to vehicle emissions.	
Toxics	• Benzene, 1-3 butadiene, and diesel PM are reduced compared with conventional fueled vehicles. • PM_{10} emissions from CNG/LNG heavy duty engines are counted as diesel PM for air toxicity purposes. This assumption may be revisited, however for newer engines, the bulk of the PM is from lube oil combustion – same for CNG/LNG. • Formaldehyde from power plants and engines contributes to WTT emissions. • Tanker ship emissions for remote NG case are included in PM_{10} however these are negligible compared to vehicle emissions.	
Multimedia Impacts	• Gaseous fuel, spills do not affect water systems. • Tankers used to haul LNG from remote NG.	
Comparison	**Passenger Car**	**HDV**
Criteria Pollutants	VOC 72% reduction NO_x 12% to 19% reduction	VOC 72% reduction NO_x 0 to 4% reduction
Weighted Toxics 2012 2022	 38% to 95% reduction 36% to 95% reduction	 1% to 6% reduction 0 to 5% reduction
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 WTT emissions. • Tanker ship emissions for remote NG case are included in PM_{10}, but are negligible compared to vehicle emissions. • PM_{10} emissions from CNG/LNG heavy duty engines are counted as diesel PM for air toxicity purposes. This assumption may be revisited, however for newer engines, the bulk of the PM is from lube oil combustion – same for CNG/LNG.
Multimedia Impacts	• Gaseous fuel, spills do not affect water systems. • Marine vessels haul LNG from remote natural gas.
Comparison	**HDV**
Criteria Pollutants	71% to 73% VOC reduction 1% to 2% PM_{10} reduction 4% increase to 5% decrease in NO_x
Weighted Toxics 2012 2022	 1% increase to 4% reduction 1% increase to 4% reduction
Multimedia Impacts	Over -90% hydrocarbon spills

Electricity

This subsection presents the results for mid-size passenger electric vehicles. Figures 3-23 and 3-24 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 3-25 and 3-26 provide the criteria pollutant and air toxic emission impacts of electric vehicles, respectively. 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. Note that new vehicle stock WTW emissions are presented here.

Figure 3-23. WTW Energy Consumption for Midsize Electric Vehicles (2012 New Vehicle Stock)

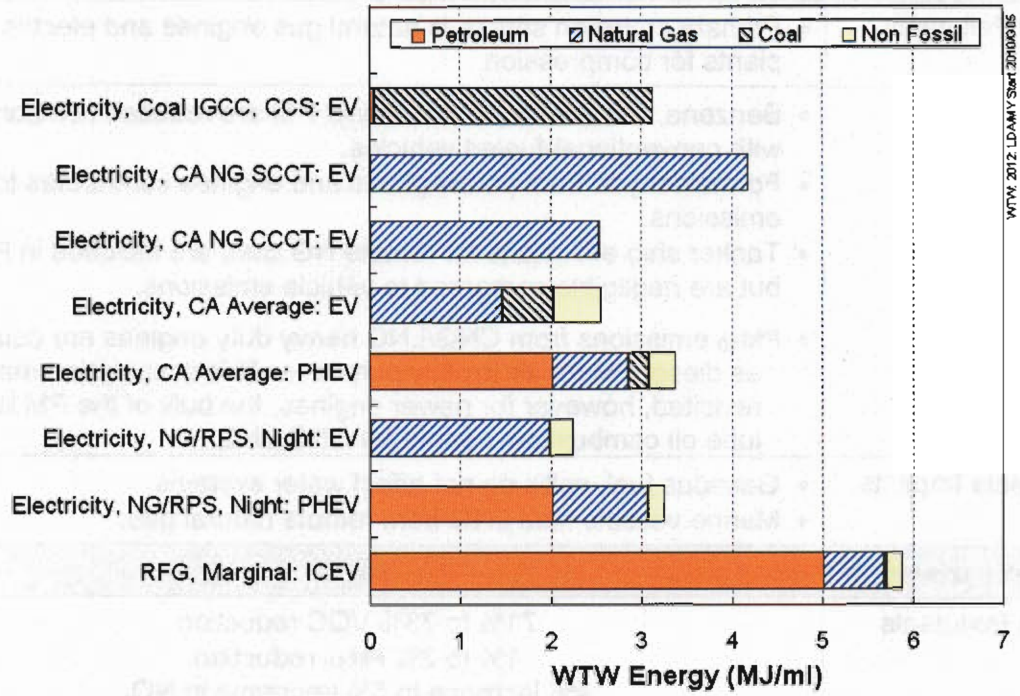


Figure 3-24. WTW GHG Emissions for Electric Vehicles (2012 New Vehicle Stock)

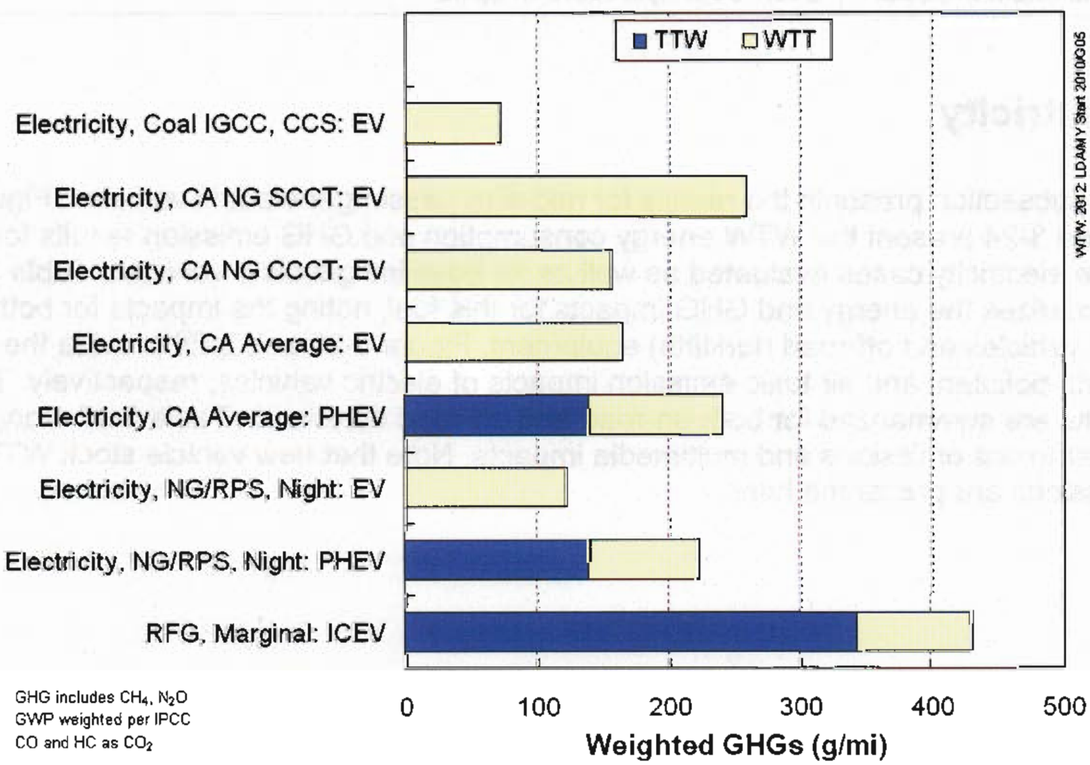


Table 3-15. Energy and GHG Impacts of Electric Vehicles

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 • WTW energy use dependent on primemover efficiency. For example, the SCCT, coal IGCC and NG CCCT generators have HV efficiencies of 31%, 40% and 52% respectively.		
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 GHGs consistent with NG CCCT • 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	 99.8% reduction 65% reduction	 60% reduction 46% reduction	 99.8% reduction 61% reduction
GHG Impact	72% reduction	48% reduction	65% reduction

Figure 3-25. Criteria Pollutant Emissions for Midsize Electric Vehicles (2012 New Vehicle Stock)

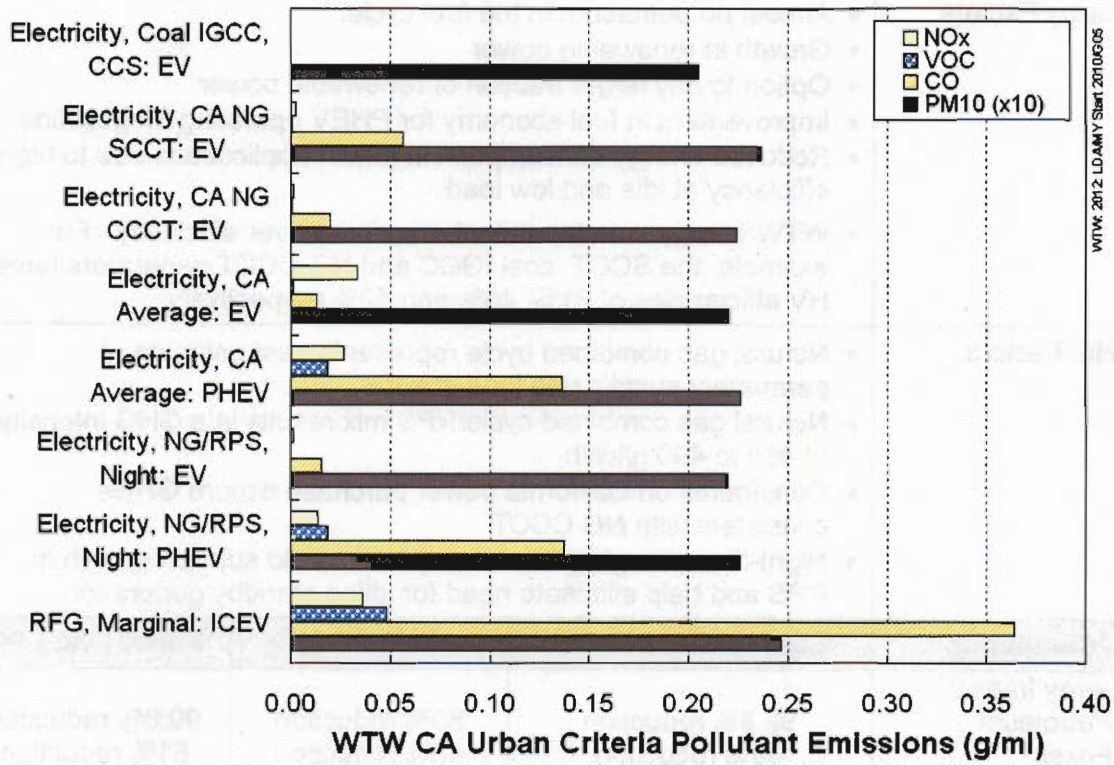


Figure 3-26. Air Toxic Emissions for Midsize Electric Vehicles (2012 New Vehicle Stock)

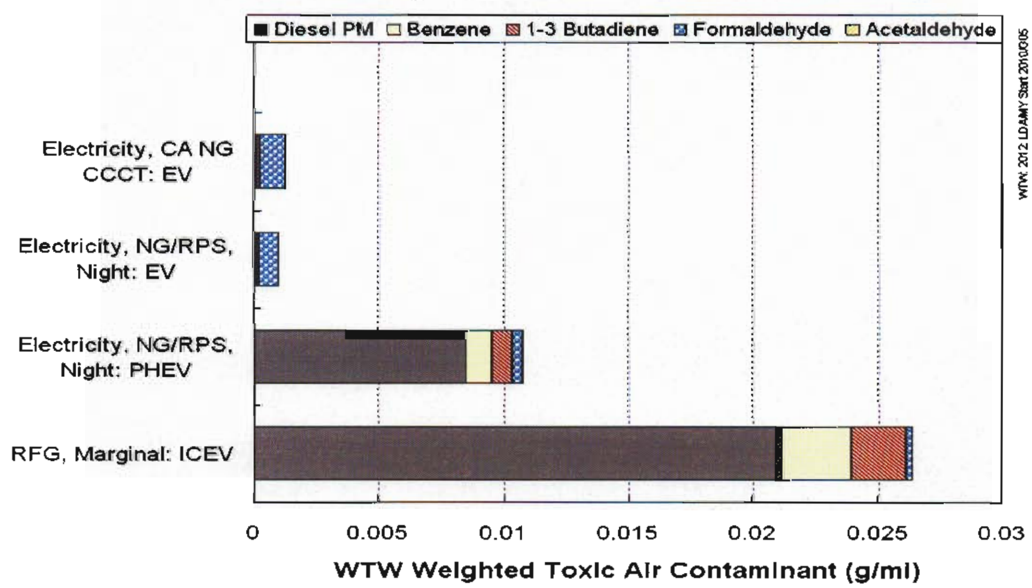


Table 3-16. Pollution Impacts of Electric Vehicles

Parameter	Pollution Impact		
Criteria Pollutants	• Zero exhaust 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. • Tire and brake PM_{10} emissions dominate WTW PM_{10} emissions. The PM_{10} from electric power generation is a very small fraction of WTW PM_{10} emissions, and would likely be offset (0) in many instances.		
Toxics	• Benzene, 1-3 butadiene, and diesel PM are eliminated compared with conventional vehicles • Formaldehyde from power plants and engines contributes to WTT 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_{10}: 11% decrease 96% to 99% decrease for other pollutants	PM_{10}: 8% decrease 62% decrease for other pollutants	PM_{10}: 10% reduction 96% to 99% decrease for other pollutants
Weighted Toxics	96% reduction	59% reduction	85% reduction
Multimedia Impacts	Over 90% reduction from reduced hydrocarbon spills		

XTL Fuels

This subsection presents the results for heavy duty diesel vehicles operated on Gas-, Biomass- and Coal- to Liquid (XTL) fuels. Because a 30 percent blend of XTL with diesel can be utilized in unmodified vehicles, the blends are shown for all model years in the inventory. The GTL100 case requires a new vehicle, so only model year 2010 and newer are considered. The ULSD baseline for both existing stock and new stock are provided on the plots for reference. Figures 3-27 and 3-28 present the WTW energy consumption and GHG emission results for the XTL fuels evaluated as well as for baseline diesel vehicles. Table 3-17 summarizes the energy and GHG impacts for these fuels. Figures 3-29 and 3-30 provide the criteria and air toxic 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 3-27. WTW Energy Consumption for XTL Urban Buses

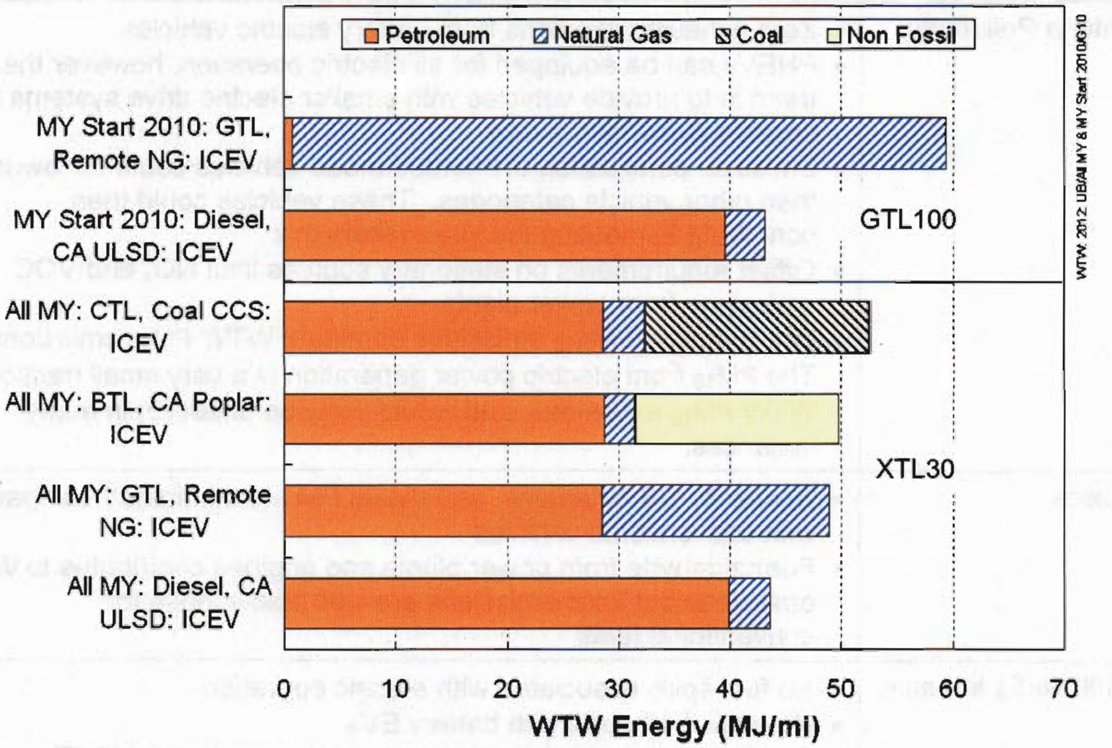


Figure 3-28. WTW GHG Emissions for XTL Urban Buses

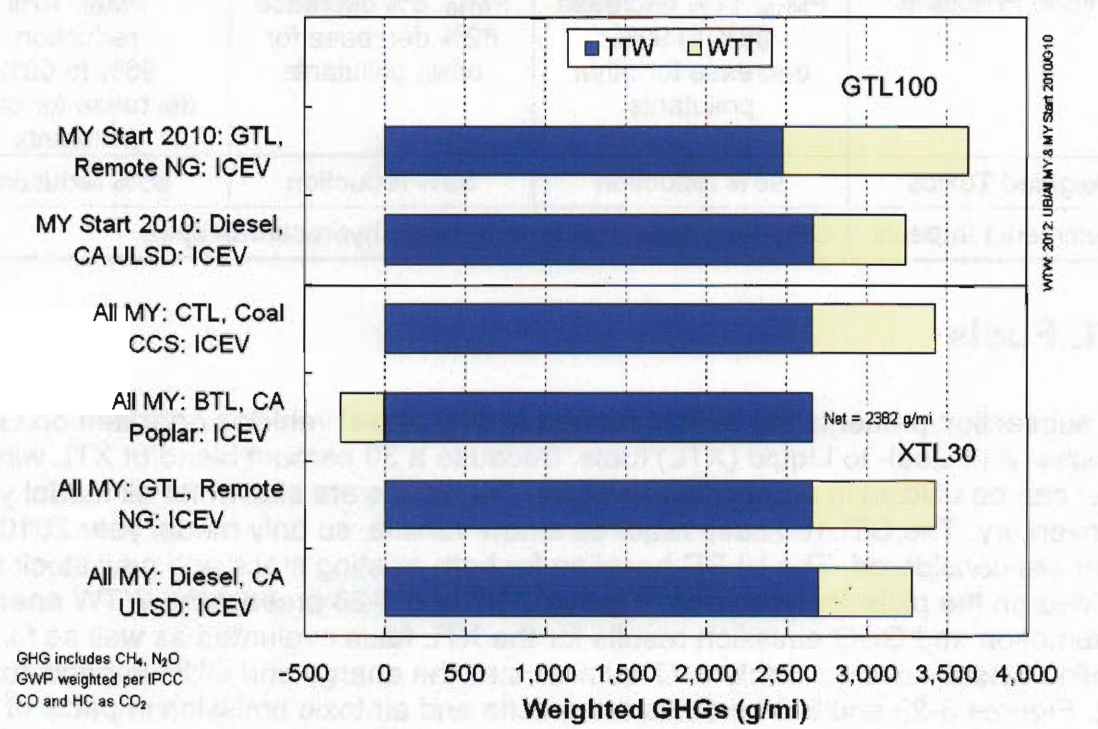


Table 3-17. Energy and GHG Impacts of XTL Vehicles

Parameter	Energy and GHG Impact		
Energy Factors	• Almost no petroleum in the XTL100 fuel cycle, but total energy consumption is higher than the basecase. • 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 (3% improvement in efficiency over diesel assumed here).		
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. • BTL30 results in GHG reductions.		
Comparison	**GTL30**	**BTL30**	**CTL30 CCS**
Energy Impact Petroleum Fossil Fuel	 29% reduction 12% increase	 28% reduction 28% reduction	 28% reduction 20% increase
GHG Impact	4% increase	28% reduction	5% increase

Figure 3-29. Criteria Pollutant Emissions for XTL Urban Buses

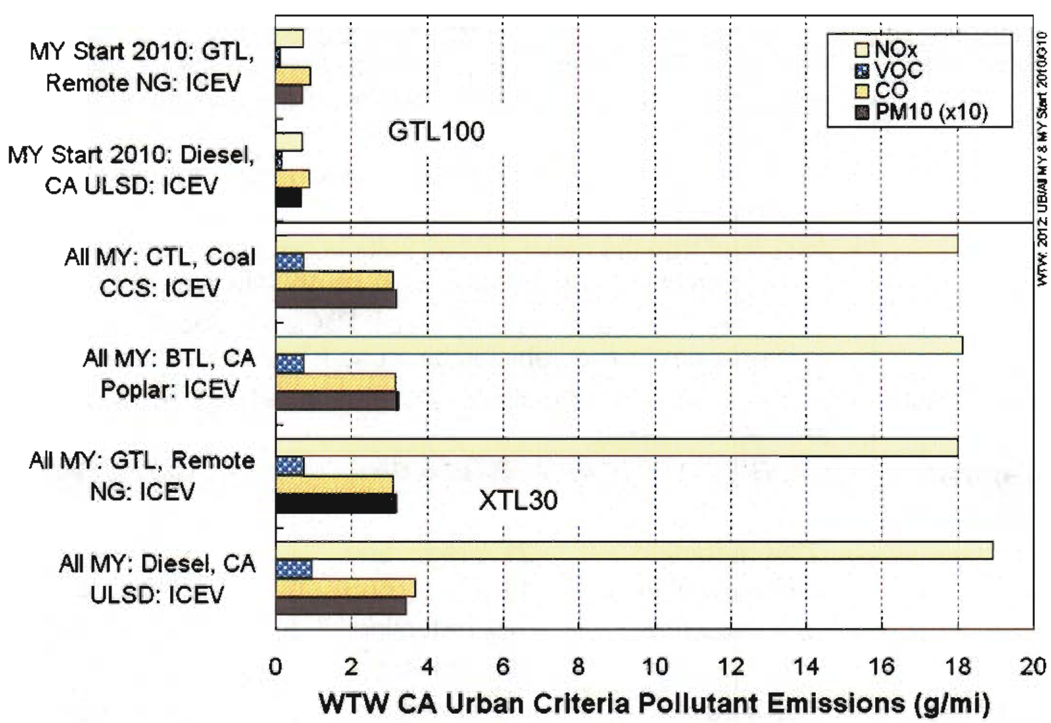


Figure 3-30. Air Toxic Contaminant Emissions for XTL Urban Buses

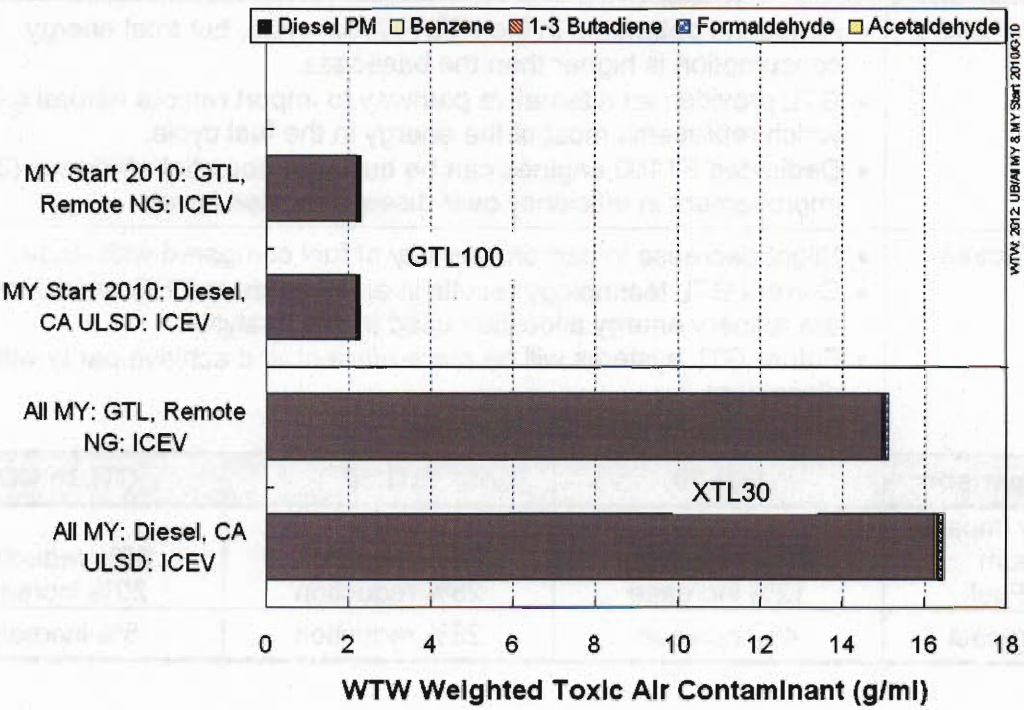


Table 3-18. Pollution Impacts of GTL Vehicles

Parameter	Pollution Impact
Criteria Pollutants	• Primary WTT emission source is natural gas engines and electric power plants for compression, but these are dominated by vehicle emissions. • FT30 blends provide reductions in criteria pollutant emissions from existing stock. • Assumed that the new FTD100 vehicle not optimized to exceed existing emission standards, therefore no improvement over diesel.
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	GTL30 UB	BTL30 UB	CTL30 CCS UB
Criteria Pollutants			
VOC	23% reduction	21% reduction	23% reduction
CO	16%reduction	14% reduction	16% reduction
NO_x	5% reduction	4% reduction	5% reduction
PM_{10}	7% reduction	6% reduction	7% reduction
Weighted Toxics	7% reduction	6% reduction	7% reduction
Multimedia Impacts	Same hydrocarbon spills		

Hydrogen

This subsection presents the results for light-duty (mid-size passenger car) hydrogen fueled vehicles. Figures 3-31 and 3-32 present the WTW energy consumption for midsize vehicles and urban buses. Figures 3-33 and 3-34 provide the corresponding GHG emission results. 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.

Figures 3-35 and 3-36 provide the criteria pollutant emission impacts of the midsize vehicle and urban bus cases evaluated, respectively. Finally, Figures 3-37 and 3-38 provide air toxic contaminant results. The criteria pollutant and air toxic contaminant 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 3-31. WTW Energy Consumption for Hydrogen Midsize Vehicles (2012 New Vehicle Stock)

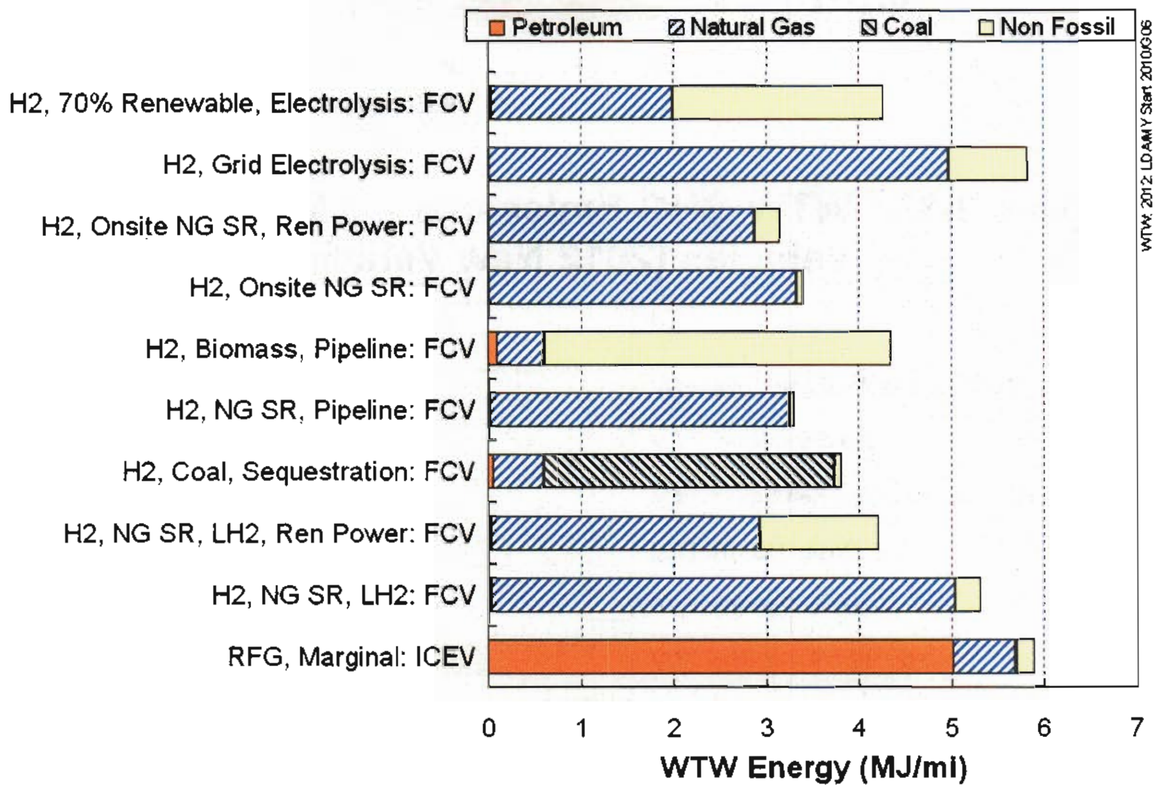


Figure 3-32. WTW Energy Consumption for Hydrogen Urban Buses (2012 New Vehicle Stock)

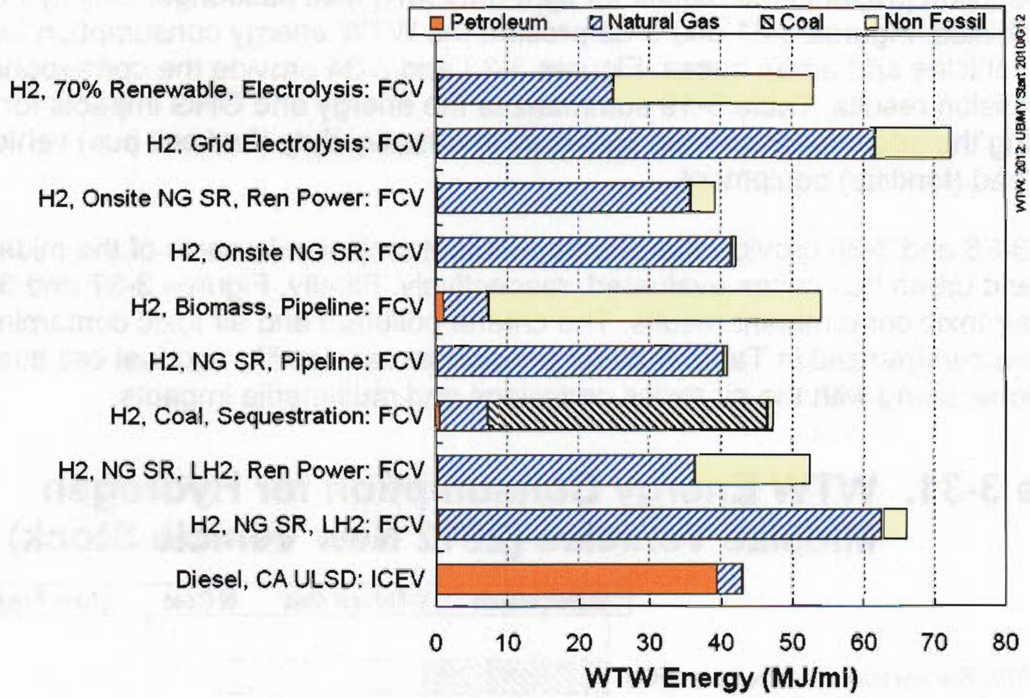


Figure 3-33. WTW GHG Emissions for Midsize Hydrogen Vehicles (2012 New Vehicle Stock)

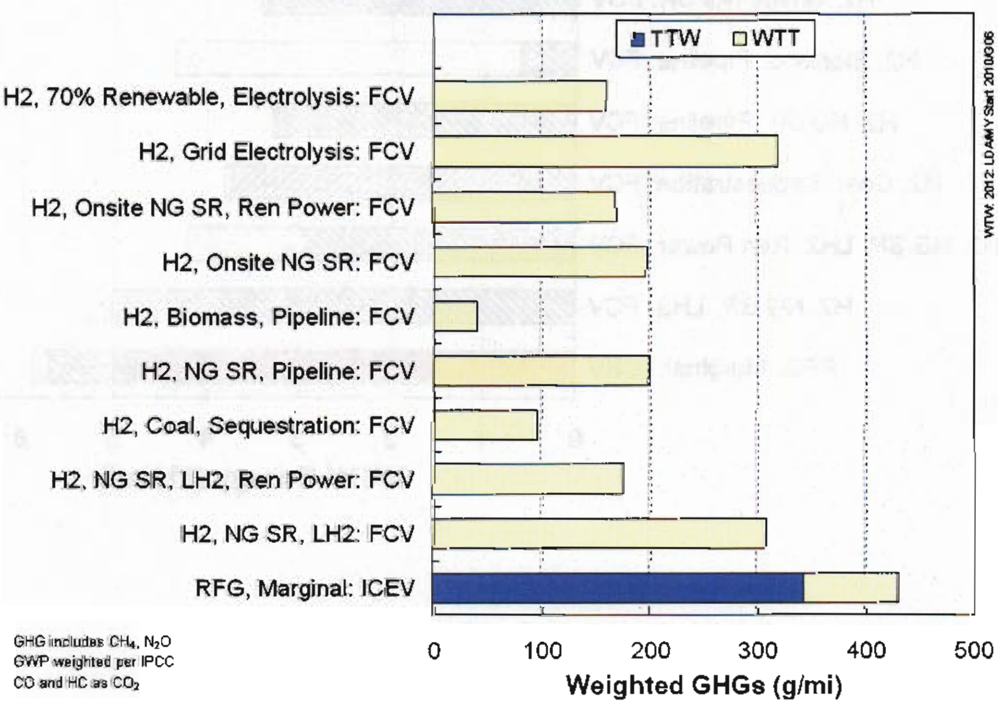


Figure 3-34. WTW GHG Emissions for Hydrogen Urban Buses (2012 New Vehicle Stock)

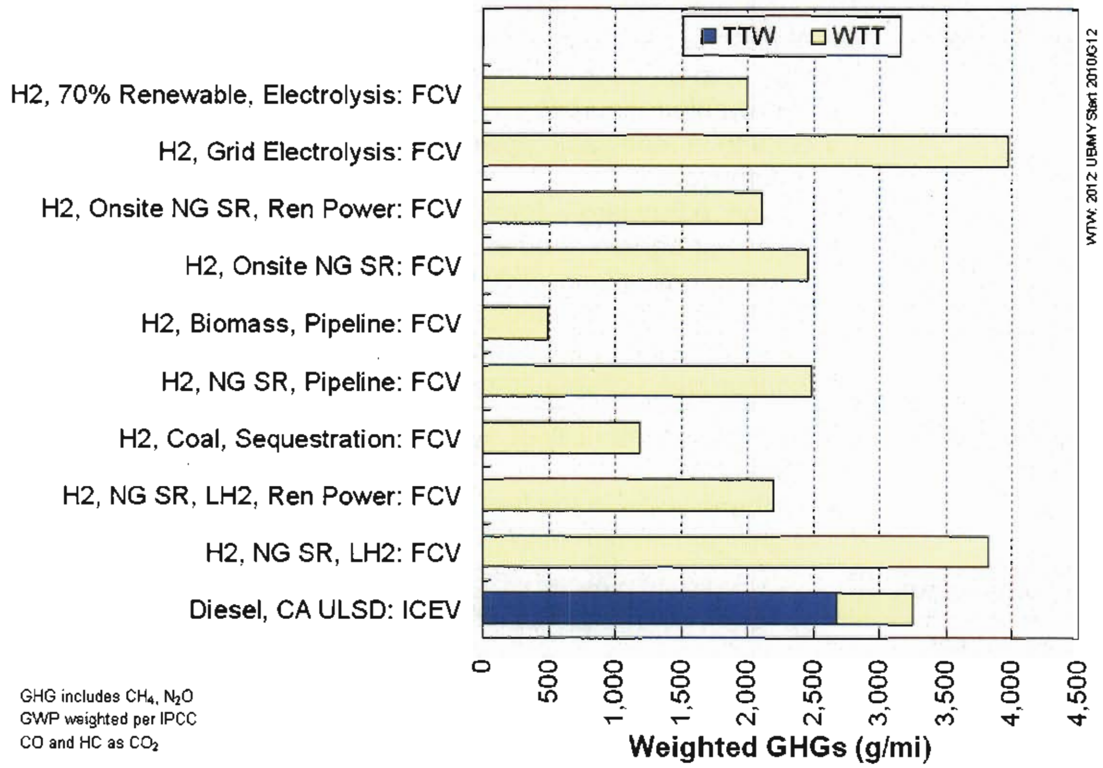


Table 3-19. Energy and GHG Impacts of Hydrogen Vehicles

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**	**Fuel Cell Bus**
Energy Impact		
Petroleum	99.7% reduction	99.6% reduction
Fossil Fuels		0% reduction
Natural Gas H_2	41% reduction	
Biomass H_2	89% reduction	
Electrolysis H_2	13% reduction	
GHG Impact		21% reduction
Natural Gas	54% reduction	
Biomass	91% reduction	
Electrolysis	26% reduction	

Figure 3-35. Criteria Pollutant Emissions for Midsize Hydrogen Vehicles (2012 New Vehicle Stock)

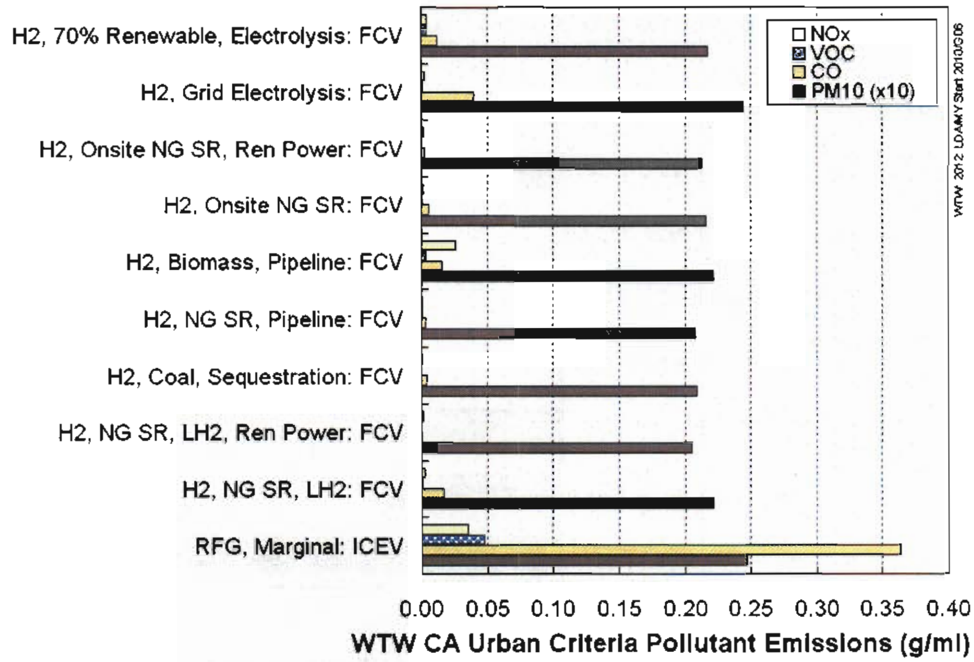


Figure 3-36. Criteria Pollutant Emissions for Hydrogen Urban Buses (2012 New Vehicle Stock)

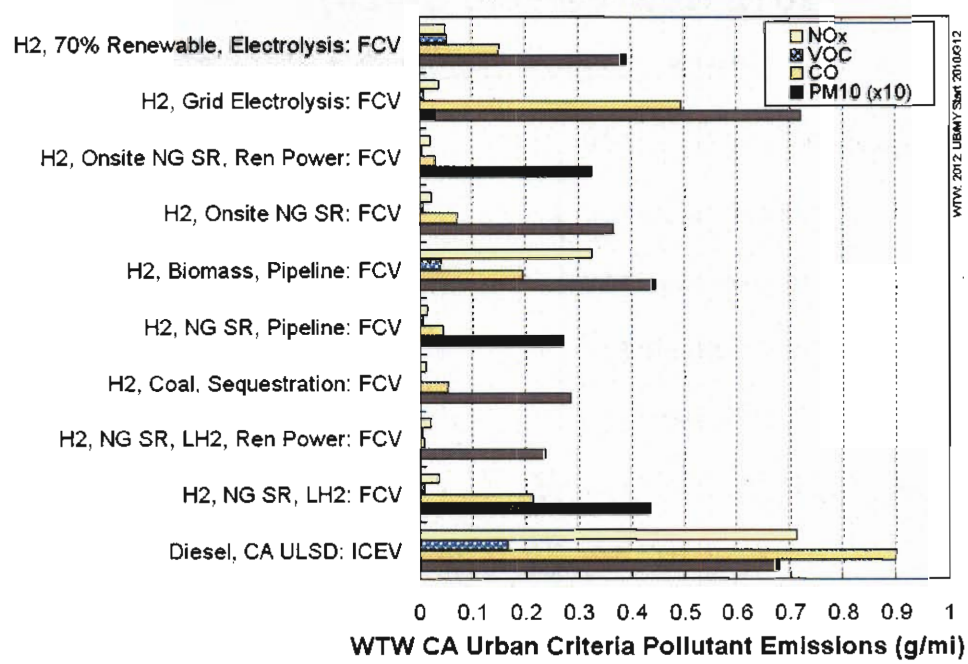


Figure 3-37. Air Toxic Emissions for Midsize Hydrogen Vehicles (2012 New Vehicle Stock)

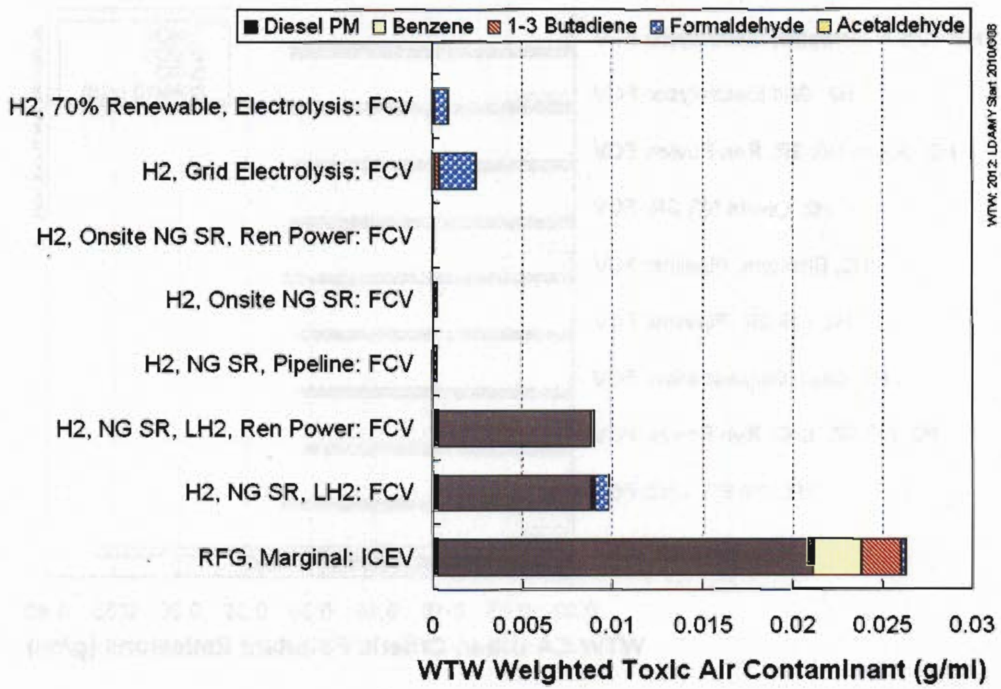


Figure 3-38. Air Toxic Emissions for Hydrogen Urban Buses (2012 New Vehicle Stock)

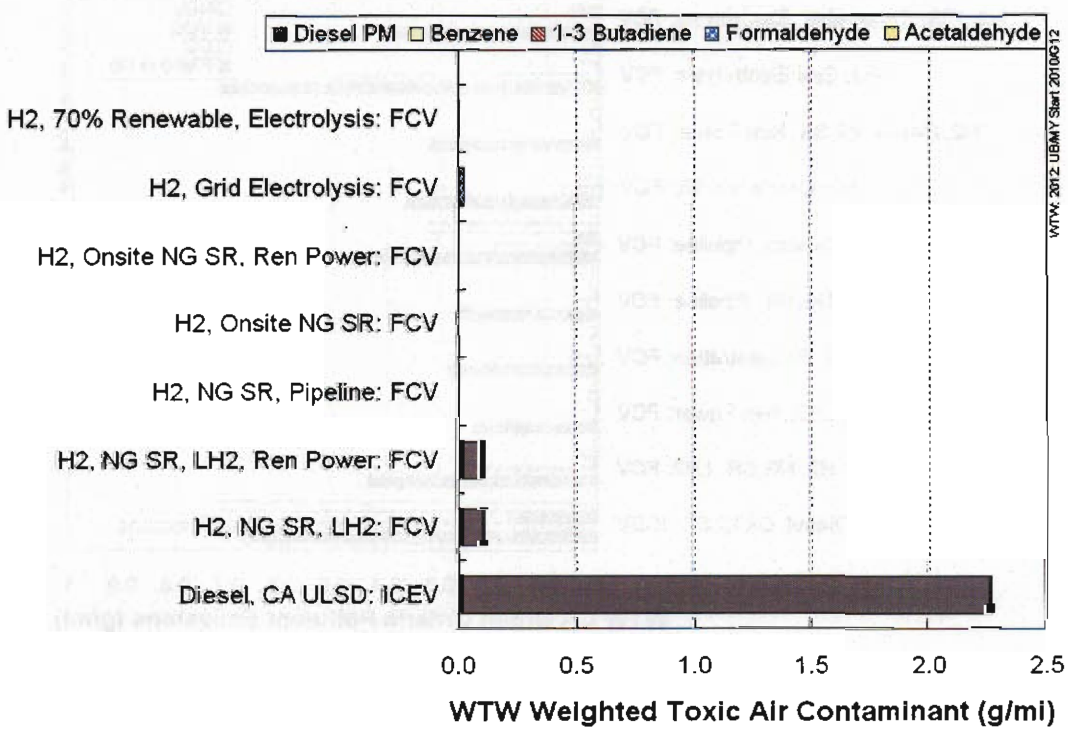


Table 3-20. Pollution Impacts of Hydrogen Vehicles

<table>
<tr><th>Parameter</th><th colspan="2">Pollutant Impact</th></tr>
<tr><td>Criteria Pollutants</td><td colspan="2">• Zero exhaust TTW 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 WTT 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 uses 2x less energy</td></tr>
<tr><td>Toxics</td><td colspan="2">• Benzene, 1-3 butadiene, and diesel PM are eliminated compared with conventional vehicles
• Formaldehyde from power plants and engines contributes to WTT emissions but weighted toxics emissions are well below those for conventional fuels</td></tr>
<tr><td>Multi-media Impacts</td><td colspan="2">• Gaseous fuel, spills do not affect water systems.
• No engine oil leaks with FCVs
• No diesel used to haul fuel except LH2 pathways</td></tr>
<tr><th>Comparison</th><th>Passenger Car</th><th>Fuel Cell Bus</th></tr>
<tr><td>Criteria Pollutants</td><td>1% to 13% PM_{10} reduction
96% to 99% reduction in all other pollutants</td><td>48% reduction in PM_{10}
93% to 96% reduction in all other pollutants</td></tr>
<tr><td>Weighted Toxics</td><td colspan="2">greater than 99% reduction</td></tr>
<tr><td>Multi-media Impacts</td><td colspan="2">Over 90% reduction in hydrocarbon spills</td></tr>
</table>

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 3-39 and 3-40 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 3-41 illustrates the criteria pollutant emission impacts for the synthetic fuel evaluation cases while Figure 3-42 provides the air toxics results. These results are summarized in Table 3-22 along with the air toxics emissions and multimedia impacts.

Figure 3-39. WTW Energy Consumption for Synthetic Fuel Vehicles (2012 New Stock)

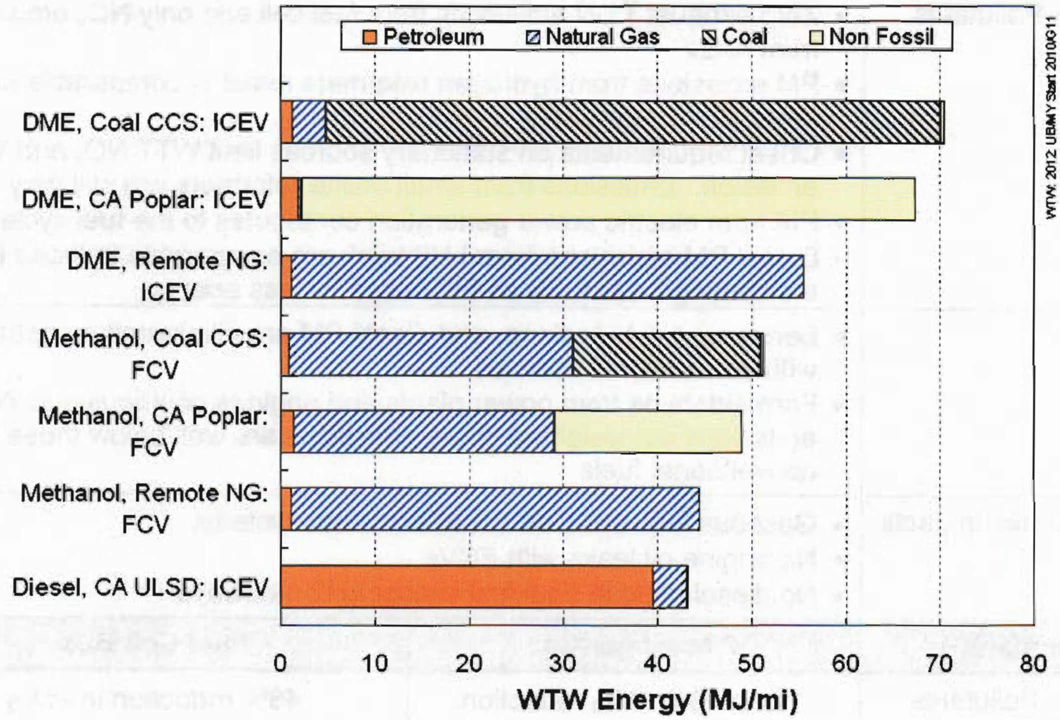


Figure 3-40. WTW GHG Emissions for Synthetic Fuel Vehicles (2012 New Stock)

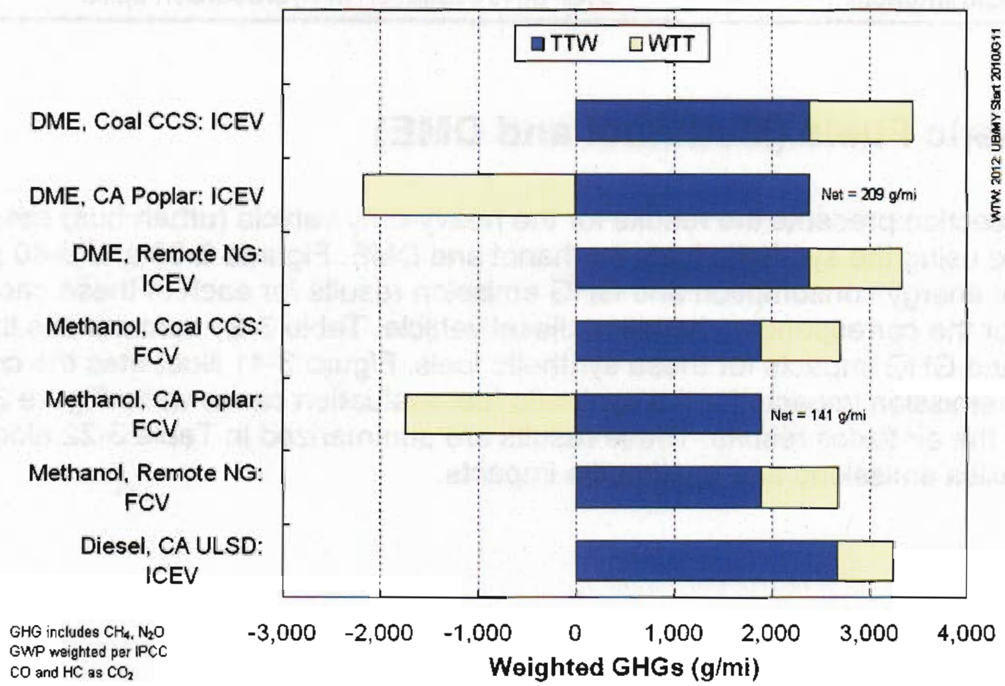


Table 3-21. Energy and GHG Impacts of Methanol and DME Buses

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 cycles. • 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	**DME UB**	**Methanol Fuel Cell UB**
Energy Impact		
Petroleum	95% to 97% reduction	97% to 98% reduction
Fossil Fuel		
Remote NG	29% increase	3% increase
CA Poplar	95% reduction	33% reduction
Coal CCS	62% increase	18% increase
GHG Impact		
Remote NG	3% increase	18% reduction
CA Poplar	94% reduction	96% reduction
Coal CCS	6% increase	17% reduction

Figure 3-41. Criteria Pollutant Emissions for Synthetic Fuel Vehicles (2012 New Stock)

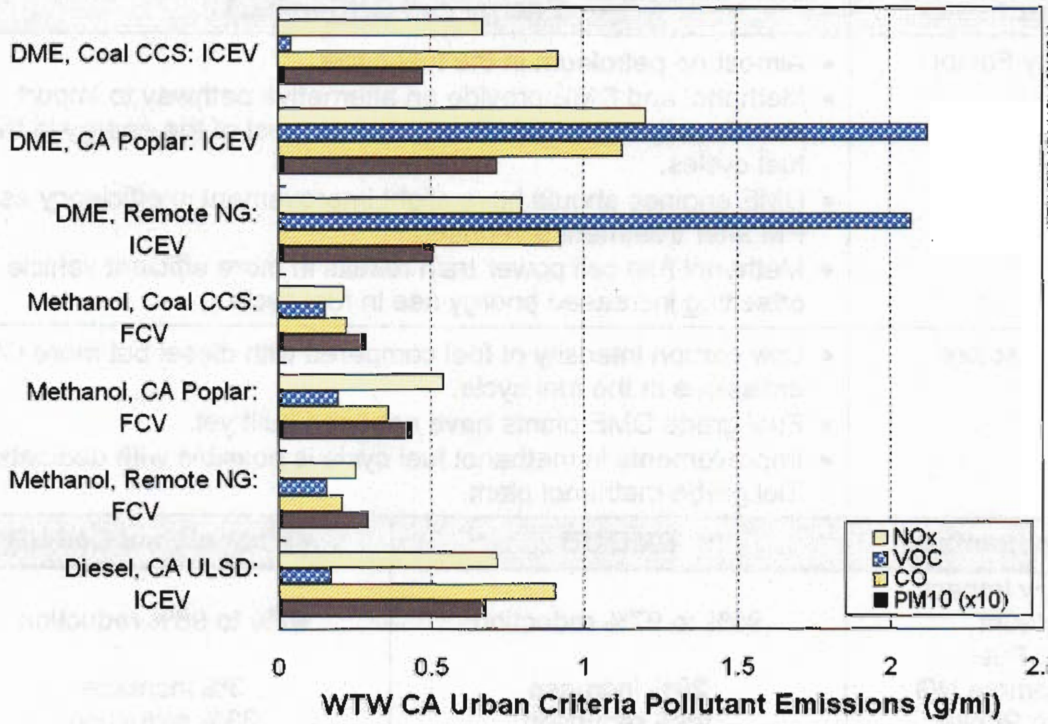


Figure 3-42. Air Toxic Contaminant Emissions for Synthetic Fuel Vehicles (2012 New Stock)

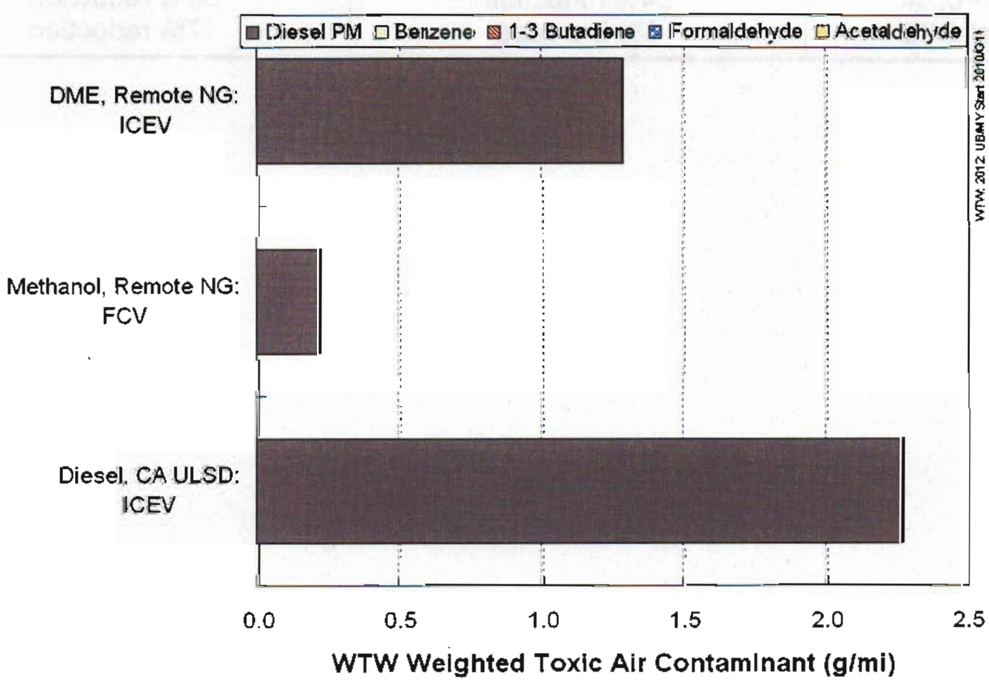


Table 3-22. Criteria Pollutant Impacts of Methanol and DME Buses

Parameter	Pollution Impact	
Criteria Pollutants	• Primary WTT emission source is natural gas engines and electric power plants for compression. • DME has a solvable VOC problem similar to LPG (GREET artifact does not show for coal, but should also be high).	
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	~40% reduction ~90% reduction
Multi-media Impacts	Over -90% hydrocarbon spills	

LPG

This subsection presents the results for mid-size passenger LPG-fueled vehicles. Figures 3-43 and 3-44 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 3-45 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 3-43. WTW Energy Consumption for LPG Vehicles (2012 New Vehicle Stock)

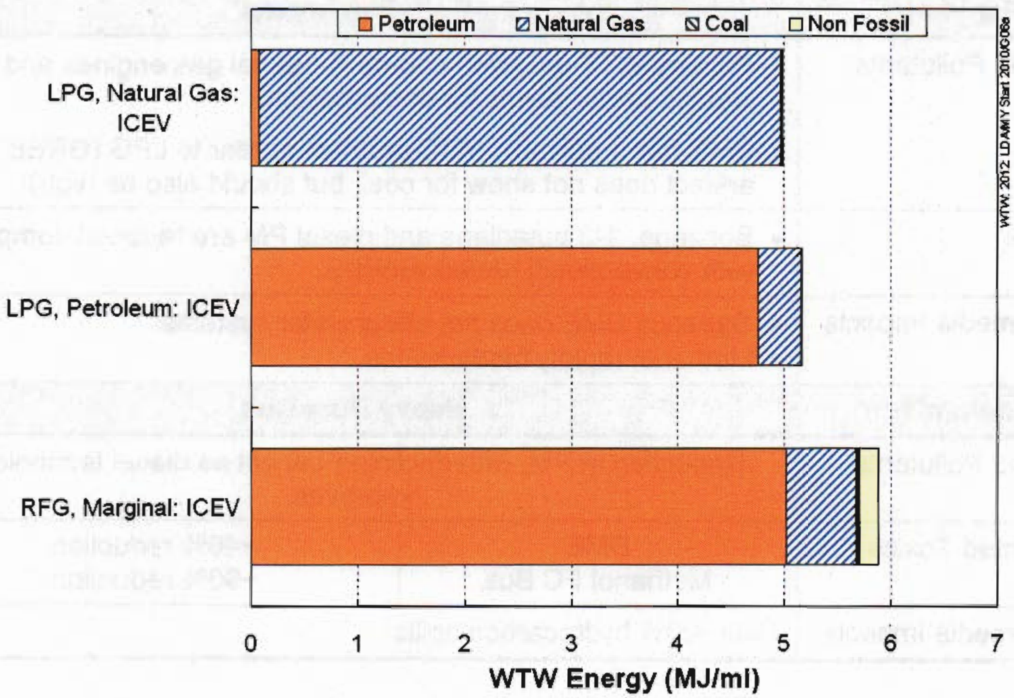


Figure 3-44. WTW GHG Emissions for LPG Vehicles (2012 New Vehicle Stock)

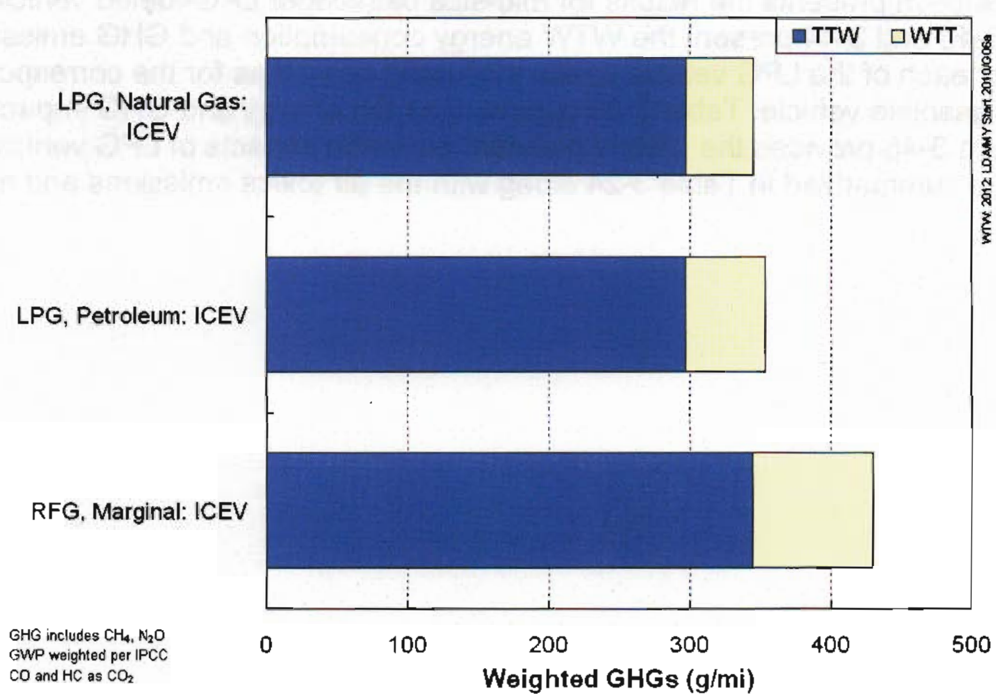


Table 3-23. Energy and GHG Impacts of LPG Vehicles

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 WTT energy input reduce vehicles GHG emissions.	
Comparison	**LPG (petroleum)**	**LPG (natural gas)**
Energy Impact Petroleum Fossil Fuel	 5% reduction 9% reduction	 98% reduction 12% reduction
GHG Impact 2012 2022	 18% reduction 18% reduction	 20% reduction 19% reduction

Figure 3-45. Criteria Pollutant Emissions for LPG Vehicles (2012 New Vehicle Stock)

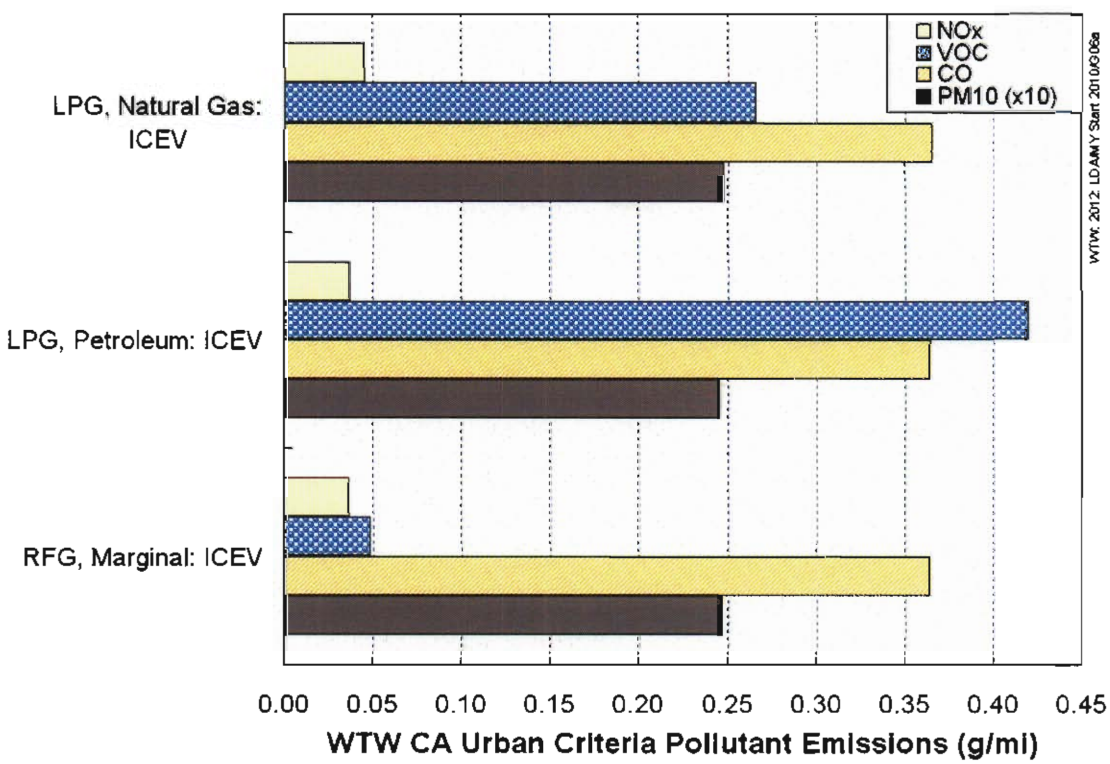


Figure 3-46. Air Toxic Contaminant Emissions for LPG Vehicles (2012 New Vehicle Stock)

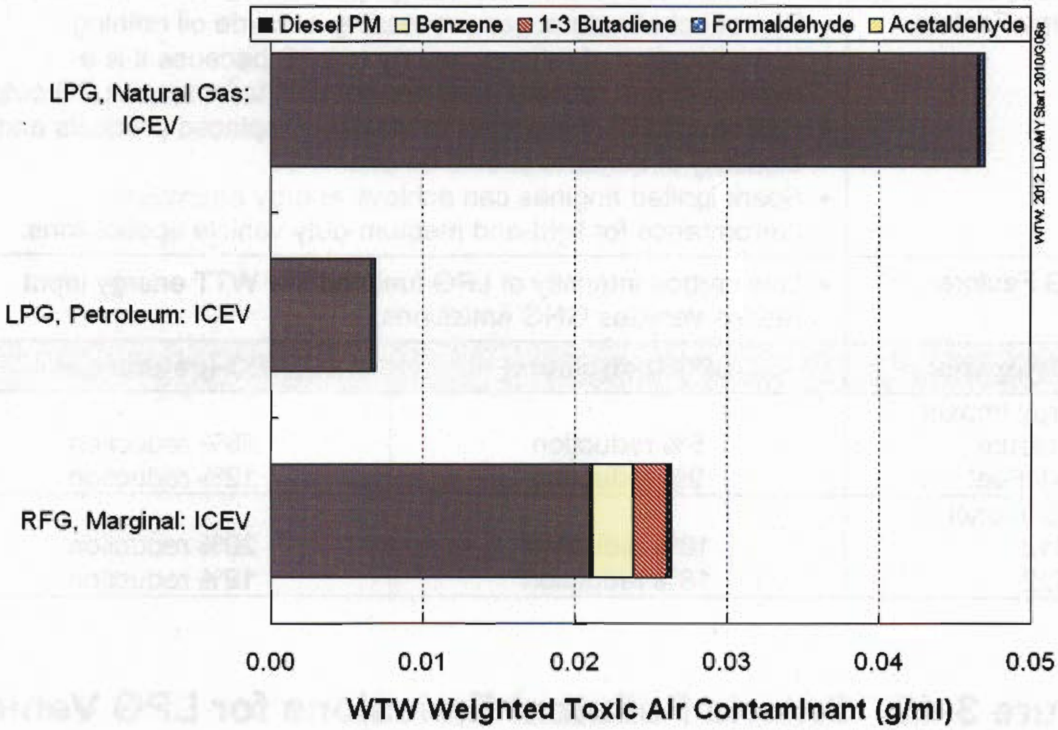


Table 3-24. Pollution Impacts of LPG Vehicles

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 – higher urban NO_x in the near term • 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 • WTT diesel PM_{10} ~ 10x higher for LPG case due to locomotive/truck transport assumptions. Vehicle diesel PM_{10} = 0.	
Multi-media Impacts	• Gaseous fuel, spills do not affect water systems.	
Comparison	**LPG (petroleum)**	**LPG (natural gas)**
Criteria Pollutants		
VOC	7X increase	5X increase
CO	0	0
NO_x	3% increase	26% increase
PM_{10}	0	0
Weighted Toxics	74% reduction	78% increase
Multi-media Impacts	Over -90% via reduction of hydrocarbon spills	

CHAPTER 4 DISCUSSION

The WTW analysis illustrates the key effects of alternative fuels on energy impacts, GHG emissions, criteria pollutant emissions, air toxics emissions, and multimedia impacts. Effects that reflect dominant assumptions, or 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 chapter are given in the Appendix.

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 related only to 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.

Petroleum Production and Refining

A wide range of petroleum processing pathways provide gasoline and diesel fuels for the United States. 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 District [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 diesel 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. The WTT GHG emissions decrease by 5 percent for every percentage point increase in refinery efficiency. A 5 percent change in WTT GHG emissions yields a one percent change in WTW GHG emissions.

Alternative 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.

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 of 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 assumed to be combined cycle natural gas combustion turbines with the California Renewables Portfolio Standard (RPS) imposed upon it. While this may be approximate in the near term, it is considered to be accurate once the new demand is adequately understood and planned for by the utilities. In the near term, an argument can be made that the new load would be served entirely by natural gas fired combined cycle combustion turbines. WTW results for both cases are provided.

Having said this, the resources used to achieve the RPS standard (wind, solar, geothermal, biomass combustion) drive the results. In the analysis we assumed that non-combustion renewable resources would satisfy the RPS (wind, solar, geothermal). If a significant portion of the RPS resources come from biomass boilers, the WTW criteria pollutant emissions will increase proportionally. The reader may perform this estimate using the data available in the appendices to the WTT and WTW reports. The WTT results for biomass combustion based electricity assume new units 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 non-attainment areas, they will be required to offset annual emissions of each non-attainment pollutant (NO_x and VOC), resulting in no net emission increase. Emissions of PM_{10} would likely also be offset in most areas of California, but power plant emissions for PM_{10} (very small) are included in the WTT and WTW values.

Another subtlety of the RPS requirement is the heavy reliance on wind power. Experience in Texas shows utilities are currently subject to an RPS-like requirement, in that a certain percentage of power sold must come from renewable resources. A counterproductive result of this requirement is that intermittent supplies of wind power 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.

However, using vehicle-to-grid technology and smart-charging, EVs and PHEVs have the capacity to counteract this result. EVs and PHEVs can be charged with intermittent generation, and market penetration of these vehicles will therefore facilitate additional wind generation to be brought online. Within the timeframe this analysis covers, vehicle owners will likely also be able to sell power to the grid, reducing the need to provide backup for intermittent resources.

WTT Modeling

Results for the WTT analysis depend on dominant assumptions regarding process energy inputs and allocation of byproducts. Some of the details of WTT 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; even then the contribution toward WTW energy is small. Thus, many times these effects were only qualitatively characterized.

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 byproducts and assumptions on land use impacts.

Transportation Logistics

Transportation distances and logistics also affect total WTT energy, but the energy inputs represent at most 6 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 WTW diesel PM and weighted air toxics emissions. In some instances the emissions for fuel production inside California are higher, while the emissions outside California are higher for other fuels. The emissions in California non-attainment areas are grouped into the urban emissions category in the GREET model for North America. Thus, the breakdown of emissions by fuel delivery mode can only be determined using the GREET model configured for California boundaries.

Greenhouse Gas (GHG) Emissions

A broad range of factors contributes to WTW GHG emissions. These include:

- WTT energy inputs and carbon intensity (as measured by its fractional carbon content) of the finished fuel.
- Vehicle energy consumption.
- Vehicle and WTT 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 was outside the boundary of the present study, but they do need to be addressed on a case-by-case basis and clearly added to the analysis results as a separate item.

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. These adopted and projected standards were employed in the present analyses.

New alternative fuel production facilities located in California will need to go through New Source Review permitting. Because most of California urban areas are classified as ozone non-attainment areas, these new facilities will be required to install Best Available Control Technology (BACT) for all criteria pollutants and 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 because the regulations in place will not allow such incareases.

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 California.

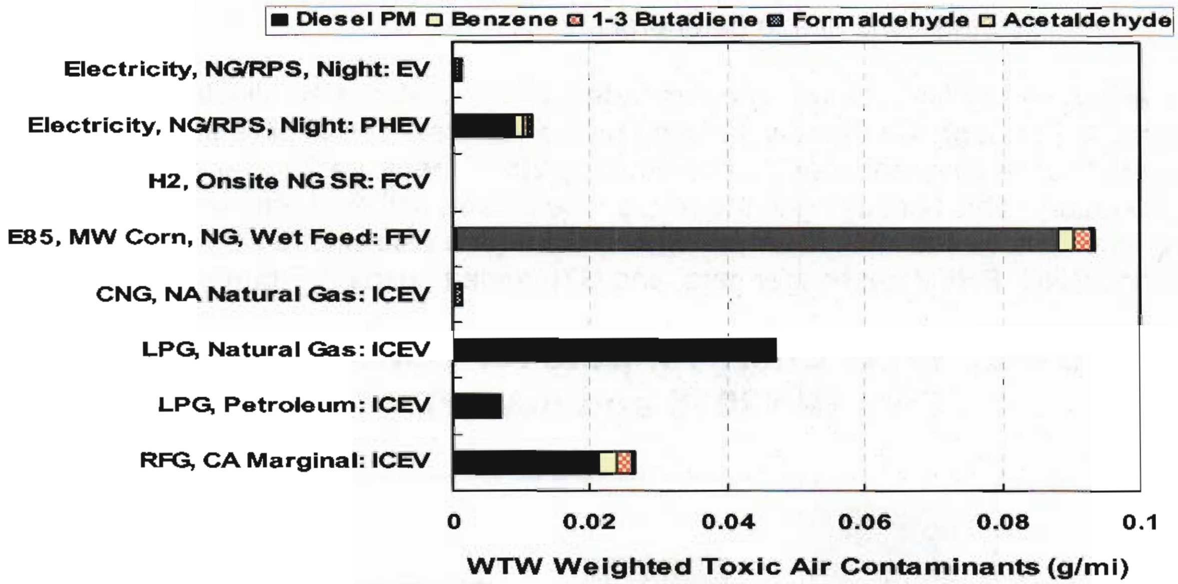
One area identified for further investigation is the PM emission factor for natural gas combined cycle combustion turbines (CCCTs). The emission factor used for these units, was taken from a single source test report. While the factor used is considered more accurate than the significantly higher AP-42 value, a survey of additional source test data should be undertaken. Another subtlety for PM_{10} emissions is that the stationary sources quantify particulate matter emissions with an entirely different method than mobile sources. The stationary method employs a sampling train that catches both solid particulate matter (the filter catch) and condensibles (nitrates and sulfates). While the mobile source method catches some condensibles as well, it is not clear whether the two methods yield results that are additive. For this analysis, it has been assumed that PM_{10} emissions from stationary and mobile sources are equivalent and may be added together.

Gasoline vehicle fuel economy, power plant efficiency, and transmission losses play significant roles in CO_2 emissions from EV operation. Because total non-methane organic gases (NMOG) from EV operation are 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). In fact, the average heat rate for existing California CCCTs in 2005 was under 7500 Btu/kWh (HHV). A key parameter in the marginal heat rate for EV operation is the total generation capacity. The Energy Commission's analysis is based on future reserve margins being lower than historical levels as deregulation would tend toward 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.

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 contaminants. 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 E-85 (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 liquid fuel delivery are driven to a large extent by transportation assumptions. Liquid fuels requiring significant rail and truck distances result in higher diesel PM emissions. E-85 toxic emissions 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 petroleum based LPG are lower than natural gas based LPG because of the significantly shorter transport distances.

Figure 4-1. Urban California Weighted Air Toxics Emissions for New Passenger Car Vehicles (2012 New Stock)



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 combined 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 2010) with a growth in vehicle emissions due to deterioration.

The effects of key time dependent parameters in the analyses are illustrated in Figures 4-2 through 4-4 for new gasoline fueled vehicles. The vehicle stock considers all model years 2010 and newer. Therefore by 2030, there are 20 year old vehicles in the inventory. This fleet aging is the reason the criteria pollutant emissions increase over time. The trends in GHG emissions over time are also illustrated for biomass ethanol, 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 (MY2010 and newer)

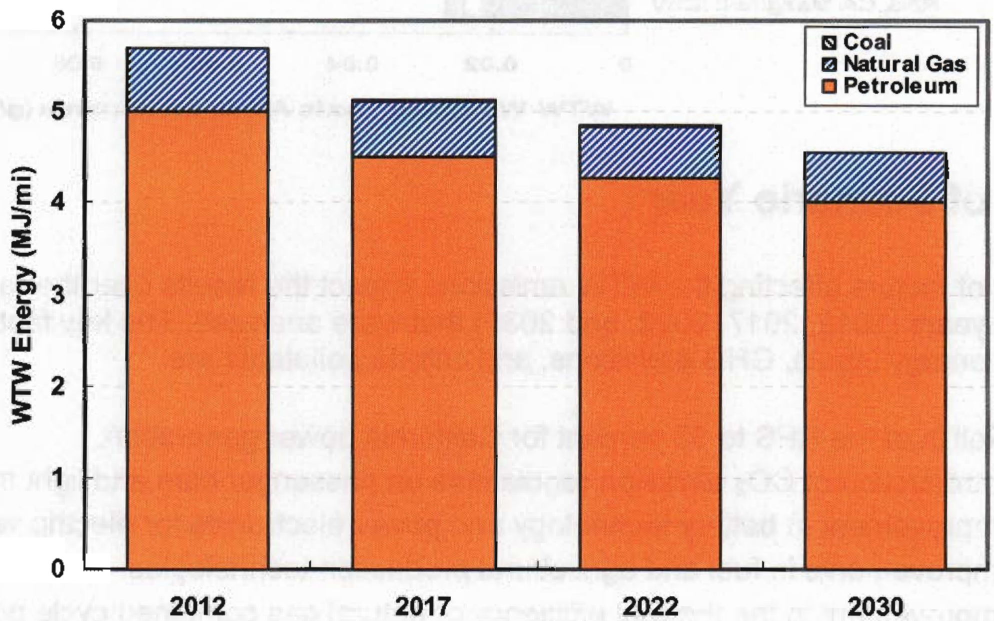


Figure 4-3. WTW GHG Emissions for Gasoline Passenger Cars (MY2010 and newer)

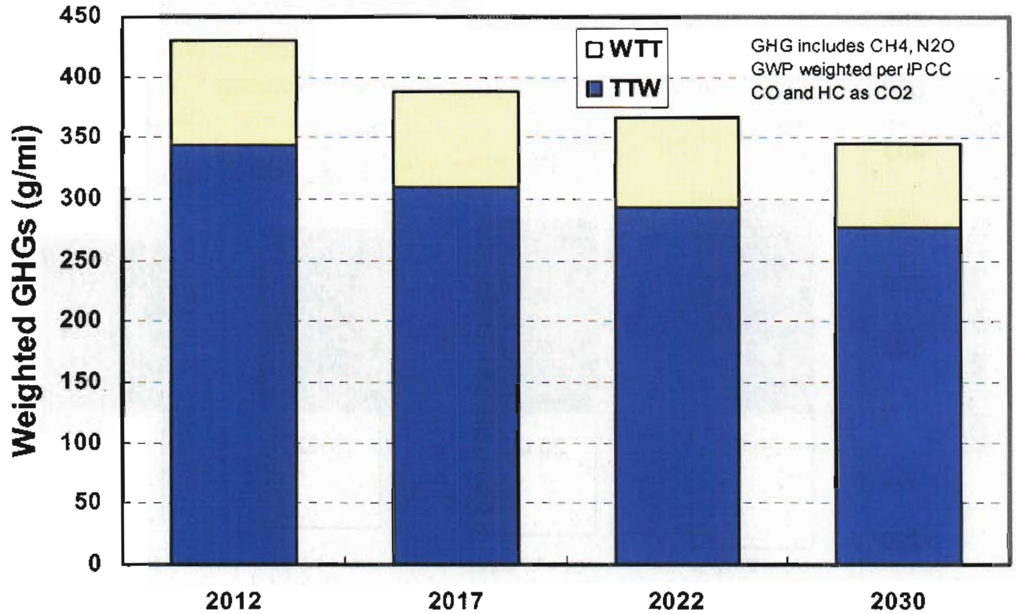


Figure 4-4. WTW Criteria Pollutant Emissions for Gasoline Passenger Cars (MY2010 and newer)

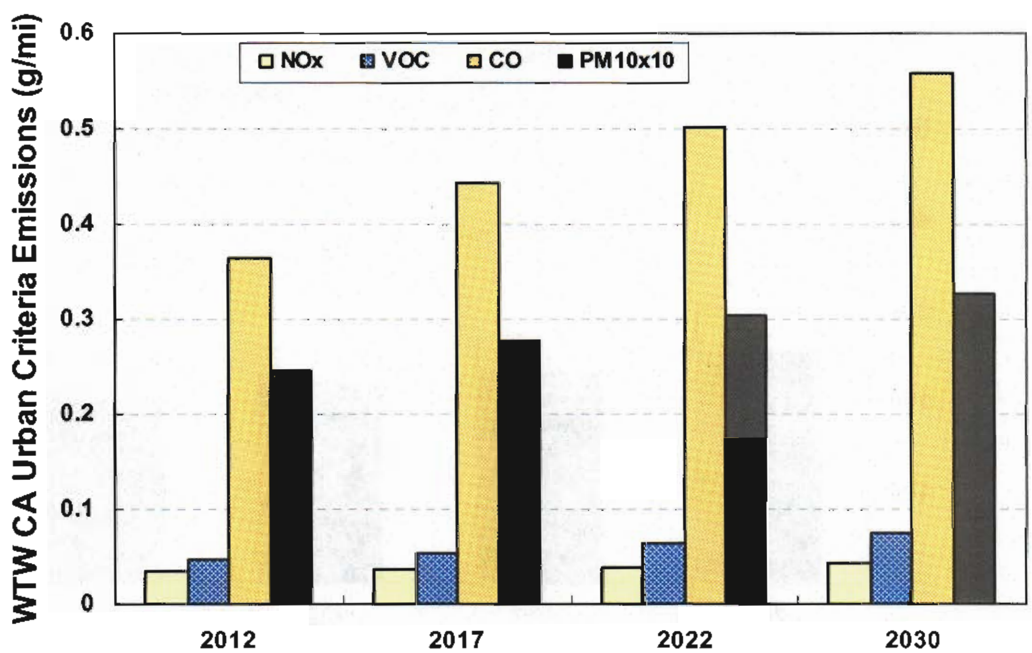


Figure 4-5. WTW GHG Emissions for Biomass Based E-85 Passenger Cars (MY2010 and newer)

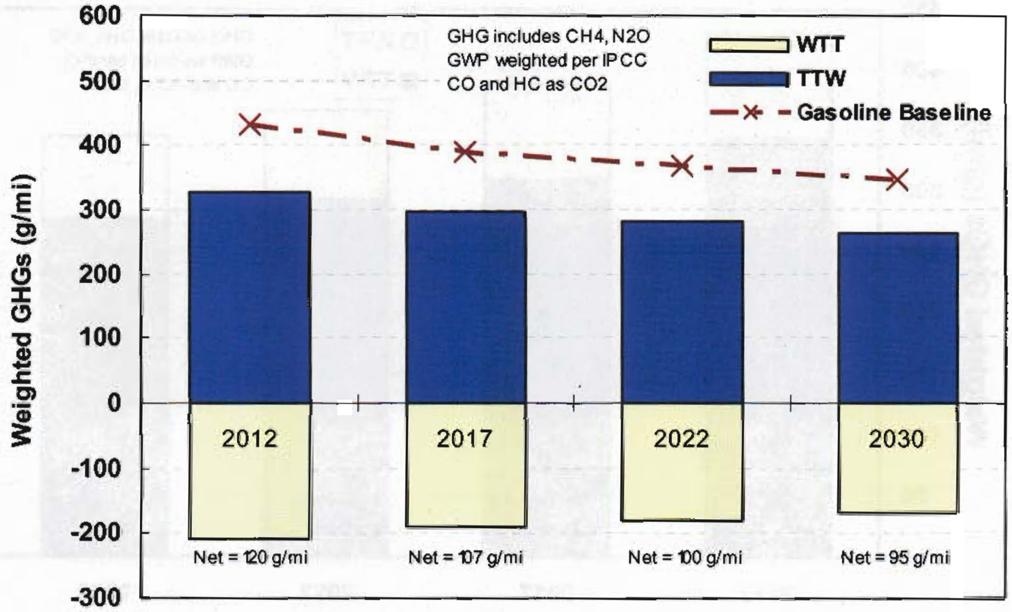


Figure 4-6. WTW GHG Emissions for CNG Passenger Cars (MY2010 and newer)

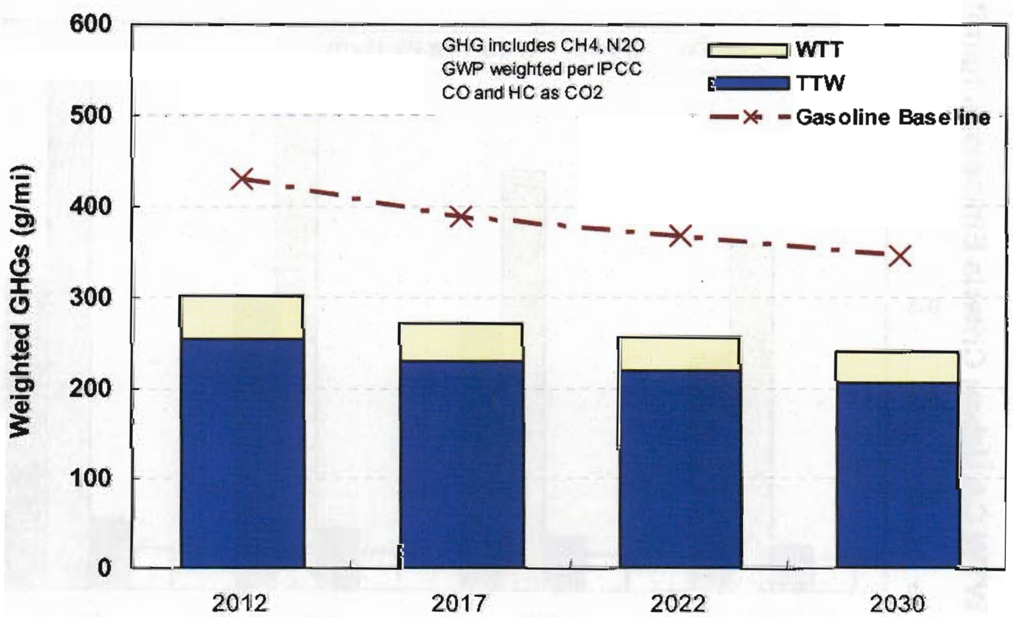


Figure 4-7. WTW GHG Emissions for PHEV Passenger Cars (MY2010 and newer)

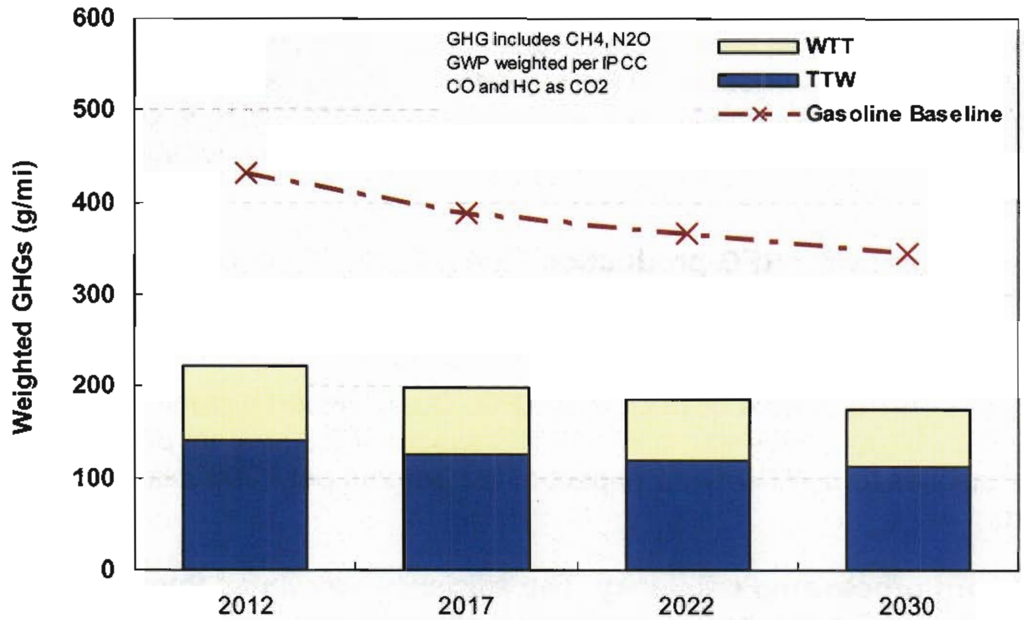
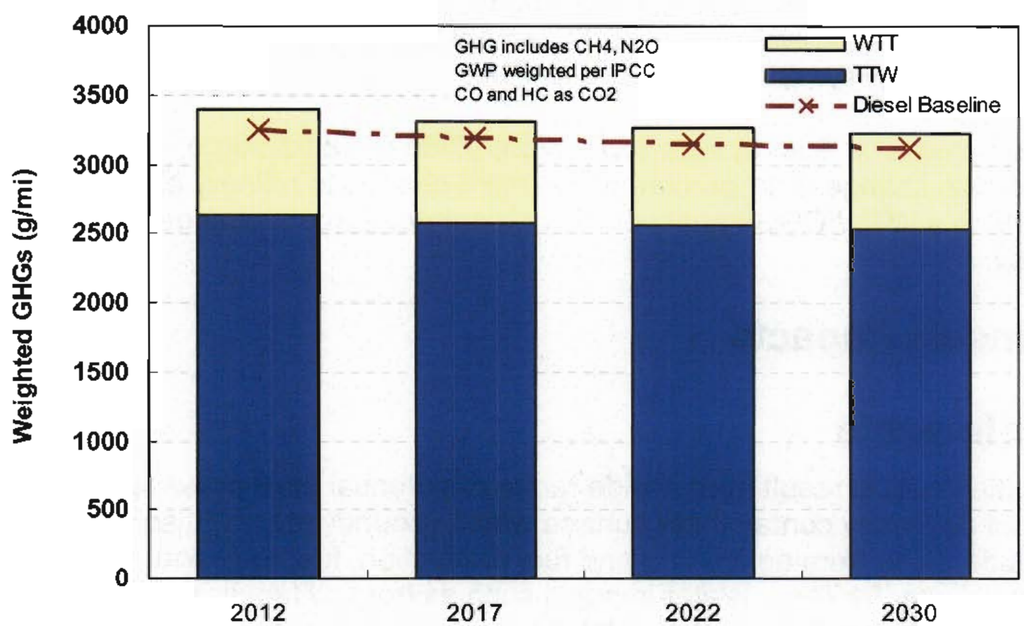


Figure 4-8. WTW GHG Emissions for Natural Gas Derived FTD30 Buses (MY2010 and newer)



Key WTW Sensitivities

This full fuel cycle analysis is relatively complex, with many assumptions made about new and evolving processes. A rigorous sensitivity analysis was not possible within the time constraints of this analysis. To a certain extent, the number of different cases analyzed here helps us understand the impacts of various assumptions. However, to shed a bit more light on key assumptions and their impact, a simple sensitivity study done at the WTT level are extended here to WTW results. Key variables tested and their results are:

Refinery efficiency for RFG production. The refinery efficiency was varied from 82.1 percent to 86.1 percent with a WTT GHG impact of 5 percent. This impact translates to a WTW GHG impact of 1 percent.

Marine transport distance of marginal RFG. The transport distance was varied from 5000 miles to 10,000 miles with a WTT GHG impact of 0.8 percent per 1000 miles. This impact translates to a WTW GHG impact of 0.2 percent per 1000 miles of marine transport.

Ethanol corn processing efficiency. The efficiency was varied from 30,000 to 34,000 Btu/gal. The WTT GHG impact of processing efficiency is 56 percent per 1000 Btu/gal change. This translates to a WTW GHG impact for E-85 of 3.9 percent per 1000 Btu/gal.

Biomass ethanol consumed as process energy. The percent consumed was varied from 40 to 50 percent with a WTT GHG impact of 0.1 percent per percent change in consumption. This translates to an 0.03 percent impact per percent change in consumption on WTW GHG emissions of E-85.

CNG Compressor efficiency was varied from 97.66 to 98.03 percent. The WTT GHG impact of this change is 11 percent per percent change in refinery efficiency. This translates to a WTW GHG impact of 1.7 percent per percent change in refinery efficiency.

Multimedia Impacts

Water Impacts

Multimedia impacts result from a wide range of potential discharges to the environment that could ultimately contaminate surface water, groundwater, 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

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.

Fuel Spill Impacts

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 be 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.

Summary Multimedia Impacts

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.

CHAPTER 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 in the 2012 through 2030 timeframe.

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 WTT impacts.

Vehicle emissions depend on vehicle energy consumption combined with the carbon intensity of the fuel and emission factors for WTT processes. 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.

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.
2. Alternative fuel use effects on off-road equipment GHG emissions equipped with internal combustion engines are comparable to the effects for on-road vehicles.
3. A wide range of GHG emission factors are achievable for various hydrogen and electric generation pathways. Significant WTW 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 due to the high energy efficiency of electric drive technologies and the improvement in gasoline vehicle energy consumption for plug-in hybrid applications. Hydrogen Fuel Cell Vehicles, another form of electric drive technology, also reduce GHG emissions by more than 50 percent and establishes that whether powered by batteries or fuel cells, electric drive vehicles can significantly reduce energy use and emissions.

6. GHG emissions from biofuels production and use depend on agricultural inputs, allocation to byproducts, and the level and carbon intensity of process energy inputs.

The GHG emissions from biofuels production and use depend on many other factors. Most important are changes in land use that vary substantially with scenario assumptions. The analysis here provides only the vehicle emissions and WTT process inputs employed. Impacts associated with changes in land use should be carefully quantified and added to these values. Land use issues associated with a modest growth in United States-based energy crops are likely to be somewhat insignificant because energy crops are likely to replace other crops rather than expand the use of additional land for agriculture. These economic impacts are consistent with producing 5 billion gallons of ethanol per year in the United States. 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 evaluated further.

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

- Some fuel blends such as biodiesel and FTD 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. It is not clear whether the new engines will be optimized to reduce emissions below standards or for fuel economy.

- Assumptions regarding the marginal source of gasoline result in the attribution of emissions to refineries and fuel production facilities outside California. New fuel production facilities in California would be subject to stringent emission constraints. In general criteria pollutant emissions in California tend to decrease for fuels that are produced in the state. However, emissions outside of California are generally larger for 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. 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. This point is clearly demonstrated in the difference between the two LPG production cases.

- Criteria pollutant emissions for electric transportation are comparable to, or lower than, those from conventional fuels. The lower emission levels result from efficient new power plants that are required to offset NO_x and VOC emissions combined with very efficient vehicles. Emissions associated with the average statewide generation mix are higher than the marginal mix, but are still below the baseline vehicle.

- 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.

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 United States.
- 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.

CHAPTER 6 RECOMMENDATIONS

Based on the information found in this study, the following are recommendations to support the requirements of AB 1007 and advance efforts in performing full fuel cycle analyses. The recommendations include those regarding analysis methods, data collection, and system boundary considerations.

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 fuel 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 WTT 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 grams per mile 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 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 toxics emissions.

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. More data are needed to confirm natural gas combined cycle combustion tubine PM_{10} emissions. It is widely recognized that the AP-42 emission factor is very high; the value used in this analysis is from a single source test conducted at a combined cycle plant outside of Sacramento (it is much lower than the AP-42 value). A thorough review of available source test data is needed to better quantify this parameter.

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. The values used in this report come from a single source test.

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 (for example, digester gas, LPG, residential solar power), the attribution of feedstocks to alternative fuels production and use should be carefully examined 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 have a dominant impact on biofuel pathways. 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 prevent tropical deforestation associated with fuel production.

APPENDIX A. CALCULATION RESULTS

The following tables and figures document the GREET model and other calculation results that are shown in the figures included in Chapter 3 of this report. Figures that detail the energy inputs, GHG emissions, criteria pollutant emissions, and air toxics emissions in 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 figures for each fuel are figures that document the effects of the scenario years on energy inputs and emissions results for the fuel and vehicle combinations discussed in Chapter 4 of the report. Scenario year effects figures are given for gasoline passenger cars, E-85 passenger cars, CNG passenger cars, PHEV passenger cars, diesel buses, and natural gas derived FTD30 buses.

Each figure 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 figures is identified by an identifier termed the WTT Case ID. Table A-1 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 Chapters 3 and 4 of the report.

Table A-1. GREET-CA Fuel Cycle Cases

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	E-10, Corn, MW EtOH
E71	1	E-85, Corn, MW mix/BR
E72	1	E-85, Corn, MW Coal
E73	1	E-85, Corn, MW NG
E74	1	E-85, Corn, MW NG, Wet Feed
E75	3	E-85, CA Corn, Wet Feed
E76	3	E-85, CA Corn, Wet Digester
E78	3	E-85, CA Poplar, Cellulose
E79	3	E-85, CA Forest Residue
E81	3	E-85, CA Switch Grass
E84	3	E-85, Brazil Sugar Cane
E98	1	E-90, 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)

Figure A-1. LDA Vehicle Class: All Model Years
(Gasoline, E10, Diesel, LPG and CNG)

Scenario Year 2012: LDA Vehicle Class: All Model Years (blend)															
WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G AvICE	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	6.27	6.27	4.65	3.38	7.08	5.25	6.37	6.19	4.59	4.89	5.68	5.49	5.46	6.02
Petroleum	MJ/mi	5.52	5.52	4.09	2.21	5.59	4.14	5.72	5.36	3.97	4.47	5.23	0.08	0.02	0.07
Natural Gas	MJ/mi	0.74	0.74	0.55	1.17	1.25	0.93	0.65	0.80	0.60	0.42	0.45	5.39	5.44	5.96
Coal	MJ/mi	0.02	0.02	0.01	0.01	0.25	0.18	0.00	0.03	0.02	0.00	0.00	0.02	0.00	0.00
Non Fossil	MJ/mi	0.21	0.21	0.16	0.20	0.03	0.02	0.01	0.37	0.27	0.01	0.02	0.00	0.03	0.00
WTT	MJ/mi	1.43	1.43	1.06	1.07	2.06	1.52	1.32	1.51	1.12	0.85	0.79	0.59	0.58	1.12
TTW	MJ/mi	5.05	5.05	3.74	2.51	5.05	3.74	5.05	5.05	3.74	4.04	4.91	4.91	4.91	4.91
GHGs (weighted)															
WTT	g/mi	96	96	71	92	166	123	100	93	69	67	63	54	51	100
TTW	g/mi	377	377	282	153	377	282	377	377	282	309	326	326	280	280
TOTAL	g/mi	473	473	353	245	543	405	477	470	350	375	389	380	331	380
Criteria, Total															
VOC	g/mi	0.394	0.351	0.333	0.042	0.341	0.326	0.345	0.356	0.337	0.220	0.621	0.472	0.176	0.183
CO	g/mi	3.004	2.750	2.719	0.192	2.716	2.693	2.719	2.774	2.736	0.823	2.700	2.701	2.674	2.714
NOx	g/mi	0.557	0.543	0.460	0.142	0.408	0.360	0.524	0.557	0.471	1.685	0.359	0.411	0.254	0.577
PM10 (x10)	g/mi	0.604	0.603	0.533	0.336	0.835	0.705	0.550	0.644	0.563	1.548	0.397	0.409	0.349	0.450
Criteria, Urban															
VOC	g/mi	0.349	0.306	0.300	0.019	—	—	0.306	0.307	0.300	0.191	0.590	0.420	0.143	0.143
CO	g/mi	2.885	2.631	2.631	0.138	—	—	2.631	2.632	2.631	0.758	2.632	2.633	2.632	2.631
NOx	g/mi	0.248	0.234	0.231	0.014	—	—	0.233	0.235	0.232	1.467	0.235	0.244	0.226	0.229
PM10 (x10)	g/mi	0.338	0.337	0.336	0.227	—	—	0.337	0.337	0.336	1.388	0.336	0.338	0.334	0.335
Urban Toxics, (weighted)															
Benzene	g/mi	2.8E-02	2.3E-02	2.3E-02	1.1E-03	—	—	2.3E-02	2.3E-02	2.3E-02	1.7E-02	3.1E-05	5.4E-05	1.0E-04	1.0E-04
1-3 Butadiene	g/mi	3.1E-02	2.6E-02	2.6E-02	8.4E-04	—	—	2.6E-02	2.6E-02	2.6E-02	9.5E-03	1.7E-05	1.5E-04	2.5E-04	2.6E-04
Formaldehyde	g/mi	2.9E-03	2.2E-03	2.2E-03	4.5E-04	—	—	2.2E-03	2.2E-03	2.2E-03	2.6E-02	2.2E-03	2.2E-03	2.8E-03	2.8E-03
Acetaldehyde	g/mi	3.0E-04	2.2E-04	2.2E-04	2.4E-05	—	—	2.2E-04	2.2E-04	2.2E-04	5.8E-03	2.2E-04	2.3E-04	2.5E-04	2.5E-04
Diesel PM	g/mi	2.3E-02	2.3E-02	1.7E-02	9.3E-03	—	—	2.0E-02	2.6E-02	1.9E-02	5.7E+00	7.3E-03	5.1E-02	0.0E+00	1.7E-02

Figure A-1. LDA Vehicle Class: All Model Years (continued)

Gasoline, E10, Diesel, LPG and CNG

Scenario Year 2017: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G Av ICE	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	5.68	5.68	4.21	3.02	6.39	4.73	5.77	5.61	4.15	4.43	5.14	4.98	4.93	5.45
Petroleum	MJ/mi	5.00	5.00	3.70	2.00	5.06	3.75	5.18	4.86	3.60	4.05	4.74	0.08	0.02	0.06
Natural Gas	MJ/mi	0.67	0.67	0.49	1.01	1.11	0.82	0.59	0.73	0.54	0.38	0.40	4.89	4.91	5.39
Coal	MJ/mi	0.01	0.01	0.01	0.01	0.21	0.16	0.00	0.03	0.02	0.00	0.00	0.02	0.00	0.00
Non Fossil	MJ/mi	0.19	0.19	0.14	0.20	0.02	0.02	0.01	0.33	0.25	0.01	0.01	0.00	0.03	0.00
WTT	MJ/mi	1.29	1.29	0.96	0.93	1.83	1.36	1.20	1.36	1.01	0.77	0.70	0.53	0.52	1.01
TTW	MJ/mi	4.58	4.58	3.39	2.28	4.58	3.39	4.58	4.58	3.39	3.66	4.45	4.45	4.45	4.45
GHGs (weighted)															
WTT	g/mi	86	86	64	80	147	109	90	83	62	60	57	49	46	90
TTW	g/mi	343	343	256	139	343	256	343	342	256	281	296	296	255	255
TOTAL	g/mi	429	429	320	219	490	366	433	426	318	341	353	345	301	344
Criteria, Total															
VOC	g/mi	0.269	0.263	0.247	0.042	0.255	0.241	0.258	0.267	0.250	0.187	0.521	0.386	0.118	0.125
CO	g/mi	1.891	1.857	1.829	0.214	1.827	1.807	1.831	1.878	1.845	0.777	1.813	1.814	1.790	1.826
NOx	g/mi	0.424	0.422	0.349	0.128	0.303	0.261	0.407	0.433	0.357	1.657	0.257	0.305	0.166	0.458
PM10 (x10)	g/mi	0.572	0.572	0.511	0.332	0.772	0.659	0.526	0.607	0.537	1.377	0.390	0.402	0.351	0.442
Criteria, Urban															
VOC	g/mi	0.229	0.224	0.218	0.021	—	—	0.223	0.224	0.218	0.161	0.494	0.340	0.089	0.089
CO	g/mi	1.786	1.752	1.751	0.166	—	—	1.752	1.752	1.751	0.718	1.752	1.753	1.753	1.752
NOx	g/mi	0.149	0.147	0.145	0.014	—	—	0.146	0.148	0.146	1.461	0.148	0.156	0.143	0.145
PM10 (x10)	g/mi	0.340	0.340	0.339	0.237	—	—	0.340	0.340	0.339	1.237	0.339	0.341	0.338	0.339
Urban Toxics, (weighted)															
Benzene	g/mi	1.6E-02	1.6E-02	1.5E-02	1.2E-03	—	—	1.6E-02	1.6E-02	1.5E-02	1.4E-02	1.7E-05	3.7E-05	9.2E-05	9.4E-05
1-3 Butadiene	g/mi	1.7E-02	1.6E-02	1.6E-02	9.9E-04	—	—	1.6E-02	1.6E-02	1.6E-02	8.0E-03	9.5E-06	1.3E-04	2.3E-04	2.4E-04
Formaldehyde	g/mi	1.5E-03	1.4E-03	1.4E-03	4.0E-04	—	—	1.4E-03	1.4E-03	1.4E-03	2.2E-02	1.4E-03	1.4E-03	2.0E-03	2.0E-03
Acetaldehyde	g/mi	1.5E-04	1.3E-04	1.3E-04	2.1E-05	—	—	1.3E-04	1.4E-04	1.3E-04	4.9E-03	1.3E-04	1.5E-04	1.7E-04	1.7E-04
Diesel PM	g/mi	1.9E-02	1.9E-02	1.4E-02	7.4E-03	—	—	1.5E-02	2.1E-02	1.5E-02	5.0E+00	3.5E-03	4.3E-02	0.0E+00	1.5E-02

Figure A-1. LDA Vehicle Class: All Model Years (continued)

Gasoline, E10, Diesel, LPG and CNG

Scenario Year 2022: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G Av ICE	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	5.10	5.10	3.78	2.67	5.72	4.24	5.18	5.04	3.73	3.98	4.61	4.48	4.43	4.87
Petroleum	MJ/mi	4.49	4.49	3.33	1.80	4.55	3.37	4.66	4.37	3.23	3.64	4.26	0.07	0.02	0.05
Natural Gas	MJ/mi	0.59	0.59	0.44	0.86	0.98	0.73	0.52	0.65	0.48	0.34	0.35	4.39	4.41	4.81
Coal	MJ/mi	0.01	0.01	0.01	0.01	0.19	0.14	0.00	0.02	0.02	0.00	0.00	0.02	0.00	0.00
Non Fossil	MJ/mi	0.17	0.17	0.13	0.19	0.02	0.01	0.01	0.30	0.22	0.00	0.01	0.00	0.03	0.00
WTT	MJ/mi	1.15	1.15	0.85	0.81	1.63	1.20	1.07	1.22	0.90	0.69	0.62	0.48	0.46	0.87
TTW	MJ/mi	4.12	4.12	3.05	2.05	4.12	3.05	4.12	4.12	3.05	3.29	4.00	4.00	4.00	4.00
GHGs (weighted)															
WTT	g/mi	77	77	57	70	131	97	81	74	55	54	50	44	41	78
TTW	g/mi	309	309	231	125	309	231	309	309	231	253	267	267	230	230
TOTAL	g/mi	386	386	288	195	440	328	390	383	286	307	317	311	271	308
Criteria, Total															
VOC	g/mi	0.205	0.205	0.191	0.042	0.198	0.186	0.200	0.209	0.194	0.138	0.447	0.326	0.085	0.091
CO	g/mi	1.310	1.309	1.284	0.228	1.282	1.264	1.285	1.327	1.298	0.727	1.269	1.271	1.249	1.281
NOx	g/mi	0.342	0.342	0.277	0.115	0.237	0.200	0.330	0.351	0.284	1.628	0.195	0.240	0.115	0.375
PM10 (x10)	g/mi	0.546	0.546	0.492	0.329	0.721	0.622	0.506	0.577	0.515	1.408	0.385	0.397	0.351	0.432
Criteria, Urban															
VOC	g/mi	0.170	0.170	0.165	0.024	—	—	0.170	0.170	0.165	0.115	0.423	0.285	0.059	0.059
CO	g/mi	1.215	1.215	1.214	0.186	—	—	1.215	1.215	1.214	0.675	1.215	1.216	1.216	1.215
NOx	g/mi	0.098	0.098	0.097	0.015	—	—	0.097	0.099	0.097	1.453	0.099	0.106	0.095	0.098
PM10 (x10)	g/mi	0.342	0.342	0.341	0.246	—	—	0.342	0.342	0.342	1.285	0.341	0.343	0.341	0.342
Urban Toxics, (weighted)															
Benzene	g/mi	1.1E-02	1.1E-02	1.1E-02	1.4E-03	—	—	1.1E-02	1.1E-02	1.1E-02	1.0E-02	1.0E-05	2.8E-05	8.2E-05	8.4E-05
1-3 Butadiene	g/mi	1.1E-02	1.0E-02	1.0E-02	1.1E-03	—	—	1.0E-02	1.0E-02	1.0E-02	5.8E-03	5.8E-06	1.2E-04	2.0E-04	2.1E-04
Formaldehyde	g/mi	9.2E-04	9.1E-04	9.1E-04	3.7E-04	—	—	9.1E-04	9.2E-04	9.1E-04	1.5E-02	9.1E-04	9.6E-04	1.5E-03	1.5E-03
Acetaldehyde	g/mi	8.9E-05	8.8E-05	8.7E-05	2.0E-05	—	—	8.7E-05	8.9E-05	8.8E-05	3.4E-03	8.7E-05	9.9E-05	1.2E-04	1.2E-04
Diesel PM	g/mi	1.6E-02	1.6E-02	1.2E-02	6.2E-03	—	—	1.3E-02	1.8E-02	1.3E-02	5.2E+00	1.9E-03	3.8E-02	0.0E+00	1.4E-02

Figure A-1. LDA Vehicle Class: All Model Years (concluded)

Gasoline, E10, Diesel, LPG and CNG

Scenario Year 2030: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G Av ICE	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	4.57	4.57	3.39	2.37	5.13	3.80	4.64	4.51	3.34	3.56	4.13	4.01	3.97	4.36
Petroleum	MJ/mi	4.03	4.03	2.98	1.61	4.08	3.02	4.17	3.91	2.90	3.26	3.81	0.06	0.02	0.05
Natural Gas	MJ/mi	0.53	0.53	0.39	0.75	0.88	0.65	0.47	0.58	0.43	0.30	0.31	3.94	3.95	4.31
Coal	MJ/mi	0.01	0.01	0.01	0.00	0.17	0.13	0.00	0.02	0.02	0.00	0.00	0.01	0.00	0.00
Non Fossil	MJ/mi	0.15	0.15	0.11	0.19	0.02	0.01	0.01	0.27	0.20	0.00	0.01	0.00	0.03	0.00
WTT	MJ/mi	1.03	1.03	0.77	0.73	1.46	1.08	0.96	1.09	0.81	0.62	0.56	0.43	0.41	0.78
TTW	MJ/mi	3.69	3.69	2.73	1.84	3.69	2.73	3.69	3.69	2.73	2.95	3.58	3.58	3.58	3.58
GHGs (weighted)															
WTT	g/mi	69	69	51	62	117	87	72	66	49	48	45	39	36	70
TTW	g/mi	278	278	208	113	278	208	278	278	208	228	240	240	207	207
TOTAL	g/mi	347	347	259	175	395	295	350	344	257	276	285	280	243	277
Criteria, Total															
VOC	g/mi	0.151	0.151	0.138	0.044	0.144	0.133	0.146	0.154	0.140	0.135	0.383	0.275	0.059	0.064
CO	g/mi	0.891	0.891	0.868	0.243	0.866	0.850	0.869	0.907	0.881	0.513	0.855	0.856	0.837	0.866
NOx	g/mi	0.282	0.282	0.224	0.106	0.188	0.155	0.271	0.290	0.230	1.786	0.150	0.190	0.079	0.311
PM10 (x10)	g/mi	0.525	0.525	0.477	0.328	0.682	0.594	0.489	0.553	0.498	1.395	0.381	0.391	0.351	0.423
Criteria, Urban															
VOC	g/mi	0.119	0.119	0.115	0.028	—	—	0.119	0.120	0.115	0.114	0.362	0.238	0.036	0.035
CO	g/mi	0.806	0.806	0.806	0.206	—	—	0.806	0.806	0.806	0.466	0.806	0.807	0.807	0.807
NOx	g/mi	0.063	0.063	0.062	0.016	—	—	0.062	0.064	0.062	1.629	0.064	0.070	0.061	0.063
PM10 (x10)	g/mi	0.342	0.342	0.342	0.253	—	—	0.342	0.343	0.342	1.284	0.341	0.343	0.342	0.343
Urban Toxics, (weighted)															
Benzene	g/mi	7.2E-03	7.2E-03	7.1E-03	1.7E-03	—	—	7.2E-03	7.2E-03	7.1E-03	1.0E-02	7.2E-06	2.3E-05	7.3E-05	7.5E-05
1-3 Butadiene	g/mi	6.2E-03	6.2E-03	6.2E-03	1.3E-03	—	—	6.2E-03	6.2E-03	6.2E-03	5.6E-03	4.0E-06	1.0E-04	1.8E-04	1.9E-04
Formaldehyde	g/mi	5.6E-04	5.6E-04	5.5E-04	3.4E-04	—	—	5.5E-04	5.6E-04	5.6E-04	1.5E-02	5.5E-04	6.0E-04	1.0E-03	1.1E-03
Acetaldehyde	g/mi	5.2E-05	5.2E-05	5.1E-05	1.9E-05	—	—	5.1E-05	5.3E-05	5.2E-05	3.4E-03	5.1E-05	6.1E-05	8.0E-05	8.2E-05
Diesel PM	g/mi	1.3E-02	1.3E-02	1.0E-02	5.4E-03	—	—	1.1E-02	1.5E-02	1.1E-02	5.2E+00	1.2E-03	3.3E-02	0.0E+00	1.2E-02

Figure A-2.LDA Vehicle Class: Model Years 2010 and Newer (Gasoline, E10, Diesel, LPG and CNG)

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

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Com, MW EtOH	E10, Com, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G new	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	5.70	5.70	4.22	3.08	6.44	4.77	5.79	5.63	4.17	4.44	5.16	4.99	4.96	5.48
Petroleum	MJ/mi	5.01	5.01	3.71	2.01	5.08	3.76	5.20	4.87	3.61	4.06	4.75	0.08	0.02	0.06
Natural Gas	MJ/mi	0.67	0.67	0.50	1.06	1.14	0.84	0.59	0.73	0.54	0.38	0.41	4.90	4.94	5.42
Coal	MJ/mi	0.02	0.02	0.01	0.01	0.22	0.17	0.00	0.03	0.02	0.00	0.00	0.02	0.00	0.00
Non Fossil	MJ/mi	0.19	0.19	0.14	0.18	0.03	0.02	0.01	0.33	0.25	0.01	0.01	0.00	0.02	0.00
WTT	MJ/mi	1.30	1.30	0.96	0.97	1.87	1.39	1.20	1.37	1.02	0.77	0.72	0.54	0.52	1.02
TTW	MJ/mi	4.59	4.59	3.40	2.29	4.59	3.40	4.59	4.59	3.40	3.68	4.46	4.46	4.46	4.46
GHGs (weighted)															
WTT	g/mi	87	87	65	84	151	112	91	84	62	61	57	49	47	91
TTW	g/mi	344	344	257	139	344	257	344	344	257	282	297	297	255	255
TOTAL	g/mi	431	431	322	223	495	369	435	428	319	342	354	346	302	346
Criteria, Total															
VOC	g/mi	0.089	0.089	0.073	0.039	0.080	0.066	0.083	0.094	0.076	—	0.448	0.312	0.044	0.050
CO	g/mi	0.472	0.472	0.443	0.186	0.441	0.420	0.444	0.493	0.459	—	0.426	0.427	0.402	0.439
NOx	g/mi	0.316	0.316	0.241	0.130	0.194	0.150	0.299	0.330	0.251	—	0.149	0.197	0.054	0.347
PM10 (x10)	g/mi	0.488	0.488	0.424	0.325	0.699	0.581	0.440	0.526	0.452	—	0.301	0.312	0.257	0.349
Criteria, Urban															
VOC	g/mi	0.048	0.048	0.042	0.018	—	—	0.048	0.048	0.042	—	0.420	0.266	0.014	0.013
CO	g/mi	0.364	0.364	0.363	0.137	—	—	0.364	0.364	0.363	—	0.364	0.365	0.364	0.364
NOx	g/mi	0.036	0.036	0.033	0.014	—	—	0.035	0.036	0.034	—	0.037	0.045	0.029	0.032
PM10 (x10)	g/mi	0.247	0.247	0.245	0.226	—	—	0.246	0.247	0.245	—	0.246	0.247	0.244	0.245
Urban Toxics, (weighted)															
Benzene	g/mi	2.7E-03	2.7E-03	2.6E-03	1.0E-03	—	—	2.7E-03	2.7E-03	2.6E-03	—	2.8E-05	4.9E-05	9.2E-05	9.4E-05
1-3 Butadiene	g/mi	2.2E-03	2.2E-03	2.2E-03	8.4E-04	—	—	2.2E-03	2.2E-03	2.2E-03	—	1.6E-05	1.4E-04	2.3E-04	2.4E-04
Formaldehyde	g/mi	2.5E-04	2.5E-04	2.4E-04	4.2E-04	—	—	2.5E-04	2.6E-04	2.4E-04	—	2.5E-04	3.1E-04	8.5E-04	8.6E-04
Acetaldehyde	g/mi	2.7E-05	2.7E-05	2.4E-05	2.2E-05	—	—	2.6E-05	2.8E-05	2.5E-05	—	2.6E-05	3.9E-05	5.7E-05	5.8E-05
Diesel PM	g/mi	2.1E-02	2.1E-02	1.6E-02	8.5E-03	—	—	1.8E-02	2.4E-02	1.7E-02	—	6.6E-03	4.7E-02	0.0E+00	1.5E-02

Figure A-2. LDA Vehicle Class: Model Years 2010 and Newer (continued)

Gasoline, E10, Diesel, LPG and CNG

Scenario Year 2017: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G new	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	5.13	5.13	3.80	2.72	5.77	4.27	5.21	5.06	3.75	4.00	4.64	4.50	4.46	4.92
Petroleum	MJ/mi	4.51	4.51	3.34	1.81	4.57	3.39	4.68	4.38	3.25	3.65	4.28	0.07	0.02	0.05
Natural Gas	MJ/mi	0.60	0.60	0.45	0.91	1.00	0.74	0.53	0.65	0.49	0.34	0.36	4.41	4.44	4.87
Coal	MJ/mi	0.01	0.01	0.01	0.01	0.19	0.14	0.00	0.02	0.02	0.00	0.00	0.02	0.00	0.00
Non Fossil	MJ/mi	0.17	0.17	0.13	0.18	0.02	0.02	0.01	0.30	0.22	0.00	0.01	0.00	0.03	0.00
WTT	MJ/mi	1.16	1.16	0.86	0.84	1.65	1.22	1.08	1.23	0.91	0.69	0.64	0.48	0.47	0.91
TTW	MJ/mi	4.14	4.14	3.06	2.06	4.14	3.06	4.14	4.14	3.06	3.31	4.02	4.02	4.02	4.02
GHGs (weighted)															
WTT	g/mi	78	78	58	73	133	99	82	75	56	54	51	44	41	81
TTW	g/mi	310	310	232	126	311	232	311	310	232	254	268	268	231	231
TOTAL	g/mi	388	388	290	199	444	331	392	385	288	309	319	312	272	312
Criteria, Total															
VOC	g/mi	0.090	0.090	0.075	0.039	0.082	0.070	0.085	0.094	0.078	—	0.406	0.284	0.042	0.048
CO	g/mi	0.539	0.539	0.514	0.208	0.512	0.494	0.515	0.558	0.528	—	0.499	0.501	0.479	0.512
NOx	g/mi	0.286	0.286	0.220	0.116	0.178	0.140	0.272	0.296	0.227	—	0.137	0.181	0.055	0.319
PM10 (x10)	g/mi	0.487	0.487	0.432	0.322	0.668	0.566	0.446	0.519	0.456	—	0.323	0.334	0.287	0.370
Criteria, Urban															
VOC	g/mi	0.054	0.054	0.049	0.020	—	—	0.054	0.054	0.049	—	0.381	0.243	0.016	0.016
CO	g/mi	0.444	0.444	0.444	0.165	—	—	0.444	0.444	0.444	—	0.444	0.445	0.445	0.445
NOx	g/mi	0.037	0.037	0.036	0.014	—	—	0.037	0.038	0.036	—	0.038	0.046	0.034	0.036
PM10 (x10)	g/mi	0.278	0.278	0.277	0.237	—	—	0.278	0.278	0.277	—	0.277	0.279	0.276	0.277
Urban Toxics, (weighted)															
Benzene	g/mi	3.2E-03	3.2E-03	3.1E-03	1.2E-03	—	—	3.2E-03	3.2E-03	3.1E-03	—	1.5E-05	3.4E-05	8.3E-05	8.5E-05
1-3 Butadiene	g/mi	2.6E-03	2.6E-03	2.6E-03	9.8E-04	—	—	2.6E-03	2.6E-03	2.6E-03	—	8.6E-06	1.2E-04	2.0E-04	2.1E-04
Formaldehyde	g/mi	2.7E-04	2.7E-04	2.7E-04	3.7E-04	—	—	2.7E-04	2.8E-04	2.7E-04	—	2.7E-04	3.2E-04	6.3E-04	8.3E-04
Acetaldehyde	g/mi	2.6E-05	2.6E-05	2.5E-05	2.0E-05	—	—	2.5E-05	2.7E-05	2.5E-05	—	2.5E-05	3.7E-05	5.6E-05	5.7E-05
Diesel PM	g/mi	1.7E-02	1.7E-02	1.2E-02	6.7E-03	—	—	1.4E-02	1.9E-02	1.4E-02	—	3.2E-03	3.9E-02	0.0E+00	1.4E-02

Figure A-2. LDA Vehicle Class: Model Years 2010 and Newer (continued)

Gasoline, E10, Diesel, LPG and CNG

Scenario Year 2022: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G new	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	4.84	4.84	3.59	2.53	5.44	4.03	4.92	4.78	3.54	3.78	4.38	4.25	4.20	4.62
Petroleum	MJ/mi	4.27	4.27	3.16	1.71	4.32	3.20	4.42	4.15	3.07	3.46	4.04	0.06	0.02	0.05
Natural Gas	MJ/mi	0.56	0.56	0.42	0.82	0.93	0.69	0.50	0.61	0.46	0.32	0.33	4.17	4.19	4.57
Coal	MJ/mi	0.01	0.01	0.01	0.00	0.18	0.13	0.00	0.02	0.02	0.00	0.00	0.01	0.00	0.00
Non Fossil	MJ/mi	0.16	0.16	0.12	0.18	0.02	0.01	0.01	0.28	0.21	0.00	0.01	0.00	0.03	0.00
WTT	MJ/mi	1.10	1.10	0.81	0.77	1.54	1.14	1.02	1.16	0.86	0.65	0.59	0.46	0.43	0.83
TTW	MJ/mi	3.91	3.91	2.90	1.95	3.91	2.90	3.91	3.91	2.90	3.13	3.80	3.80	3.80	3.80
GHGs (weighted)															
WTT	g/mi	73	73	54	66	124	92	77	70	52	51	48	42	39	74
TTW	g/mi	294	294	220	119	294	220	294	294	220	241	254	254	219	219
TOTAL	g/mi	367	367	274	185	418	312	371	364	272	292	302	296	257	293
Criteria, Total															
VOC	g/mi	0.097	0.097	0.084	0.041	0.090	0.079	0.093	0.101	0.086	—	0.386	0.271	0.043	0.048
CO	g/mi	0.592	0.592	0.569	0.226	0.566	0.550	0.570	0.610	0.582	—	0.554	0.556	0.535	0.566
NOx	g/mi	0.271	0.271	0.210	0.110	0.172	0.136	0.260	0.280	0.216	—	0.131	0.174	0.056	0.302
PM10 (x10)	g/mi	0.497	0.497	0.446	0.324	0.663	0.569	0.459	0.526	0.468	—	0.344	0.355	0.312	0.389
Criteria, Urban															
VOC	g/mi	0.064	0.064	0.059	0.024	—	—	0.064	0.064	0.059	—	0.364	0.232	0.018	0.018
CO	g/mi	0.503	0.503	0.502	0.186	—	—	0.503	0.503	0.503	—	0.503	0.504	0.504	0.503
NOx	g/mi	0.039	0.039	0.038	0.015	—	—	0.039	0.040	0.038	—	0.040	0.047	0.037	0.039
PM10 (x10)	g/mi	0.303	0.303	0.303	0.245	—	—	0.303	0.303	0.303	—	0.302	0.304	0.302	0.303
Urban Toxics, (weighted)															
Benzene	g/mi	3.8E-03	3.8E-03	3.6E-03	1.4E-03	—	—	3.8E-03	3.8E-03	3.6E-03	—	9.9E-06	2.7E-05	7.8E-05	8.0E-05
1-3 Butadiene	g/mi	3.0E-03	3.0E-03	3.0E-03	1.1E-03	—	—	3.0E-03	3.0E-03	3.0E-03	—	5.5E-06	1.1E-04	1.9E-04	2.0E-04
Formaldehyde	g/mi	3.0E-04	3.0E-04	2.9E-04	3.5E-04	—	—	2.9E-04	3.0E-04	3.0E-04	—	2.9E-04	3.5E-04	8.3E-04	8.3E-04
Acetaldehyde	g/mi	2.7E-05	2.7E-05	2.6E-05	1.9E-05	—	—	2.7E-05	2.8E-05	2.7E-05	—	2.6E-05	3.7E-05	5.7E-05	5.8E-05
Diesel PM	g/mi	1.5E-02	1.5E-02	1.1E-02	5.9E-03	—	—	1.2E-02	1.7E-02	1.2E-02	—	1.8E-03	3.6E-02	0.0E+00	1.3E-02

Figure A-2. LDA Vehicle Class: Model Years 2010 and Newer (concluded)

Gasoline, E10, Diesel, LPG and CNG

Scenario Year 2030: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		G1	G1	G1	G1/e2	G15	G15	G0	E10	E10	D2	P1	P2	C1	C2
WTT Description		RFG, Marginal	RFG, Marginal	RFG, Marginal	Electricity, NG/RPS, Night	RFG, Tar Sands	RFG, Tar Sands	RFG, 0 Oxygen	E10, Corn, MW EtOH	E10, Corn, MW EtOH	Diesel, CA ULSD	LPG, Petroleum	LPG, Natural Gas	CNG, NA Natural Gas	CNG, LNG, Remote NG
Vehicle Type		G new	G FFV	G HEV	PHEV	G new	G HEV	G new	G new	G HEV	ULSD	LPG	LPG	CNG	CNG
Vehicle Technology		ICEV	FFV	HEV	PHEV	ICEV	HEV	ICEV	ICEV	HEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	4.55	4.55	3.37	2.36	5.11	3.78	4.62	4.49	3.33	3.55	4.11	3.99	3.95	4.34
Petroleum	MJ/mi	4.01	4.01	2.97	1.61	4.06	3.01	4.16	3.89	2.89	3.25	3.80	0.06	0.02	0.05
Natural Gas	MJ/mi	0.53	0.53	0.39	0.75	0.88	0.65	0.47	0.58	0.43	0.30	0.31	3.92	3.93	4.29
Coal	MJ/mi	0.01	0.01	0.01	0.00	0.17	0.13	0.00	0.02	0.02	0.00	0.00	0.01	0.00	0.00
Non Fossil	MJ/mi	0.15	0.15	0.11	0.19	0.02	0.01	0.01	0.27	0.20	0.00	0.01	0.00	0.03	0.00
WTT	MJ/mi	1.03	1.03	0.76	0.72	1.45	1.07	0.95	1.09	0.80	0.61	0.56	0.43	0.41	0.78
TTW	MJ/mi	3.67	3.67	2.72	1.83	3.67	2.72	3.67	3.87	2.72	2.94	3.57	3.57	3.57	3.57
GHGs (weighted)															
WTT	g/mi	69	69	51	62	117	86	72	66	49	48	45	39	36	70
TTW	g/mi	277	277	207	113	277	208	277	277	207	227	239	239	206	206
TOTAL	g/mi	346	346	258	175	394	294	349	343	256	275	284	278	242	276
Criteria, Total															
VOC	g/mi	0.107	0.107	0.094	0.044	0.101	0.090	0.103	0.110	0.097	—	0.367	0.259	0.045	0.050
CO	g/mi	0.643	0.643	0.621	0.243	0.619	0.603	0.622	0.659	0.633	—	0.607	0.609	0.590	0.618
NOx	g/mi	0.261	0.261	0.203	0.108	0.168	0.134	0.250	0.289	0.209	—	0.129	0.169	0.059	0.290
PM10 (x10)	g/mi	0.508	0.508	0.461	0.327	0.665	0.577	0.473	0.536	0.481	—	0.365	0.375	0.335	0.407
Criteria, Urban															
VOC	g/mi	0.076	0.076	0.071	0.028	—	—	0.076	0.076	0.071	—	0.346	0.223	0.021	0.021
CO	g/mi	0.559	0.559	0.559	0.205	—	—	0.559	0.559	0.559	—	0.559	0.560	0.560	0.560
NOx	g/mi	0.043	0.043	0.042	0.016	—	—	0.042	0.044	0.042	—	0.044	0.050	0.041	0.043
PM10 (x10)	g/mi	0.327	0.327	0.326	0.253	—	—	0.326	0.327	0.326	—	0.326	0.327	0.326	0.327
Urban Toxics, (weighted)															
Benzene	g/mi	4.5E-03	4.5E-03	4.4E-03	1.7E-03	—	—	4.5E-03	4.5E-03	4.4E-03	—	7.1E-06	2.3E-05	7.3E-05	7.4E-05
1-3 Butadiene	g/mi	3.6E-03	3.6E-03	3.6E-03	1.3E-03	—	—	3.6E-03	3.6E-03	3.6E-03	—	4.0E-06	1.0E-04	1.8E-04	1.9E-04
Formaldehyde	g/mi	3.5E-04	3.5E-04	3.4E-04	3.4E-04	—	—	3.4E-04	3.5E-04	3.5E-04	—	3.4E-04	3.9E-04	8.4E-04	8.4E-04
Acetaldehyde	g/mi	3.1E-05	3.1E-05	3.0E-05	1.9E-05	—	—	3.0E-05	3.2E-05	3.1E-05	—	3.0E-05	4.0E-05	5.9E-05	6.0E-05
Diesel PM	g/mi	1.3E-02	1.3E-02	9.9E-03	5.4E-03	—	—	1.1E-02	1.5E-02	1.1E-02	—	1.1E-03	3.3E-02	0.0E+00	1.2E-02

Figure A-3. LDA Vehicle Class: Model Years 2010 and Newer (EVs and PHEVs)

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

WTT Case ID		e1	e2	e31	e37	e54	e92	G1/e1	G1/e2	G1/e31	G1/e37	G1/e54	G1/e92
WTT Description		Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear	Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear
Vehicle Type		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Vehicle Technology		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Fossil	MJ/mi	2.00	1.99	4.19	3.13	0.12	0.05	3.08	3.08	3.96	3.53	2.33	2.30
Petroleum	MJ/mi	0.01	0.01	0.02	0.04	0.10	0.00	2.01	2.01	2.01	2.02	2.04	2.01
Natural Gas	MJ/mi	1.99	1.98	4.17	0.01	0.02	0.04	1.07	1.06	1.94	0.27	0.28	0.29
Coal	MJ/mi	0.00	0.00	0.00	3.09	0.00	0.00	0.01	0.01	0.01	1.24	0.01	0.01
Non Fossil	MJ/mi	0.26	0.26	0.00	0.00	3.80	1.22	0.18	0.18	0.08	0.08	1.60	0.57
WTT	MJ/mi	1.14	1.13	3.07	2.02	2.80	0.15	0.98	0.97	1.75	1.33	1.64	0.58
TTW	MJ/mi	1.12	1.12	1.12	1.12	1.12	1.12	2.29	2.29	2.29	2.29	2.29	2.29
GHGs (weighted)													
WTT	g/mi	124	123	259	73	17	3	84	84	138	64	42	36
TTW	g/mi	0	0	0	0	0	0	139	139	139	139	139	139
TOTAL	g/mi	124	123	259	73	17	3	224	223	278	203	181	175
Criteria, Total													
VOC	g/mi	0.012	0.012	0.026	0.028	0.008	0.002	0.039	0.039	0.045	0.046	0.038	0.035
CO	g/mi	0.031	0.031	0.089	0.080	0.284	0.010	0.187	0.186	0.210	0.206	0.288	0.178
NOx	g/mi	0.011	0.011	0.023	0.074	0.056	0.001	0.130	0.130	0.135	0.155	0.148	0.126
PM10 (x10)	g/mi	0.226	0.225	0.248	5.205	0.579	0.207	0.325	0.325	0.334	2.317	0.466	0.318
Criteria, Urban													
VOC	g/mi	0.000	0.000	0.001	0.000	0.003	0.000	0.018	0.018	0.018	0.018	0.020	0.018
CO	g/mi	0.015	0.015	0.056	0.000	0.270	0.000	0.137	0.137	0.154	0.131	0.239	0.131
NOx	g/mi	0.001	0.001	0.002	0.000	0.026	0.000	0.014	0.014	0.014	0.013	0.024	0.013
PM10 (x10)	g/mi	0.220	0.220	0.237	0.205	0.562	0.205	0.226	0.226	0.233	0.220	0.363	0.220
Urban Toxics, (weighted)													
Benzene	g/mi	8.3E-05	8.2E-05	---	---	---	---	1.0E-03	1.0E-03	---	---	---	---
1-3 Butadiene	g/mi	1.0E-04	1.0E-04	---	---	---	---	8.4E-04	8.4E-04	---	---	---	---
Formaldehyde	g/mi	8.2E-04	8.1E-04	---	---	---	---	4.2E-04	4.2E-04	---	---	---	---
Acetaldehyde	g/mi	3.1E-05	3.0E-05	---	---	---	---	2.2E-05	2.2E-05	---	---	---	---
Diesel PM	g/mi	0.0E+00	0.0E+00	---	---	---	---	8.5E-03	8.5E-03	---	---	---	---

Figure A-3. LDA Vehicle Class: Model Years 2010 and Newer (continued)

EVs and PHEVs

Scenario Year 2017: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		e1	e2	e31	e37	e54	e92	G1/e1	G1/e2	G1/e31	G1/e37	G1/e54	G1/e92
WTT Description		Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear	Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear
Vehicle Type		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Vehicle Technology		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Fossil	MJ/mi	1.69	1.68	3.61	2.79	0.10	0.03	2.73	2.72	3.50	3.17	2.09	2.06
Petroleum	MJ/mi	0.01	0.01	0.01	0.03	0.09	0.00	1.81	1.81	1.81	1.82	1.84	1.81
Natural Gas	MJ/mi	1.68	1.68	3.60	0.01	0.02	0.03	0.91	0.91	1.68	0.24	0.25	0.25
Coal	MJ/mi	0.00	0.00	0.00	2.75	0.00	0.00	0.01	0.01	0.01	1.11	0.01	0.01
Non Fossil	MJ/mi	0.27	0.27	0.00	0.00	3.42	1.10	0.18	0.18	0.07	0.07	1.44	0.51
WTT	MJ/mi	0.95	0.94	2.60	1.79	2.52	0.12	0.85	0.84	1.51	1.18	1.47	0.51
TTW	MJ/mi	1.01	1.01	1.01	1.01	1.01	1.01	2.06	2.06	2.06	2.06	2.06	2.06
GHGs (weighted)													
WTT	g/mi	105	104	223	65	16	2	73	73	121	57	38	32
TTW	g/mi	0	0	0	0	0	0	126	126	126	126	126	126
TOTAL	g/mi	105	104	223	65	16	2	199	199	247	183	164	158
Criteria, Total													
VOC	g/mi	0.010	0.010	0.022	0.025	0.005	0.001	0.039	0.039	0.043	0.044	0.037	0.035
CO	g/mi	0.026	0.026	0.076	0.072	0.253	0.009	0.208	0.208	0.228	0.227	0.299	0.201
NOx	g/mi	0.009	0.009	0.019	0.066	0.034	0.001	0.116	0.116	0.121	0.139	0.126	0.113
PM10 (x10)	g/mi	0.223	0.222	0.242	4.661	0.532	0.207	0.322	0.322	0.330	2.098	0.446	0.316
Criteria, Urban													
VOC	g/mi	0.000	0.000	0.000	0.000	0.002	0.000	0.020	0.020	0.021	0.020	0.021	0.020
CO	g/mi	0.013	0.013	0.049	0.000	0.242	0.000	0.165	0.165	0.179	0.160	0.257	0.160
NOx	g/mi	0.001	0.001	0.002	0.000	0.015	0.000	0.014	0.014	0.014	0.014	0.020	0.014
PM10 (x10)	g/mi	0.218	0.218	0.233	0.206	0.522	0.206	0.237	0.237	0.243	0.232	0.358	0.232
Urban Toxics, (weighted)													
Benzene	g/mi	7.0E-05	6.9E-05	—	—	—	—	1.2E-03	1.2E-03	—	—	—	—
1-3 Butadiene	g/mi	8.6E-05	8.5E-05	—	—	—	—	9.8E-04	9.8E-04	—	—	—	—
Formaldehyde	g/mi	6.9E-04	6.9E-04	—	—	—	—	3.8E-04	3.7E-04	—	—	—	—
Acetaldehyde	g/mi	2.6E-05	2.6E-05	—	—	—	—	2.0E-05	2.0E-05	—	—	—	—
Diesel PM	g/mi	0.0E+00	0.0E+00	—	—	—	—	6.7E-03	6.7E-03	—	—	—	—

Figure A-3. LDA Vehicle Class: Model Years 2010 and Newer (continued)

EVs and PHEVs

Scenario Year 2022: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		e1	e2	e31	e37	e54	e92	G1/e1	G1/e2	G1/e31	G1/e37	G1/e54	G1/e92
WTT Description		Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear	Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear
Vehicle Type		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Vehicle Technology		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Fossil	MJ/mi	1.50	1.49	3.26	2.61	0.10	0.02	2.54	2.53	3.24	2.98	1.98	1.95
Petroleum	MJ/mi	0.01	0.01	0.01	0.03	0.08	0.00	1.71	1.71	1.71	1.72	1.74	1.71
Natural Gas	MJ/mi	1.49	1.48	3.25	0.01	0.02	0.02	0.82	0.82	1.53	0.23	0.23	0.23
Coal	MJ/mi	0.00	0.00	0.00	2.57	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00
Non Fossil	MJ/mi	0.29	0.29	0.00	0.00	3.20	1.04	0.18	0.18	0.07	0.07	1.35	0.48
WTT	MJ/mi	0.83	0.83	2.31	1.66	2.35	0.11	0.77	0.77	1.36	1.10	1.38	0.48
TTW	MJ/mi	0.95	0.95	0.95	0.95	0.95	0.95	1.95	1.95	1.95	1.95	1.95	1.95
GHGs (weighted)													
WTT	g/mi	93	92	202	60	15	1	66	66	110	53	35	30
TTW	g/mi	0	0	0	0	0	0	119	119	119	119	119	119
TOTAL	g/mi	93	92	202	60	15	1	186	185	230	173	155	149
Criteria, Total													
VOC	g/mi	0.009	0.009	0.020	0.023	0.004	0.001	0.041	0.041	0.045	0.046	0.039	0.038
CO	g/mi	0.023	0.023	0.069	0.067	0.236	0.008	0.226	0.226	0.244	0.244	0.311	0.220
NOx	g/mi	0.008	0.007	0.016	0.062	0.022	0.001	0.110	0.110	0.114	0.132	0.116	0.107
PM10 (x10)	g/mi	0.220	0.220	0.238	4.367	0.505	0.207	0.324	0.324	0.331	1.983	0.438	0.319
Criteria, Urban													
VOC	g/mi	0.000	0.000	0.000	0.000	0.001	0.000	0.024	0.024	0.024	0.024	0.024	0.024
CO	g/mi	0.012	0.011	0.044	0.000	0.226	0.000	0.186	0.186	0.199	0.181	0.271	0.181
NOx	g/mi	0.001	0.001	0.002	0.000	0.009	0.000	0.015	0.015	0.015	0.014	0.018	0.014
PM10 (x10)	g/mi	0.217	0.217	0.230	0.206	0.499	0.206	0.245	0.245	0.251	0.241	0.358	0.241
Urban Toxics, (weighted)													
Benzene	g/mi	6.2E-05	6.2E-05	---	---	---	---	1.4E-03	1.4E-03	---	---	---	---
1-3 Butadiene	g/mi	7.6E-05	7.6E-05	---	---	---	---	1.1E-03	1.1E-03	---	---	---	---
Formaldehyde	g/mi	6.1E-04	6.1E-04	---	---	---	---	3.5E-04	3.5E-04	---	---	---	---
Acetaldehyde	g/mi	2.3E-05	2.3E-05	---	---	---	---	1.9E-05	1.9E-05	---	---	---	---
Diesel PM	g/mi	0.0E+00	0.0E+00	---	---	---	---	5.9E-03	5.9E-03	---	---	---	---

Figure A-3. LDA Vehicle Class: Model Years 2010 and Newer (concluded)

EVs and PHEVs

Scenario Year 2030: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		e1	e2	e31	e37	e54	e92	G1/e1	G1/e2	G1/e31	G1/e37	G1/e54	G1/e92
WTT Description		Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear	Electricity, NG/RPS	Electricity, NG/RPS, Night	Electricity, CA NG SCCT	Electricity, Coal IGCC, CCS	Electricity, Woody Biomass	Electricity, Nuclear
Vehicle Type		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Vehicle Technology		EV	EV	EV	EV	EV	EV	PHEV	PHEV	PHEV	PHEV	PHEV	PHEV
Fossil	MJ/mi	1.36	1.35	3.07	2.45	0.09	0.02	2.36	2.36	3.05	2.80	1.86	1.83
Petroleum	MJ/mi	0.01	0.01	0.01	0.03	0.08	0.00	1.61	1.61	1.61	1.62	1.63	1.61
Natural Gas	MJ/mi	1.35	1.35	3.05	0.01	0.02	0.02	0.75	0.75	1.43	0.21	0.22	0.22
Coal	MJ/mi	0.00	0.00	0.00	2.41	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.00
Non Fossil	MJ/mi	0.32	0.32	0.00	0.00	3.01	0.98	0.19	0.19	0.06	0.06	1.27	0.45
WTT	MJ/mi	0.78	0.78	2.17	1.56	2.21	0.10	0.72	0.72	1.28	1.03	1.29	0.45
TTW	MJ/mi	0.90	0.90	0.90	0.90	0.90	0.90	1.83	1.83	1.83	1.83	1.83	1.83
GHGs (weighted)													
WTT	g/mi	87	86	190	57	14	1	62	62	103	50	33	28
TTW	g/mi	0	0	0	0	0	0	113	113	113	113	113	113
TOTAL	g/mi	87	86	190	57	14	1	175	175	216	163	146	141
Criteria, Total													
VOC	g/mi	0.008	0.008	0.018	0.022	0.003	0.001	0.044	0.044	0.048	0.049	0.042	0.041
CO	g/mi	0.021	0.021	0.065	0.063	0.221	0.008	0.243	0.243	0.261	0.260	0.323	0.238
NOx	g/mi	0.007	0.007	0.015	0.058	0.019	0.001	0.106	0.106	0.109	0.126	0.110	0.103
PM10 (x10)	g/mi	0.219	0.219	0.236	4.115	0.487	0.207	0.327	0.327	0.334	1.885	0.434	0.322
Criteria, Urban													
VOC	g/mi	0.000	0.000	0.000	0.000	0.001	0.000	0.028	0.028	0.028	0.028	0.028	0.028
CO	g/mi	0.011	0.011	0.041	0.000	0.212	0.000	0.206	0.205	0.218	0.201	0.286	0.201
NOx	g/mi	0.001	0.001	0.002	0.000	0.008	0.000	0.016	0.016	0.016	0.016	0.019	0.016
PM10 (x10)	g/mi	0.216	0.216	0.229	0.205	0.481	0.206	0.253	0.253	0.258	0.249	0.359	0.249
Urban Toxics, (weighted)													
Benzene	g/mi	5.4E-05	5.4E-05	—	—	—	—	1.7E-03	1.7E-03	—	—	—	—
1-3 Butadiene	g/mi	6.6E-05	6.6E-05	—	—	—	—	1.3E-03	1.3E-03	—	—	—	—
Formaldehyde	g/mi	5.4E-04	5.3E-04	—	—	—	—	3.4E-04	3.4E-04	—	—	—	—
Acetaldehyde	g/mi	2.0E-05	2.0E-05	—	—	—	—	1.9E-05	1.9E-05	—	—	—	—
Diesel PM	g/mi	0.0E+00	0.0E+00	—	—	—	—	5.4E-03	5.4E-03	—	—	—	—

Figure A-4. LDA Vehicle Class: Model Years 2010 and Newer (Hydrogen)

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

WTT Case ID		H2	H2	H3	H4c	H5	H7	H11	H13	H22	H23
WTT Description		H2, NG SR, LH2	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, NG SR, Pipeline	H2, Biomass, Pipeline	H2, Onsite NG SR	H2, Onsite NG SR, Ren Power	H2, Grid Electrolysis	H2, 70% Renewable, Electrolysis
Vehicle Type		H2ICE	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	9.31	5.04	2.93	3.74	3.26	0.61	3.34	2.88	4.97	2.00
Petroleum	MJ/mi	0.06	0.03	0.02	0.05	0.01	0.09	0.01	0.01	0.01	0.03
Natural Gas	MJ/mi	9.25	5.01	2.90	0.55	3.24	0.51	3.32	2.87	4.95	1.97
Coal	MJ/mi	0.00	0.00	0.00	3.13	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.51	0.28	1.29	0.07	0.05	3.75	0.06	0.28	0.86	2.26
WTT	MJ/mi	6.29	3.41	2.30	1.90	1.39	2.44	1.48	1.25	3.91	2.35
TTW	MJ/mi	3.53	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
GHGs (weighted)											
WTT	g/mi	568	308	177	96	200	40	198	170	319	161
TTW	g/mi	8	0	0	0	0	0	0	0	0	0
TOTAL	g/mi	576	308	177	96	200	40	198	170	319	161
Criteria, Total											
VOC	g/mi	0.062	0.032	0.019	0.032	0.020	0.011	0.021	0.018	0.032	0.021
CO	g/mi	0.187	0.062	0.029	0.029	0.032	0.033	0.032	0.024	0.079	0.036
NOx	g/mi	0.089	0.034	0.023	0.074	0.019	0.031	0.019	0.016	0.029	0.058
PM10 (x10)	g/mi	0.298	0.254	0.232	5.229	0.232	0.229	0.225	0.220	0.258	0.266
Criteria, Urban											
VOC	g/mi	0.004	0.001	0.000	0.000	0.000	0.003	0.000	0.000	0.001	0.004
CO	g/mi	0.104	0.017	0.001	0.004	0.004	0.016	0.006	0.002	0.040	0.012
NOx	g/mi	0.031	0.003	0.002	0.001	0.001	0.026	0.002	0.002	0.003	0.004
PM10 (x10)	g/mi	0.239	0.221	0.205	0.209	0.208	0.222	0.216	0.212	0.244	0.217
Urban Toxics, (weighted)											
Benzene	g/mi	2.1E-04	1.2E-04	4.8E-05	—	2.6E-05	—	2.6E-05	1.1E-05	2.0E-04	7.7E-05
1-3 Butadiene	g/mi	2.3E-04	1.3E-04	4.3E-05	—	4.1E-05	—	4.1E-05	2.2E-05	2.5E-04	9.4E-05
Formaldehyde	g/mi	1.5E-03	7.9E-04	1.3E-04	—	2.2E-04	—	2.2E-04	7.6E-05	2.0E-03	7.6E-04
Acetaldehyde	g/mi	7.6E-05	4.1E-05	1.7E-05	—	9.4E-06	—	9.4E-06	3.9E-06	7.4E-05	2.8E-05
Diesel PM	g/mi	1.6E-02	8.8E-03	8.8E-03	—	0.0E+00	—	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Figure A-4. LDA Vehicle Class: Model Years 2010 and Newer (continued)

Hydrogen

Scenario Year 2017: LDA Vehicle Class: Model Year Start 2010 (new)

		WTT Case ID	H2	H2	H3	H4c	H5	H7	H11	H13	H22	H23
		WTT Description	H2, NG SR, LH2	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestrati on	H2, NG SR, Pipeline	H2, Biomass, Pipeline	H2, Onsite NG SR	H2, Onsite NG SR, Ren Power	H2, Grid Electrolysis	H2, 70% Renewable, Electrolysis
		Vehicle Type	H2ICE	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
		Vehicle Technology	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi		7.55	4.09	2.62	3.26	2.89	0.48	2.91	2.58	4.09	1.72
Petroleum	MJ/mi		0.05	0.03	0.02	0.05	0.01	0.08	0.01	0.01	0.01	0.03
Natural Gas	MJ/mi		7.49	4.06	2.60	0.44	2.88	0.41	2.90	2.57	4.08	1.69
Coal	MJ/mi		0.00	0.00	0.00	2.77	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi		0.43	0.24	0.95	0.07	0.05	3.04	0.05	0.21	0.87	2.00
WTT	MJ/mi		4.80	2.60	1.85	1.61	1.22	1.80	1.24	1.07	3.24	1.99
TTW	MJ/mi		3.18	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
GHGs (weighted)												
WTT	g/mi		459	249	158	82	178	32	172	152	265	141
TTW	g/mi		8	0	0	0	0	0	0	0	0	0
TOTAL	g/mi		468	249	158	82	178	32	172	152	265	141
Criteria, Total												
VOC	g/mi		0.050	0.025	0.017	0.028	0.017	0.007	0.018	0.016	0.026	0.018
CO	g/mi		0.177	0.048	0.025	0.025	0.028	0.024	0.027	0.022	0.065	0.031
NOx	g/mi		0.077	0.025	0.017	0.065	0.015	0.019	0.015	0.014	0.022	0.050
PM10 (x10)	g/mi		0.281	0.243	0.228	4.655	0.229	0.222	0.222	0.219	0.249	0.259
Criteria, Urban												
VOC	g/mi		0.004	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.004
CO	g/mi		0.111	0.012	0.001	0.003	0.003	0.011	0.005	0.002	0.033	0.010
NOx	g/mi		0.035	0.002	0.001	0.001	0.001	0.014	0.002	0.001	0.002	0.003
PM10 (x10)	g/mi		0.233	0.217	0.206	0.209	0.208	0.215	0.215	0.212	0.238	0.216
Urban Toxics, (weighted)												
Benzene	g/mi		1.6E-04	8.7E-05	3.0E-05	---	2.3E-05	---	2.3E-05	9.8E-06	1.7E-04	6.8E-05
1-3 Butadiene	g/mi		1.9E-04	1.0E-04	3.1E-05	---	3.6E-05	---	3.6E-05	2.0E-05	2.1E-04	8.3E-05
Formaldehyde	g/mi		1.2E-03	6.6E-04	9.9E-05	---	1.9E-04	---	1.9E-04	6.8E-05	1.7E-03	6.7E-04
Acetaldehyde	g/mi		5.8E-05	3.1E-05	1.0E-05	---	8.2E-06	---	8.2E-06	3.5E-06	6.3E-05	2.5E-05
Diesel PM	g/mi		7.8E-03	4.2E-03	4.2E-03	---	0.0E+00	---	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Figure A-4. LDA Vehicle Class: Model Years 2010 and Newer (continued)

Hydrogen

Scenario Year 2022: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		H2	H2	H3	H4c	H5	H7	H11	H13	H22	H23
WTT Description		H2, NG SR, LH2	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, NG SR, Pipeline	H2, Biomass, Pipeline	H2, Onsite NG SR	H2, Onsite NG SR, Ren Power	H2, Grid Electrolysis	H2, 70% Renewable, Electrolysis
Vehicle Type		H2ICE	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	6.60	3.58	2.44	3.00	2.68	0.42	2.64	2.40	3.45	1.54
Petroleum	MJ/mi	0.05	0.02	0.02	0.04	0.01	0.07	0.01	0.01	0.01	0.03
Natural Gas	MJ/mi	6.55	3.55	2.42	0.38	2.67	0.35	2.63	2.39	3.44	1.52
Coal	MJ/mi	0.00	0.00	0.00	2.58	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.40	0.22	0.79	0.07	0.05	2.74	0.05	0.16	0.89	1.83
WTT	MJ/mi	4.00	2.16	1.60	1.45	1.11	1.53	1.06	0.94	2.71	1.74
TTW	MJ/mi	3.01	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63
GHGs (weighted)											
WTT	g/mi	401	217	147	74	165	28	156	142	225	128
TTW	g/mi	8	0	0	0	0	0	0	0	0	0
TOTAL	g/mi	410	217	147	74	165	28	156	142	225	128
Criteria, Total											
VOC	g/mi	0.044	0.022	0.015	0.026	0.016	0.005	0.016	0.015	0.022	0.016
CO	g/mi	0.175	0.041	0.023	0.022	0.026	0.020	0.024	0.020	0.056	0.028
NOx	g/mi	0.072	0.020	0.014	0.061	0.014	0.013	0.013	0.012	0.018	0.046
PM10 (x10)	g/mi	0.273	0.237	0.225	4.346	0.227	0.218	0.220	0.217	0.242	0.255
Criteria, Urban											
VOC	g/mi	0.004	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.003
CO	g/mi	0.117	0.009	0.001	0.003	0.003	0.010	0.004	0.002	0.028	0.009
NOx	g/mi	0.038	0.002	0.001	0.001	0.001	0.008	0.001	0.001	0.002	0.002
PM10 (x10)	g/mi	0.231	0.214	0.206	0.208	0.208	0.211	0.213	0.212	0.233	0.215
Urban Toxics, (weighted)											
Benzene	g/mi	1.3E-04	7.2E-05	2.2E-05	—	2.1E-05	—	2.1E-05	9.3E-06	1.5E-04	6.3E-05
1-3 Butadiene	g/mi	1.6E-04	8.8E-05	2.6E-05	—	3.3E-05	—	3.3E-05	1.9E-05	1.9E-04	7.7E-05
Formaldehyde	g/mi	1.1E-03	5.8E-04	8.4E-05	—	1.8E-04	—	1.8E-04	6.4E-05	1.5E-03	6.2E-04
Acetaldehyde	g/mi	4.8E-05	2.6E-05	7.8E-06	—	7.4E-06	—	7.4E-06	3.3E-06	5.6E-05	2.3E-05
Diesel PM	g/mi	4.4E-03	2.4E-03	2.4E-03	—	0.0E+00	—	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Figure A-4. LDA Vehicle Class: Model Years 2010 and Newer (concluded)

Hydrogen

Scenario Year 2030: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		H2	H2	H3	H4c	H5	H7	H11	H13	H22	H23
WTT Description		H2, NG SR, LH2	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestrati on	H2, NG SR, Pipeline	H2, Biomass, Pipeline	H2, Onsite NG SR	H2, Onsite NG SR, Ren Power	H2, Grid Electrolysis	H2, 70% Renewable, Electrolysis
Vehicle Type		H2ICE	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	6.20	3.36	2.29	2.82	2.52	0.40	2.48	2.26	3.16	1.45
Petroleum	MJ/mi	0.04	0.02	0.02	0.04	0.01	0.06	0.01	0.01	0.01	0.02
Natural Gas	MJ/mi	6.16	3.33	2.27	0.35	2.51	0.33	2.47	2.25	3.15	1.42
Coal	MJ/mi	0.00	0.00	0.00	2.43	0.00	0.00	0.00	0.00	0.00	0.00
Non Fossil	MJ/mi	0.38	0.21	0.74	0.07	0.05	2.58	0.04	0.15	0.92	1.72
WTT	MJ/mi	3.75	2.03	1.50	1.36	1.04	1.44	0.99	0.88	2.55	1.63
TTW	MJ/mi	2.83	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53
GHGs (weighted)											
WTT	g/mi	377	204	138	70	155	26	147	133	212	121
TTW	g/mi	8	0	0	0	0	0	0	0	0	0
TOTAL	g/mi	386	204	138	70	155	26	147	133	212	121
Criteria, Total											
VOC	g/mi	0.042	0.021	0.014	0.024	0.015	0.005	0.015	0.014	0.021	0.015
CO	g/mi	0.182	0.038	0.022	0.021	0.024	0.019	0.022	0.019	0.052	0.026
NOx	g/mi	0.073	0.019	0.013	0.057	0.013	0.011	0.013	0.011	0.017	0.043
PM10 (x10)	g/mi	0.271	0.235	0.224	4.095	0.225	0.217	0.219	0.216	0.239	0.251
Criteria, Urban											
VOC	g/mi	0.005	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.003
CO	g/mi	0.128	0.009	0.001	0.003	0.003	0.009	0.004	0.002	0.026	0.008
NOx	g/mi	0.043	0.002	0.001	0.001	0.001	0.007	0.001	0.001	0.002	0.002
PM10 (x10)	g/mi	0.233	0.214	0.206	0.208	0.208	0.211	0.213	0.211	0.231	0.214
Urban Toxics, (weighted)											
Benzene	g/mi	1.1E-04	6.2E-05	1.8E-05	—	1.9E-05	—	1.9E-05	8.7E-06	1.3E-04	5.9E-05
1-3 Butadiene	g/mi	1.4E-04	7.7E-05	2.3E-05	—	3.0E-05	—	3.0E-05	1.8E-05	1.6E-04	7.2E-05
Formaldehyde	g/mi	9.3E-04	5.0E-04	7.5E-05	—	1.6E-04	—	1.6E-04	6.0E-05	1.3E-03	5.8E-04
Acetaldehyde	g/mi	4.1E-05	2.2E-05	6.3E-06	—	6.7E-06	—	6.7E-06	3.1E-06	4.8E-05	2.2E-05
Diesel PM	g/mi	2.8E-03	1.5E-03	1.5E-03	—	0.0E+00	—	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Figure A-5. LDA Vehicle Class: All Model Years (E85)

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

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Corn, MW Ave	Ethanol, Corn, MW Coal	Ethanol, Corn, MW NG	Ethanol, Corn, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	4.33	4.59	4.24	3.69	3.48	1.53	1.32	1.74
Petroleum	MJ/mi	1.59	1.63	1.61	1.61	1.49	1.38	1.49	1.44
Natural Gas	MJ/mi	2.08	0.62	2.30	1.75	1.98	0.15	-0.17	0.29
Coal	MJ/mi	0.65	2.35	0.34	0.34	0.01	0.00	0.01	0.01
Non Fossil	MJ/mi	3.95	3.95	3.95	3.95	3.92	10.77	10.86	9.58
WTT	MJ/mi	3.37	3.64	3.28	2.73	2.50	7.39	7.28	6.41
TTW	MJ/mi	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
GHGs (weighted)									
WTT	g/mi	43	184	14	-19	-57	-207	-228	-164
TTW	g/mi	360	360	360	360	360	360	360	360
TOTAL	g/mi	402	544	373	340	302	153	132	195
Criteria, Total									
VOC	g/mi	0.447	0.480	0.474	0.470	0.463	—	0.416	0.444
CO	g/mi	3.277	3.421	3.321	3.304	3.223	—	3.082	3.028
NOx	g/mi	0.920	1.150	0.884	0.863	0.548	—	0.967	0.926
PM10 (x10)	g/mi	2.369	6.635	1.586	1.567	0.970	—	1.463	1.353
Criteria, Urban									
VOC	g/mi	0.312	0.312	0.312	0.312	0.312	—	0.317	0.322
CO	g/mi	2.633	2.634	2.634	2.634	2.635	—	2.664	2.684
NOx	g/mi	0.250	0.251	0.253	0.252	0.234	—	0.308	0.338
PM10 (x10)	g/mi	0.339	0.340	0.340	0.340	0.339	—	0.372	0.393
Urban Toxics, (weighted)									
Benzene	g/mi	2.3E-02	2.3E-02	2.3E-02	2.3E-02	—	—	—	—
1-3 Butadiene	g/mi	2.6E-02	2.6E-02	2.6E-02	2.6E-02	—	—	—	—
Formaldehyde	g/mi	2.4E-03	2.4E-03	2.4E-03	2.4E-03	—	—	—	—
Acetaldehyde	g/mi	2.6E-04	2.6E-04	2.6E-04	2.6E-04	—	—	—	—
Diesel PM	g/mi	9.7E-02	9.7E-02	9.7E-02	9.7E-02	—	—	—	—

Figure A-5. LDA Vehicle Class: All Model Years (continued)

E85

Scenario Year 2017: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Com, MW Ave	Ethanol, Com, MW Coal	Ethanol, Com, MW NG	Ethanol, Com, MW NG, Wet Feed	Ethanol, CA Com, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.90	4.15	3.83	3.33	3.12	1.39	1.18	1.46
Petroleum	MJ/mi	1.44	1.47	1.46	1.45	1.35	1.25	1.33	1.26
Natural Gas	MJ/mi	1.89	0.56	2.08	1.58	1.76	0.13	-0.16	0.20
Coal	MJ/mi	0.57	2.11	0.29	0.29	0.01	0.00	0.01	0.01
Non Fossil	MJ/mi	3.57	3.58	3.57	3.57	3.56	9.76	8.93	6.71
WTT	MJ/mi	3.03	3.28	2.95	2.45	2.23	6.70	5.66	3.73
TTW	MJ/mi	4.45	4.45	4.45	4.45	4.45	4.45	4.45	4.45
GHGs (weighted)									
WTT	g/mi	34	162	8	-22	-57	-188	-210	-168
TTW	g/mi	327	327	327	327	327	327	327	327
TOTAL	g/mi	360	489	335	305	270	139	117	159
Criteria, Total									
VOC	g/mi	0.343	0.371	0.366	0.362	0.356	—	0.313	0.329
CO	g/mi	2.315	2.443	2.352	2.337	2.265	—	2.115	2.028
NOx	g/mi	0.713	0.870	0.689	0.670	0.386	—	0.706	0.610
PM10 (x10)	g/mi	2.086	5.734	1.416	1.399	0.887	—	1.274	1.123
Criteria, Urban									
VOC	g/mi	0.229	0.229	0.229	0.229	0.228	—	0.230	0.231
CO	g/mi	1.754	1.754	1.754	1.754	1.754	—	1.774	1.785
NOx	g/mi	0.162	0.162	0.163	0.163	0.146	—	0.185	0.194
PM10 (x10)	g/mi	0.342	0.342	0.343	0.342	0.341	—	0.355	0.362
Urban Toxics, (weighted)									
Benzene	g/mi	1.5E-02	1.5E-02	1.5E-02	1.5E-02	—	—	—	—
1-3 Butadiene	g/mi	1.6E-02	1.6E-02	1.6E-02	1.6E-02	—	—	—	—
Formaldehyde	g/mi	1.5E-03	1.5E-03	1.5E-03	1.5E-03	—	—	—	—
Acetaldehyde	g/mi	1.6E-04	1.6E-04	1.6E-04	1.6E-04	—	—	—	—
Diesel PM	g/mi	8.1E-02	8.1E-02	8.1E-02	8.1E-02	—	—	—	—

Figure A-5. LDA Vehicle Class: All Model Years (continued)

E85

Scenario Year 2022: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Corn, MW Ave	Ethanol, Corn, MW Coal	Ethanol, Corn, MW NG	Ethanol, Corn, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.50	3.72	3.43	2.98	2.77	1.24	1.05	1.30
Petroleum	MJ/mi	1.29	1.32	1.31	1.31	1.21	1.12	1.18	1.12
Natural Gas	MJ/mi	1.69	0.50	1.87	1.42	1.55	0.12	-0.14	0.17
Coal	MJ/mi	0.51	1.89	0.26	0.25	0.01	0.00	0.01	0.01
Non Fossil	MJ/mi	3.21	3.21	3.21	3.21	3.21	8.78	7.59	5.75
WTT	MJ/mi	2.71	2.93	2.64	2.19	1.98	6.02	4.64	3.05
TTW	MJ/mi	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
GHGs (weighted)									
WTT	g/mi	27	143	4	-23	-55	-169	-190	-153
TTW	g/mi	295	295	295	295	295	295	295	295
TOTAL	g/mi	322	437	299	272	240	126	105	141
Criteria, Total									
VOC	g/mi	0.277	0.300	0.295	0.292	0.286	—	0.246	0.260
CO	g/mi	1.719	1.832	1.750	1.736	1.671	—	1.521	1.450
NOx	g/mi	0.577	0.699	0.558	0.541	0.286	—	0.551	0.479
PM10 (x10)	g/mi	1.876	5.090	1.285	1.269	0.819	—	1.140	1.018
Criteria, Urban									
VOC	g/mi	0.175	0.175	0.175	0.175	0.174	—	0.174	0.175
CO	g/mi	1.217	1.216	1.217	1.217	1.217	—	1.232	1.241
NOx	g/mi	0.112	0.112	0.113	0.112	0.097	—	0.118	0.124
PM10 (x10)	g/mi	0.344	0.344	0.344	0.344	0.343	—	0.347	0.351
Urban Toxics, (weighted)									
Benzene	g/mi	1.1E-02	1.1E-02	1.1E-02	1.1E-02	—	—	—	—
1-3 Butadiene	g/mi	1.1E-02	1.1E-02	1.1E-02	1.1E-02	—	—	—	—
Formaldehyde	g/mi	1.0E-03	1.0E-03	1.0E-03	1.0E-03	—	—	—	—
Acetaldehyde	g/mi	1.1E-04	1.1E-04	1.1E-04	1.1E-04	—	—	—	—
Diesel PM	g/mi	7.0E-02	7.0E-02	7.0E-02	7.0E-02	—	—	—	—

Figure A-5. LDA Vehicle Class: All Model Years (concluded)

E85

Scenario Year 2030: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Corn, MW Ave	Ethanol, Corn, MW Coal	Ethanol, Corn, MW NG	Ethanol, Corn, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.14	3.33	3.07	2.67	2.48	1.11	0.94	1.16
Petroleum	MJ/mi	1.16	1.19	1.17	1.17	1.09	1.01	1.06	1.01
Natural Gas	MJ/mi	1.52	0.45	1.67	1.27	1.39	0.11	-0.13	0.15
Coal	MJ/mi	0.46	1.70	0.23	0.23	0.01	0.00	0.00	0.00
Non Fossil	MJ/mi	2.88	2.88	2.87	2.87	2.87	7.86	6.80	5.15
WTT	MJ/mi	2.43	2.63	2.37	1.96	1.78	5.40	4.15	2.73
TTW	MJ/mi	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58
GHGs (weighted)									
WTT	g/mi	24	128	3	-21	-49	-151	-170	-137
TTW	g/mi	265	265	265	265	265	265	265	265
TOTAL	g/mi	289	393	268	244	216	114	95	128
Criteria, Total									
VOC	g/mi	0.215	0.235	0.231	0.228	0.223	—	0.187	0.200
CO	g/mi	1.257	1.358	1.285	1.273	1.215	—	1.079	1.017
NOx	g/mi	0.489	0.599	0.473	0.457	0.229	—	0.465	0.402
PM10 (x10)	g/mi	1.715	4.595	1.186	1.172	0.768	—	1.056	0.947
Criteria, Urban									
VOC	g/mi	0.124	0.124	0.124	0.124	0.123	—	0.123	0.123
CO	g/mi	0.808	0.808	0.808	0.808	0.808	—	0.821	0.830
NOx	g/mi	0.076	0.075	0.076	0.076	0.062	—	0.080	0.085
PM10 (x10)	g/mi	0.344	0.344	0.344	0.344	0.343	—	0.347	0.350
Urban Toxics, (weighted)									
Benzene	g/mi	6.9E-03	6.9E-03	6.9E-03	6.9E-03	—	—	—	—
1-3 Butadiene	g/mi	6.4E-03	6.4E-03	6.4E-03	6.4E-03	—	—	—	—
Formaldehyde	g/mi	6.5E-04	6.5E-04	6.5E-04	6.5E-04	—	—	—	—
Acetaldehyde	g/mi	7.3E-05	7.3E-05	7.3E-05	7.3E-05	—	—	—	—
Diesel PM	g/mi	6.1E-02	6.1E-02	6.1E-02	6.1E-02	—	—	—	—

Figure A-6. LDA Vehicle Class: Model Years 2010 and Newer (E85)

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

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Corn, MW Ave	Ethanol, Corn, MW Coal	Ethanol, Corn, MW NG	Ethanol, Corn, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.93	4.17	3.86	3.35	3.16	1.39	1.20	1.58
Petroleum	MJ/mi	1.45	1.48	1.46	1.46	1.36	1.25	1.36	1.31
Natural Gas	MJ/mi	1.89	0.56	2.09	1.59	1.80	0.13	-0.16	0.27
Coal	MJ/mi	0.59	2.14	0.31	0.30	0.01	0.00	0.01	0.01
Non Fossil	MJ/mi	3.59	3.59	3.59	3.59	3.57	9.79	9.87	8.71
WTT	MJ/mi	3.06	3.31	2.98	2.48	2.27	6.72	6.62	5.83
TTW	MJ/mi	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46
GHGs (weighted)									
WTT	g/mi	39	167	12	-17	-52	-188	-207	-149
TTW	g/mi	328	328	328	328	328	328	328	328
TOTAL	g/mi	367	495	340	310	276	140	120	178
Criteria, Total									
VOC	g/mi	0.176	0.206	0.200	0.197	0.191	—	0.147	0.173
CO	g/mi	0.951	1.082	0.991	0.975	0.902	—	0.773	0.725
NOx	g/mi	0.659	0.868	0.627	0.607	0.321	—	0.702	0.665
PM10 (x10)	g/mi	2.094	5.971	1.382	1.364	0.822	—	1.270	1.170
Criteria, Urban									
VOC	g/mi	0.053	0.053	0.054	0.054	0.053	—	0.058	0.062
CO	g/mi	0.366	0.366	0.366	0.366	0.367	—	0.393	0.412
NOx	g/mi	0.050	0.052	0.053	0.052	0.036	—	0.103	0.130
PM10 (x10)	g/mi	0.248	0.249	0.249	0.249	0.248	—	0.278	0.297
Urban Toxics, (weighted)									
Benzene	g/mi	2.3E-03	2.3E-03	2.3E-03	2.3E-03	—	—	—	—
1-3 Butadiene	g/mi	2.4E-03	2.4E-03	2.4E-03	2.4E-03	—	—	—	—
Formaldehyde	g/mi	4.2E-04	4.2E-04	4.2E-04	4.2E-04	—	—	—	—
Acetaldehyde	g/mi	6.2E-05	6.2E-05	6.2E-05	6.2E-05	—	—	—	—
Diesel PM	g/mi	8.8E-02	8.8E-02	8.8E-02	8.8E-02	—	—	—	—

Figure A-6. LDA Vehicle Class: Model Years 2010 and Newer (continued)

E85

Scenario Year 2017: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Corn, MW Ave	Ethanol, Corn, MW Coal	Ethanol, Corn, MW NG	Ethanol, Corn, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.52	3.74	3.46	3.00	2.81	1.25	1.06	1.32
Petroleum	MJ/mi	1.30	1.33	1.31	1.31	1.22	1.13	1.20	1.13
Natural Gas	MJ/mi	1.70	0.51	1.88	1.43	1.59	0.12	-0.14	0.18
Coal	MJ/mi	0.52	1.91	0.26	0.26	0.01	0.00	0.01	0.01
Non Fossil	MJ/mi	3.23	3.23	3.23	3.23	3.22	8.81	8.06	6.06
WTT	MJ/mi	2.74	2.96	2.67	2.21	2.02	6.05	5.11	3.36
TTW	MJ/mi	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
GHGs (weighted)									
WTT	g/mi	30	146	7	-20	-51	-170	-189	-151
TTW	g/mi	296	296	296	296	296	296	296	296
TOTAL	g/mi	326	442	303	276	245	126	107	145
Criteria, Total									
VOC	g/mi	0.162	0.188	0.183	0.179	0.174	—	0.135	0.149
CO	g/mi	0.952	1.069	0.987	0.973	0.907	—	0.772	0.694
NOx	g/mi	0.549	0.691	0.527	0.510	0.253	—	0.542	0.456
PM10 (x10)	g/mi	1.855	5.149	1.250	1.234	0.772	—	1.121	0.985
Criteria, Urban									
VOC	g/mi	0.059	0.059	0.059	0.059	0.059	—	0.060	0.061
CO	g/mi	0.446	0.446	0.446	0.446	0.446	—	0.464	0.474
NOx	g/mi	0.051	0.051	0.052	0.052	0.037	—	0.072	0.080
PM10 (x10)	g/mi	0.280	0.280	0.280	0.280	0.279	—	0.291	0.298
Urban Toxics, (weighted)									
Benzene	g/mi	2.8E-03	2.8E-03	2.8E-03	2.8E-03	—	—	—	—
1-3 Butadiene	g/mi	2.8E-03	2.8E-03	2.8E-03	2.8E-03	—	—	—	—
Formaldehyde	g/mi	4.0E-04	4.0E-04	4.0E-04	4.0E-04	—	—	—	—
Acetaldehyde	g/mi	5.3E-05	5.3E-05	5.3E-05	5.3E-05	—	—	—	—
Diesel PM	g/mi	7.3E-02	7.3E-02	7.3E-02	7.3E-02	—	—	—	—

Figure A-6. LDA Vehicle Class: Model Years 2010 and Newer (continued)

E85

Scenario Year 2022: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		E1	E2	E3	E4	E74	E77	E21	E23
WTT Description		Ethanol, Com, MW Ave	Ethanol, Com, MW Coal	Ethanol, Com, MW NG	Ethanol, Com, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.32	3.53	3.26	2.83	2.63	1.18	1.00	1.23
Petroleum	MJ/mi	1.23	1.26	1.24	1.24	1.15	1.07	1.12	1.07
Natural Gas	MJ/mi	1.61	0.48	1.77	1.35	1.48	0.11	-0.13	0.16
Coal	MJ/mi	0.49	1.80	0.24	0.24	0.01	0.00	0.00	0.00
Non Fossil	MJ/mi	3.05	3.05	3.05	3.05	3.05	8.34	7.21	5.46
WTT	MJ/mi	2.58	2.79	2.51	2.08	1.88	5.72	4.40	2.90
TTW	MJ/mi	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
GHGs (weighted)									
WTT	g/mi	26	135	4	-22	-52	-160	-180	-146
TTW	g/mi	280	280	280	280	280	280	280	280
TOTAL	g/mi	306	416	284	259	228	120	100	135
Criteria, Total									
VOC	g/mi	0.165	0.187	0.182	0.179	0.174	—	0.136	0.149
CO	g/mi	0.982	1.089	1.011	0.998	0.937	—	0.793	0.726
NOx	g/mi	0.494	0.610	0.476	0.460	0.218	—	0.469	0.401
PM10 (x10)	g/mi	1.760	4.813	1.199	1.184	0.756	—	1.061	0.945
Criteria, Urban									
VOC	g/mi	0.068	0.068	0.069	0.069	0.068	—	0.067	0.068
CO	g/mi	0.505	0.504	0.505	0.505	0.505	—	0.519	0.528
NOx	g/mi	0.053	0.052	0.053	0.053	0.039	—	0.058	0.064
PM10 (x10)	g/mi	0.305	0.305	0.305	0.305	0.304	—	0.308	0.312
Urban Toxics, (weighted)									
Benzene	g/mi	3.4E-03	3.4E-03	3.4E-03	3.4E-03	—	—	—	—
1-3 Butadiene	g/mi	3.2E-03	3.2E-03	3.2E-03	3.2E-03	—	—	—	—
Formaldehyde	g/mi	4.1E-04	4.1E-04	4.1E-04	4.1E-04	—	—	—	—
Acetaldehyde	g/mi	5.0E-05	5.0E-05	5.0E-05	5.0E-05	—	—	—	—
Diesel PM	g/mi	6.6E-02	6.6E-02	6.6E-02	6.6E-02	—	—	—	—

Figure A-6. LDA Vehicle Class: Model Years 2010 and Newer (concluded)

E85

Scenario Year 2030: LDA Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		Et1	Et2	Et3	Et4	Et74	Et77	Et21	Et23
WTT Description		Ethanol, Corn, MW Ave	Ethanol, Corn, MW Coal	Ethanol, Corn, MW NG	Ethanol, Corn, MW NG, Wet Feed	Ethanol, CA Corn, Wet Feed	Ethanol, Brazil Sugar Cane	Ethanol, CA Poplar, Cellulose	Ethanol, CA Switch Grass
Vehicle Type		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
Fossil	MJ/mi	3.12	3.32	3.06	2.66	2.47	1.11	0.94	1.16
Petroleum	MJ/mi	1.15	1.18	1.17	1.16	1.08	1.00	1.06	1.00
Natural Gas	MJ/mi	1.51	0.45	1.67	1.27	1.39	0.11	-0.12	0.15
Coal	MJ/mi	0.46	1.69	0.23	0.23	0.01	0.00	0.00	0.00
Non Fossil	MJ/mi	2.86	2.87	2.86	2.86	2.86	7.83	6.77	5.13
WTT	MJ/mi	2.42	2.62	2.36	1.95	1.77	5.37	4.14	2.72
TTW	MJ/mi	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57
GHGs (weighted)									
WTT	g/mi	24	127	3	-20	-49	-151	-169	-137
TTW	g/mi	264	264	264	264	264	264	264	264
TOTAL	g/mi	288	391	267	244	215	113	95	127
Criteria, Total									
VOC	g/mi	0.171	0.191	0.187	0.184	0.179	—	0.143	0.156
CO	g/mi	1.008	1.108	1.036	1.023	0.965	—	0.831	0.768
NOx	g/mi	0.468	0.577	0.451	0.436	0.208	—	0.444	0.381
PM10 (x10)	g/mi	1.694	4.562	1.167	1.153	0.751	—	1.037	0.929
Criteria, Urban									
VOC	g/mi	0.080	0.080	0.080	0.080	0.080	—	0.079	0.080
CO	g/mi	0.560	0.560	0.561	0.561	0.561	—	0.574	0.582
NOx	g/mi	0.056	0.055	0.056	0.056	0.042	—	0.059	0.065
PM10 (x10)	g/mi	0.328	0.328	0.329	0.328	0.327	—	0.331	0.334
Urban Toxics, (weighted)									
Benzene	g/mi	4.2E-03	4.2E-03	4.2E-03	4.2E-03	—	—	—	—
1-3 Butadiene	g/mi	3.8E-03	3.8E-03	3.8E-03	3.8E-03	—	—	—	—
Formaldehyde	g/mi	4.4E-04	4.4E-04	4.4E-04	4.4E-04	—	—	—	—
Acetaldehyde	g/mi	5.2E-05	5.2E-05	5.2E-05	5.2E-05	—	—	—	—
Diesel PM	g/mi	6.1E-02	6.1E-02	6.1E-02	6.1E-02	—	—	—	—

Figure A-7. LDA Vehicle Class: All Model Years (Biodiesel Blends, Renewable Diesel Blends and XTL Blends)

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

WTT Case ID		D2	D6	BD1	BD3	BD4	BD5	BD23	F1	F3	F5
WTT Description		Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	BTL, CA Poplar	CTL, Coal CCS
Vehicle Type		ULSD	ULSD	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FTD 30	FTD 30
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	4.89	4.82	4.31	4.37	4.48	3.64	3.64	5.48	3.53	5.88
Petroleum	MJ/mi	4.47	4.29	3.71	3.76	3.79	3.17	3.17	3.19	3.21	3.20
Natural Gas	MJ/mi	0.42	0.42	0.60	0.62	0.69	0.46	0.46	2.30	0.31	0.42
Coal	MJ/mi	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26
Non Fossil	MJ/mi	0.01	0.22	0.76	0.77	0.77	1.22	1.22	0.00	2.05	0.02
WTT	MJ/mi	0.85	1.00	1.03	1.10	1.20	0.81	0.81	1.44	1.54	1.86
TTW	MJ/mi	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04
GHGs (weighted)											
WTT	g/mi	67	72	16	21	27	-6	-2	87	-31	87
TTW	g/mi	309	309	310	310	310	305	305	305	305	305
TOTAL	g/mi	375	381	326	331	337	299	303	392	274	392
Criteria, Total											
VOC	g/mi	0.220	0.227	0.286	0.297	0.362	—	—	0.178	0.168	0.181
CO	g/mi	0.823	0.861	0.856	1.056	1.139	—	—	0.705	0.700	0.693
NOx	g/mi	1.685	1.751	1.711	1.739	1.748	—	—	1.618	1.587	1.600
PM10 (x10)	g/mi	1.548	1.789	1.438	1.461	1.463	—	—	1.444	1.441	5.027
Criteria, Urban											
VOC	g/mi	0.191	0.191	0.153	0.153	0.154	—	—	0.145	0.147	0.145
CO	g/mi	0.758	0.758	0.679	0.679	0.681	—	—	0.637	0.643	0.638
NOx	g/mi	1.467	1.468	1.509	1.509	1.516	—	—	1.395	1.408	1.394
PM10 (x10)	g/mi	1.388	1.388	1.279	1.279	1.282	—	—	1.298	1.305	1.298
Urban Toxics, (weighted)											
Benzene	g/mi	1.7E-02	—	—	—	—	—	—	1.3E-02	—	—
1-3 Butadiene	g/mi	9.5E-03	—	—	—	—	—	—	7.1E-03	—	—
Formaldehyde	g/mi	2.6E-02	—	—	—	—	—	—	2.0E-02	—	—
Acetaldehyde	g/mi	5.8E-03	—	—	—	—	—	—	4.4E-03	—	—
Diesel PM	g/mi	5.7E+00	—	—	—	—	—	—	5.2E+00	—	—

Figure A-7. LDA Vehicle Class: All Model Years (continued)

Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2017: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		D2	D6	BD1	BD3	BD4	BD5	BD23	F1	F3	F5
WTT Description		Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	BTL, CA Poplar	CTL, Coal CCS
Vehicle Type		ULSD	ULSD	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FTD 30	FTD 30
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	4.43	4.37	3.90	3.95	4.05	3.29	3.29	4.94	3.19	5.32
Petroleum	MJ/mi	4.05	3.89	3.36	3.40	3.43	2.88	2.88	2.89	2.91	2.90
Natural Gas	MJ/mi	0.38	0.39	0.54	0.55	0.62	0.42	0.42	2.05	0.28	0.38
Coal	MJ/mi	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04
Non Fossil	MJ/mi	0.01	0.20	0.69	0.69	0.70	1.11	1.11	0.00	1.86	0.02
WTT	MJ/mi	0.77	0.90	0.93	0.98	1.08	0.73	0.73	1.28	1.39	1.67
TTW	MJ/mi	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
GHGs (weighted)											
WTT	g/mi	60	65	14	19	24	-6	-2	76	-28	78
TTW	g/mi	281	281	282	282	282	277	277	277	277	277
TOTAL	g/mi	341	346	296	301	305	272	275	353	249	356
Criteria, Total											
VOC	g/mi	0.187	0.194	0.247	0.254	0.311	—	—	0.152	0.142	0.155
CO	g/mi	0.777	0.810	0.796	0.968	1.038	—	—	0.664	0.658	0.653
NOx	g/mi	1.657	1.714	1.676	1.695	1.699	—	—	1.589	1.553	1.573
PM10 (x10)	g/mi	1.377	1.587	1.278	1.295	1.295	—	—	1.287	1.279	4.534
Criteria, Urban											
VOC	g/mi	0.161	0.161	0.129	0.129	0.130	—	—	0.123	0.124	0.123
CO	g/mi	0.718	0.718	0.642	0.642	0.643	—	—	0.603	0.608	0.604
NOx	g/mi	1.461	1.462	1.497	1.497	1.501	—	—	1.389	1.397	1.388
PM10 (x10)	g/mi	1.237	1.237	1.140	1.140	1.141	—	—	1.158	1.162	1.159
Urban Toxics, (weighted)											
Benzene	g/mi	1.4E-02	—	—	—	—	—	—	1.1E-02	—	—
1-3 Butadiene	g/mi	8.0E-03	—	—	—	—	—	—	6.0E-03	—	—
Formaldehyde	g/mi	2.2E-02	—	—	—	—	—	—	1.6E-02	—	—
Acetaldehyde	g/mi	4.9E-03	—	—	—	—	—	—	3.7E-03	—	—
Diesel PM	g/mi	5.0E+00	—	—	—	—	—	—	4.6E+00	—	—

Figure A-7. LDA Vehicle Class: All Model Years (continued)

Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2022: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		D2	D6	BD1	BD3	BD4	BD5	BD23	F1	F3	F5
WTT Description		Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	BTL, CA Poplar	CTL, Coal CCS
Vehicle Type		ULSD	ULSD	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FTD 30	FTD 30
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	3.98	3.93	3.50	3.55	3.63	2.96	2.96	4.41	2.87	4.77
Petroleum	MJ/mi	3.64	3.50	3.02	3.06	3.08	2.59	2.59	2.60	2.62	2.61
Natural Gas	MJ/mi	0.34	0.35	0.48	0.49	0.55	0.37	0.37	1.82	0.25	0.33
Coal	MJ/mi	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.84
Non Fossil	MJ/mi	0.00	0.18	0.62	0.62	0.63	0.99	0.99	0.00	1.67	0.02
WTT	MJ/mi	0.69	0.81	0.83	0.88	0.97	0.66	0.66	1.12	1.25	1.50
TTW	MJ/mi	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29
GHGs (weighted)											
WTT	g/mi	54	58	12	17	21	-5	-2	67	-25	70
TTW	g/mi	253	253	254	254	254	250	250	250	250	250
TOTAL	g/mi	307	312	267	271	275	245	248	317	225	320
Criteria, Total											
VOC	g/mi	0.138	0.144	0.198	0.203	0.254	—	—	0.114	0.104	0.117
CO	g/mi	0.727	0.757	0.740	0.893	0.955	—	—	0.621	0.615	0.612
NOx	g/mi	1.628	1.678	1.644	1.657	1.658	—	—	1.559	1.522	1.546
PM10 (x10)	g/mi	1.408	1.594	1.303	1.316	1.314	—	—	1.316	1.306	4.235
Criteria, Urban											
VOC	g/mi	0.115	0.115	0.092	0.092	0.093	—	—	0.088	0.089	0.088
CO	g/mi	0.675	0.675	0.602	0.602	0.603	—	—	0.567	0.571	0.567
NOx	g/mi	1.453	1.454	1.486	1.487	1.489	—	—	1.381	1.385	1.381
PM10 (x10)	g/mi	1.285	1.285	1.181	1.181	1.182	—	—	1.202	1.204	1.202
Urban Toxics, (weighted)											
Benzene	g/mi	1.0E-02	—	—	—	—	—	—	7.5E-03	—	—
1-3 Butadiene	g/mi	5.6E-03	—	—	—	—	—	—	4.2E-03	—	—
Formaldehyde	g/mi	1.5E-02	—	—	—	—	—	—	1.1E-02	—	—
Acetaldehyde	g/mi	3.4E-03	—	—	—	—	—	—	2.6E-03	—	—
Diesel PM	g/mi	5.2E+00	—	—	—	—	—	—	4.8E+00	—	—

Figure A-7. LDA Vehicle Class: All Model Years (concluded)

Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2030: LDA Vehicle Class: All Model Years (blend)

WTT Case ID		D2	D6	BD1	BD3	BD4	BD5	BD23	F1	F3	F5
WTT Description		Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	BTL, CA Poplar	CTL, Coal CCS
Vehicle Type		ULSD	ULSD	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FTD 30	FTD 30
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	3.56	3.52	3.13	3.18	3.26	2.65	2.65	3.95	2.57	4.28
Petroleum	MJ/mi	3.26	3.13	2.71	2.74	2.76	2.32	2.32	2.33	2.35	2.33
Natural Gas	MJ/mi	0.30	0.31	0.43	0.44	0.49	0.33	0.33	1.63	0.22	0.30
Coal	MJ/mi	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65
Non Fossil	MJ/mi	0.00	0.16	0.56	0.56	0.56	0.89	0.89	0.00	1.50	0.02
WTT	MJ/mi	0.62	0.73	0.74	0.79	0.86	0.59	0.59	1.00	1.12	1.34
TTW	MJ/mi	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95
GHGs (weighted)											
WTT	g/mi	48	52	11	15	19	-5	-2	60	-23	63
TTW	g/mi	228	228	229	229	229	225	225	225	225	225
TOTAL	g/mi	276	280	240	244	247	220	223	285	202	288
Criteria, Total											
VOC	g/mi	0.135	0.140	0.185	0.190	0.236	—	—	0.110	0.101	0.113
CO	g/mi	0.513	0.539	0.539	0.677	0.732	—	—	0.440	0.435	0.431
NOx	g/mi	1.786	1.831	1.807	1.818	1.819	—	—	1.708	1.674	1.696
PM10 (x10)	g/mi	1.395	1.562	1.289	1.301	1.299	—	—	1.304	1.294	3.919
Criteria, Urban											
VOC	g/mi	0.114	0.114	0.091	0.091	0.092	—	—	0.087	0.088	0.087
CO	g/mi	0.466	0.466	0.416	0.416	0.417	—	—	0.391	0.395	0.392
NOx	g/mi	1.629	1.630	1.665	1.665	1.667	—	—	1.549	1.552	1.548
PM10 (x10)	g/mi	1.284	1.285	1.181	1.181	1.181	—	—	1.202	1.203	1.202
Urban Toxics, (weighted)											
Benzene	g/mi	1.0E-02	—	—	—	—	—	—	7.5E-03	—	—
1-3 Butadiene	g/mi	5.6E-03	—	—	—	—	—	—	4.2E-03	—	—
Formaldehyde	g/mi	1.5E-02	—	—	—	—	—	—	1.1E-02	—	—
Acetaldehyde	g/mi	3.4E-03	—	—	—	—	—	—	2.6E-03	—	—
Diesel PM	g/mi	5.2E+00	—	—	—	—	—	—	4.8E+00	—	—

Figure A-8. Urban Buses: All Model Years
(Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends)

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

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	43.67	34.93	43.05	34.44	38.50	39.07	40.01	32.49	32.49	48.98	60.04	31.49	1.97	52.52	71.80
Petroleum	MJ/mi	39.89	31.92	38.34	30.67	33.13	33.55	33.82	28.35	28.35	28.47	0.78	28.72	1.62	28.57	1.11
Natural Gas	MJ/mi	3.77	3.02	3.79	3.03	5.36	5.51	6.18	4.14	4.14	20.52	59.27	2.77	0.35	3.80	3.74
Coal	MJ/mi	0.00	0.00	0.93	0.74	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	20.16	66.94
Non Fossil	MJ/mi	0.05	0.04	1.97	1.58	6.83	6.84	6.85	10.90	10.90	0.04	0.01	18.34	60.80	0.18	0.48
WTT	MJ/mi	7.60	6.08	8.90	7.12	9.21	9.79	10.74	7.26	7.26	12.90	24.99	13.72	27.70	16.58	37.21
TTW	MJ/mi	36.12	28.90	36.12	28.90	36.12	36.12	36.12	36.12	36.12	36.12	35.07	36.12	35.07	36.12	35.07
GHGs (weighted)																
WTT	g/mi	595	476	648	518	143	190	239	-55	-21	776	1178	-276	-2313	778	1184
TTW	g/mi	2692	2157	2692	2157	2704	2704	2704	2659	2659	2658	2501	2658	2501	2658	2501
TOTAL	g/mi	3287	2633	3340	2675	2846	2894	2942	2603	2638	3434	3678	2382	188	3436	3685
Criteria, Total																
VOC	g/mi	1.199	1.121	1.264	1.172	1.952	2.043	2.626	—	—	1.016	1.248	0.923	0.941	1.042	1.335
CO	g/mi	4.257	4.137	4.596	4.408	4.889	6.682	7.417	—	—	3.697	4.323	3.649	4.163	3.587	3.959
NOx	g/mi	20.889	20.489	21.479	20.961	21.239	21.491	21.570	—	—	20.000	21.016	19.722	20.094	19.838	20.477
PM10 (x10)	g/mi	4.861	4.571	7.013	6.293	4.577	4.783	4.798	—	—	4.488	4.435	4.455	4.326	36.490	110.716
Criteria, Urban																
VOC	g/mi	0.934	0.909	0.938	0.912	0.760	0.761	0.770	—	—	0.723	0.898	0.738	0.947	0.722	0.896
CO	g/mi	3.672	3.669	3.674	3.670	3.308	3.309	3.330	—	—	3.089	3.877	3.146	3.868	3.096	3.700
NOx	g/mi	18.942	18.932	18.952	18.940	19.435	19.436	19.499	—	—	18.007	18.970	18.123	19.357	17.999	18.944
PM10 (x10)	g/mi	3.433	3.429	3.435	3.431	3.156	3.156	3.181	—	—	3.181	3.448	3.241	3.650	3.184	3.461
Urban Toxics, (weighted)																
Benzene	g/mi	7.8E-02	7.8E-02	—	—	—	—	—	—	—	5.9E-02	7.8E-02	—	—	—	—
1-3 Butadiene	g/mi	4.4E-02	4.4E-02	—	—	—	—	—	—	—	3.3E-02	4.4E-02	—	—	—	—
Formaldehyde	g/mi	1.2E-01	1.2E-01	—	—	—	—	—	—	—	8.9E-02	1.2E-01	—	—	—	—
Acetaldehyde	g/mi	2.7E-02	2.7E-02	—	—	—	—	—	—	—	2.0E-02	2.7E-02	—	—	—	—
Diesel PM	g/mi	1.6E+01	1.6E+01	—	—	—	—	—	—	—	1.5E+01	1.6E+01	—	—	—	—

Figure A-8. Urban Buses: All Model Years (continued)

Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2017: UB Vehicle Class: All Model Years (blend)

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	42.99	34.39	42.42	33.93	37.85	38.40	39.31	31.99	31.99	47.96	58.24	31.01	1.93	51.66	70.52
Petroleum	MJ/mi	39.31	31.45	37.77	30.22	32.64	33.05	33.31	27.93	27.93	28.05	0.76	28.30	1.60	26.15	1.10
Natural Gas	MJ/mi	3.68	2.95	3.77	3.01	5.21	5.35	8.00	4.06	4.06	19.91	57.48	2.71	0.33	3.65	3.46
Coal	MJ/mi	0.00	0.00	0.88	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.86	65.96
Non Fossil	MJ/mi	0.05	0.04	1.93	1.55	6.74	6.74	6.76	10.74	10.74	0.04	0.01	18.07	59.91	0.20	0.55
WTT	MJ/mi	7.45	5.96	8.76	7.01	9.00	9.56	10.48	7.13	7.13	12.41	23.70	13.49	27.29	16.27	36.51
TTW	MJ/mi	35.59	28.47	35.59	28.47	35.59	35.59	35.59	35.59	35.59	35.59	34.55	35.59	34.55	35.59	34.55
GHGs (weighted)																
WTT	g/mi	584	467	634	507	136	183	229	-56	-22	735	1068	-273	-2280	761	1153
TTW	g/mi	2653	2125	2653	2125	2664	2664	2664	2620	2620	2619	2464	2619	2464	2619	2464
TOTAL	g/mi	3237	2593	3287	2633	2601	2847	2893	2564	2598	3354	3532	2346	184	3380	3617
Criteria, Total																
VOC	g/mi	1.138	1.062	1.198	1.110	1.861	1.926	2.483	—	—	0.965	1.161	0.865	0.852	0.993	1.275
CO	g/mi	3.857	3.741	4.180	4.000	4.452	6.122	6.804	—	—	3.355	3.915	3.297	3.720	3.250	3.565
NOx	g/mi	18.935	18.550	19.494	18.997	19.181	19.363	19.400	—	—	18.134	19.044	17.783	17.678	17.984	18.545
PM10 (x10)	g/mi	4.497	4.223	6.530	5.849	4.210	4.376	4.367	—	—	4.156	4.102	4.076	3.837	35.692	108.837
Criteria, Urban																
VOC	g/mi	0.882	0.857	0.886	0.860	0.714	0.715	0.722	—	—	0.683	0.846	0.692	0.877	0.682	0.844
CO	g/mi	3.287	3.285	3.289	3.286	2.953	2.953	2.967	—	—	2.764	3.292	2.613	3.455	2.771	3.313
NOx	g/mi	17.037	17.032	17.047	17.039	17.444	17.445	17.481	—	—	16.196	17.065	16.266	17.299	16.188	17.039
PM10 (x10)	g/mi	3.134	3.132	3.136	3.134	2.865	2.865	2.879	—	—	2.904	3.150	2.938	3.260	2.908	3.160
Urban Toxics, (weighted)																
Benzene	g/mi	7.3E-02	7.3E-02	—	—	—	—	—	—	—	5.5E-02	7.4E-02	—	—	—	—
1-3 Butadiene	g/mi	4.1E-02	4.1E-02	—	—	—	—	—	—	—	3.1E-02	4.1E-02	—	—	—	—
Formaldehyde	g/mi	1.1E-01	1.1E-01	—	—	—	—	—	—	—	8.4E-02	1.1E-01	—	—	—	—
Acetaldehyde	g/mi	2.5E-02	2.5E-02	—	—	—	—	—	—	—	1.9E-02	2.5E-02	—	—	—	—
Diesel PM	g/mi	1.5E+01	1.5E+01	—	—	—	—	—	—	—	1.4E+01	1.5E+01	—	—	—	—

Figure A-8. Urban Buses: All Model Years (continued)

Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2022: UB Vehicle Class: All Model Years (blend)

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	42.43	33.94	41.90	33.52	37.33	37.88	38.77	31.57	31.57	47.08	56.64	30.60	1.90	50.94	69.44
Petroleum	MJ/mi	38.83	31.06	37.31	29.85	32.24	32.64	32.90	27.59	27.59	27.70	0.75	27.95	1.58	27.80	1.08
Natural Gas	MJ/mi	3.60	2.88	3.73	2.98	5.09	5.23	5.86	3.98	3.98	19.38	55.89	2.85	0.32	3.52	3.21
Coal	MJ/mi	0.00	0.00	0.86	0.69	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	19.62	65.15
Non Fossil	MJ/mi	0.05	0.04	1.90	1.52	6.66	6.67	6.68	10.60	10.60	0.04	0.01	17.85	59.18	0.22	0.61
WTT	MJ/mi	7.33	5.86	8.65	6.92	8.84	9.39	10.30	7.02	7.02	11.97	22.52	13.30	26.95	16.00	35.92
TTW	MJ/mi	35.15	28.12	35.15	28.12	35.15	35.15	35.15	35.15	35.15	35.15	34.13	35.15	34.13	35.15	34.13
GHGs (weighted)																
WTT	g/mi	574	459	624	499	131	176	222	-57	-24	715	1025	-272	-2252	745	1126
TTW	g/mi	2620	2099	2620	2099	2632	2632	2632	2588	2588	2587	2434	2587	2434	2587	2434
TOTAL	g/mi	3194	2559	3244	2598	2763	2808	2854	2530	2564	3302	3459	2315	182	3332	3560
Criteria, Total																
VOC	g/mi	1.075	1.001	1.135	1.049	1.792	1.846	2.391	—	—	0.914	1.114	0.812	0.775	0.944	1.213
CO	g/mi	3.572	3.459	3.891	3.714	4.171	5.804	6.469	—	—	3.111	3.622	3.049	3.417	3.009	3.284
NOx	g/mi	17.376	17.001	17.917	17.433	17.554	17.688	17.700	—	—	16.646	17.470	16.253	16.164	16.505	17.002
PM10 (x10)	g/mi	4.235	3.969	6.216	5.554	3.949	4.087	4.065	—	—	3.915	3.856	3.806	3.496	35.065	107.309
Criteria, Urban																
VOC	g/mi	0.826	0.802	0.830	0.805	0.668	0.669	0.675	—	—	0.640	0.790	0.646	0.810	0.640	0.789
CO	g/mi	3.013	3.011	3.014	3.013	2.702	2.703	2.713	—	—	2.534	3.016	2.578	3.167	2.539	3.037
NOx	g/mi	15.515	15.512	15.525	15.520	15.871	15.871	15.896	—	—	14.749	15.543	14.791	15.684	14.741	15.517
PM10 (x10)	g/mi	2.913	2.911	2.915	2.913	2.655	2.655	2.664	—	—	2.700	2.928	2.716	2.982	2.702	2.937
Urban Toxics, (weighted)																
Benzene	g/mi	6.8E-02	6.8E-02	—	—	—	—	—	—	—	5.1E-02	6.8E-02	—	—	—	—
1-3 Butadiene	g/mi	3.8E-02	3.8E-02	—	—	—	—	—	—	—	2.9E-02	3.8E-02	—	—	—	—
Formaldehyde	g/mi	1.0E-01	1.0E-01	—	—	—	—	—	—	—	7.8E-02	1.0E-01	—	—	—	—
Acetaldehyde	g/mi	2.3E-02	2.3E-02	—	—	—	—	—	—	—	1.8E-02	2.3E-02	—	—	—	—
Diesel PM	g/mi	1.4E+01	1.4E+01	—	—	—	—	—	—	—	1.3E+01	1.4E+01	—	—	—	—

Figure A-8. Urban Buses: All Model Years (concluded)

Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2030: UB Vehicle Class: All Model Years (blend)

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	41.96	33.57	41.43	33.15	36.92	37.46	38.34	31.22	31.22	46.56	56.01	30.26	1.88	50.37	68.67
Petroleum	MJ/mi	38.39	30.72	38.89	29.51	31.88	32.28	32.54	27.28	27.28	27.39	0.74	27.64	1.56	27.49	1.07
Natural Gas	MJ/mi	3.56	2.85	3.69	2.95	5.03	5.17	5.80	3.94	3.94	19.16	55.27	2.62	0.32	3.48	3.17
Coal	MJ/mi	0.00	0.00	0.85	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.40	64.43
Non Fossil	MJ/mi	0.05	0.04	1.88	1.50	6.59	6.59	6.61	10.49	10.49	0.04	0.01	17.65	58.52	0.21	0.60
WTT	MJ/mi	7.24	5.80	8.55	6.84	8.74	9.29	10.19	6.94	6.94	11.83	22.27	13.15	26.65	15.62	35.52
TTW	MJ/mi	34.76	27.81	34.76	27.81	34.76	34.76	34.76	34.76	34.76	34.76	33.75	34.76	33.75	34.76	33.75
GHGs (weighted)																
WTT	g/mi	568	454	617	493	129	174	219	-57	-23	707	1013	-269	-2227	737	1113
TTW	g/mi	2591	2076	2591	2076	2603	2603	2603	2559	2559	2559	2407	2559	2407	2559	2407
TOTAL	g/mi	3159	2530	3208	2570	2732	2777	2822	2502	2536	3265	3420	2290	180	3295	3520
Criteria, Total																
VOC	g/mi	0.970	0.897	1.029	0.944	1.698	1.752	2.290	—	—	0.834	1.009	0.732	0.671	0.863	1.106
CO	g/mi	2.935	2.823	3.250	3.075	3.592	5.206	5.863	—	—	2.575	2.984	2.512	2.774	2.474	2.650
NOx	g/mi	14.215	13.844	14.748	14.270	14.326	14.458	14.467	—	—	13.641	14.307	13.245	12.992	13.502	13.845
PM10 (x10)	g/mi	3.800	3.538	5.759	5.105	3.554	3.691	3.667	—	—	3.514	3.426	3.404	3.059	34.318	105.728
Criteria, Urban																
VOC	g/mi	0.724	0.700	0.728	0.703	0.586	0.587	0.593	—	—	0.563	0.688	0.569	0.707	0.562	0.687
CO	g/mi	2.382	2.381	2.384	2.382	2.138	2.138	2.147	—	—	2.004	2.387	2.047	2.531	2.009	2.406
NOx	g/mi	12.375	12.372	12.384	12.380	12.657	12.658	12.678	—	—	11.765	12.402	11.803	12.529	11.757	12.377
PM10 (x10)	g/mi	2.493	2.492	2.495	2.494	2.272	2.273	2.279	—	—	2.313	2.508	2.327	2.556	2.315	2.517
Urban Toxics, (weighted)																
Benzene	g/mi	5.9E-02	5.9E-02	—	—	—	—	—	—	—	4.4E-02	5.9E-02	—	—	—	—
1-3 Butadiene	g/mi	3.3E-02	3.3E-02	—	—	—	—	—	—	—	2.5E-02	3.3E-02	—	—	—	—
Formaldehyde	g/mi	8.9E-02	8.9E-02	—	—	—	—	—	—	—	6.7E-02	8.9E-02	—	—	—	—
Acetaldehyde	g/mi	2.0E-02	2.0E-02	—	—	—	—	—	—	—	1.5E-02	2.0E-02	—	—	—	—
Diesel PM	g/mi	1.2E+01	1.2E+01	—	—	—	—	—	—	—	1.1E+01	1.2E+01	—	—	—	—

Figure A-9. Urban Buses: Model Years 2010 and Newer (Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends)

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

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	43.23	34.59	42.63	34.10	38.12	38.68	39.61	32.16	32.16	48.50	59.45	31.18	1.95	52.00	71.09
Petroleum	MJ/mi	39.50	31.60	37.96	30.37	32.61	33.22	33.48	28.06	28.06	28.18	0.77	28.44	1.61	28.28	1.10
Natural Gas	MJ/mi	3.73	2.99	3.75	3.00	5.31	5.46	6.12	4.10	4.10	20.31	58.68	2.75	0.34	3.76	3.70
Coal	MJ/mi	0.00	0.00	0.92	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.96	66.28
Non Fossil	MJ/mi	0.05	0.04	1.95	1.56	6.76	6.77	6.78	10.79	10.79	0.04	0.01	18.16	60.20	0.18	0.47
WTT	MJ/mi	7.52	6.02	8.81	7.05	9.12	9.69	10.63	7.19	7.19	12.77	24.74	13.58	27.43	16.42	36.84
TTW	MJ/mi	35.76	28.61	35.76	28.61	35.76	35.76	35.76	35.76	35.76	35.76	34.72	35.76	34.72	35.76	34.72
GHGs (weighted)																
WTT	g/mi	589	471	641	513	141	188	236	-55	-20	768	1166	-273	-2290	770	1172
TTW	g/mi	2666	2136	2665	2135	2677	2677	2677	2632	2632	2632	2476	2632	2476	2632	2476
TOTAL	g/mi	3255	2607	3307	2648	2818	2865	2913	2578	2612	3400	3642	2359	186	3402	3648
Criteria, Total																
VOC	g/mi	0.430	0.353	0.494	0.404	1.336	1.426	2.002	—	—	0.438	0.479	0.346	0.175	0.464	0.565
CO	g/mi	1.479	1.361	1.815	1.629	2.406	4.181	4.910	—	—	1.363	1.545	1.315	1.386	1.254	1.185
NOx	g/mi	2.641	2.245	3.225	2.712	2.626	2.876	2.954	—	—	2.663	2.766	2.388	1.854	2.502	2.233
PM10 (x10)	g/mi	2.090	1.803	4.221	3.509	2.088	2.292	2.307	—	—	1.942	1.668	1.909	1.561	33.627	106.897
Criteria, Urban																
VOC	g/mi	0.168	0.143	0.172	0.146	0.155	0.156	0.166	—	—	0.148	0.132	0.162	0.181	0.147	0.130
CO	g/mi	0.901	0.898	0.902	0.899	0.841	0.842	0.862	—	—	0.761	0.906	0.818	1.094	0.768	0.928
NOx	g/mi	0.714	0.704	0.723	0.711	0.840	0.841	0.903	—	—	0.689	0.741	0.804	1.124	0.681	0.715
PM10 (x10)	g/mi	0.677	0.673	0.679	0.674	0.681	0.682	0.706	—	—	0.648	0.692	0.708	0.891	0.651	0.704
Urban Toxics, (weighted)																
Benzene	g/mi	4.3E-03	4.3E-03	—	—	—	—	—	—	—	3.3E-03	4.3E-03	—	—	—	—
1-3 Butadiene	g/mi	2.5E-03	2.4E-03	—	—	—	—	—	—	—	1.9E-03	2.5E-03	—	—	—	—
Formaldehyde	g/mi	6.6E-03	6.5E-03	—	—	—	—	—	—	—	5.0E-03	6.6E-03	—	—	—	—
Acetaldehyde	g/mi	1.5E-03	1.5E-03	—	—	—	—	—	—	—	1.1E-03	1.5E-03	—	—	—	—
Diesel PM	g/mi	2.3E+00	2.2E+00	—	—	—	—	—	—	—	2.1E+00	2.3E+00	—	—	—	—

Figure A-9. Urban Buses: Model Years 2010 and Newer (continued)

Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2017: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	42.35	33.88	41.79	33.43	37.29	37.83	38.73	31.51	31.51	47.25	57.38	30.55	1.91	50.89	69.47
Petroleum	MJ/mi	38.73	30.98	37.21	29.77	32.16	32.56	32.82	27.51	27.51	27.63	0.75	27.88	1.58	27.73	1.08
Natural Gas	MJ/mi	3.63	2.90	3.71	2.97	5.13	5.27	5.91	4.00	4.00	19.82	56.63	2.67	0.33	3.59	3.41
Coal	MJ/mi	0.00	0.00	0.87	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.57	64.98
Non Fossil	MJ/mi	0.05	0.04	1.90	1.52	6.64	6.64	6.66	10.58	10.58	0.04	0.01	17.81	59.02	0.20	0.54
WTT	MJ/mi	7.34	5.87	8.63	6.90	8.87	9.42	10.32	7.03	7.03	12.22	23.35	13.29	26.88	16.03	35.97
TTW	MJ/mi	35.06	28.05	35.06	28.05	35.06	35.06	35.06	35.06	35.06	35.06	34.04	35.06	34.04	35.06	34.04
GHGs (weighted)																
WTT	g/mi	576	461	625	500	134	180	228	-55	-21	724	1052	-269	-2246	749	1136
TTW	g/mi	2614	2094	2614	2094	2625	2625	2625	2581	2581	2581	2428	2581	2428	2581	2428
TOTAL	g/mi	3189	2555	3238	2594	2759	2805	2850	2526	2560	3305	3480	2312	182	3330	3564
Criteria, Total																
VOC	g/mi	0.416	0.341	0.475	0.389	1.277	1.341	1.890	—	—	0.422	0.459	0.324	0.134	0.449	0.551
CO	g/mi	1.538	1.424	1.857	1.679	2.373	4.018	4.690	—	—	1.406	1.595	1.348	1.403	1.302	1.251
NOx	g/mi	2.492	2.113	3.043	2.553	2.411	2.590	2.627	—	—	2.511	2.600	2.165	1.451	2.363	2.108
PM10 (x10)	g/mi	2.010	1.740	4.013	3.342	1.976	2.139	2.131	—	—	1.871	1.820	1.792	1.360	32.938	104.798
Criteria, Urban																
VOC	g/mi	0.164	0.140	0.168	0.143	0.147	0.149	0.156	—	—	0.144	0.126	0.153	0.159	0.143	0.127
CO	g/mi	0.977	0.975	0.978	0.976	0.896	0.897	0.910	—	—	0.824	0.982	0.872	1.142	0.830	1.002
NOx	g/mi	0.623	0.617	0.632	0.625	0.700	0.701	0.737	—	—	0.601	0.650	0.671	0.881	0.594	0.824
PM10 (x10)	g/mi	0.667	0.665	0.669	0.667	0.651	0.652	0.665	—	—	0.638	0.682	0.671	0.792	0.641	0.693
Urban Toxics, (weighted)																
Benzene	g/mi	4.2E-03	4.2E-03	—	—	—	—	—	—	—	3.2E-03	4.2E-03	—	—	—	—
1-3 Butadiene	g/mi	2.4E-03	2.4E-03	—	—	—	—	—	—	—	1.9E-03	2.4E-03	—	—	—	—
Formaldehyde	g/mi	6.4E-03	6.4E-03	—	—	—	—	—	—	—	4.9E-03	6.5E-03	—	—	—	—
Acetaldehyde	g/mi	1.4E-03	1.4E-03	—	—	—	—	—	—	—	1.1E-03	1.5E-03	—	—	—	—
Diesel PM	g/mi	2.2E+00	2.2E+00	—	—	—	—	—	—	—	2.1E+00	2.3E+00	—	—	—	—

Figure A-9. Urban Buses: Model Years 2010 and Newer (continued)

Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2022: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	41.90	33.52	41.38	33.10	36.87	37.40	38.28	31.18	31.18	46.49	55.94	30.22	1.88	50.30	68.58
Petroleum	MJ/mi	38.34	30.67	36.84	29.47	31.84	32.24	32.49	27.24	27.24	27.36	0.74	27.60	1.56	27.45	1.07
Natural Gas	MJ/mi	3.56	2.85	3.68	2.95	5.03	5.16	5.79	3.93	3.93	19.14	55.20	2.61	0.32	3.47	3.17
Coal	MJ/mi	0.00	0.00	0.85	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.37	64.34
Non Fossil	MJ/mi	0.05	0.04	1.88	1.50	6.58	6.58	6.60	10.47	10.47	0.04	0.01	17.63	58.44	0.21	0.60
WTT	MJ/mi	7.23	5.79	8.54	6.83	8.73	9.28	10.17	6.93	6.93	11.82	22.24	13.13	26.61	15.80	35.47
TTW	MJ/mi	34.71	27.77	34.71	27.77	34.71	34.71	34.71	34.71	34.71	34.71	33.70	34.71	33.70	34.71	33.70
GHGs (weighted)																
WTT	g/mi	567	453	616	493	129	174	219	-57	-23	706	1012	-269	-2224	736	1112
TTW	g/mi	2588	2073	2588	2073	2599	2599	2599	2556	2556	2555	2404	2555	2404	2555	2404
TOTAL	g/mi	3155	2527	3204	2566	2728	2773	2818	2499	2532	3261	3416	2286	180	3291	3516
Criteria, Total																
VOC	g/mi	0.408	0.335	0.467	0.382	1.254	1.307	1.846	—	—	0.412	0.446	0.311	0.111	0.442	0.544
CO	g/mi	1.535	1.423	1.849	1.675	2.346	3.957	4.614	—	—	1.398	1.584	1.337	1.381	1.298	1.250
NOx	g/mi	2.407	2.036	2.941	2.463	2.288	2.419	2.431	—	—	2.423	2.499	2.035	1.210	2.284	2.037
PM10 (x10)	g/mi	1.969	1.707	3.925	3.272	1.915	2.052	2.029	—	—	1.834	1.595	1.727	1.239	32.596	103.757
Criteria, Urban																
VOC	g/mi	0.162	0.138	0.166	0.141	0.144	0.145	0.151	—	—	0.142	0.127	0.148	0.146	0.141	0.125
CO	g/mi	0.982	0.981	0.984	0.982	0.895	0.895	0.905	—	—	0.828	0.987	0.872	1.134	0.834	1.006
NOx	g/mi	0.569	0.566	0.579	0.573	0.625	0.626	0.650	—	—	0.550	0.597	0.592	0.736	0.542	0.571
PM10 (x10)	g/mi	0.663	0.662	0.665	0.664	0.637	0.638	0.646	—	—	0.634	0.678	0.650	0.732	0.636	0.687
Urban Toxics, (weighted)																
Benzene	g/mi	4.2E-03	4.2E-03	—	—	—	—	—	—	—	3.2E-03	4.2E-03	—	—	—	—
1-3 Butadiene	g/mi	2.4E-03	2.4E-03	—	—	—	—	—	—	—	1.8E-03	2.4E-03	—	—	—	—
Formaldehyde	g/mi	6.4E-03	6.4E-03	—	—	—	—	—	—	—	4.8E-03	6.4E-03	—	—	—	—
Acetaldehyde	g/mi	1.4E-03	1.4E-03	—	—	—	—	—	—	—	1.1E-03	1.4E-03	—	—	—	—
Diesel PM	g/mi	2.2E+00	2.2E+00	—	—	—	—	—	—	—	2.1E+00	2.2E+00	—	—	—	—

Figure A-9. Urban Buses: Model Years 2010 and Newer (concluded)

Diesel, Biodiesel Blends, Renewable Diesel Blends and XTL Blends

Scenario Year 2030: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		D2	D2	D6	D6	BD1	BD3	BD4	BD5	BD23	F1	F1	F3	F3	F5	F5
WTT Description		Diesel, CA ULSD	Diesel, CA ULSD	E-Diesel, Ave. MW EtOH	E-Diesel, Ave. MW EtOH	BD, Canola	BD, MW SoyBean	BD, CA Mustard	Ren. Diesel Canola	Ren. Diesel Palm Oil	GTL, Remote NG	GTL, Remote NG	BTL, CA Poplar	BTL, CA Poplar	CTL, Coal CCS	CTL, Coal CCS
Vehicle Type		ULSD	ULSD HEV	ULSD	ULSD HEV	BD20	BD20	BD20	FTD 30	FTD 30	FTD 30	FT100	FTD 30	FT100	FTD 30	FT100
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV
Fossil	MJ/mi	41.49	33.19	40.97	32.77	36.50	37.03	37.91	30.87	30.87	46.03	55.38	29.92	1.86	49.80	67.90
Petroleum	MJ/mi	37.96	30.37	36.48	29.18	31.53	31.92	32.17	26.97	26.97	27.08	0.73	27.33	1.55	27.18	1.06
Natural Gas	MJ/mi	3.52	2.82	3.65	2.92	4.98	5.11	5.73	3.89	3.89	18.95	54.65	2.59	0.31	3.44	3.14
Coal	MJ/mi	0.00	0.00	0.84	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.18	63.70
Non Fossil	MJ/mi	0.05	0.04	1.86	1.49	6.51	6.52	6.54	10.37	10.37	0.04	0.01	17.45	57.86	0.21	0.60
WTT	MJ/mi	7.16	5.73	8.45	6.76	8.65	9.18	10.07	6.87	6.87	11.70	22.02	13.00	26.35	15.64	35.12
TTW	MJ/mi	34.37	27.50	34.37	27.50	34.37	34.37	34.37	34.37	34.37	34.37	33.37	34.37	33.37	34.37	33.37
GHGs (weighted)																
WTT	g/mi	561	449	610	488	128	172	217	-56	-23	699	1002	-266	-2202	729	1101
TTW	g/mi	2562	2053	2562	2053	2573	2573	2573	2531	2531	2530	2380	2530	2380	2530	2380
TOTAL	g/mi	3124	2502	3172	2541	2701	2746	2790	2474	2508	3229	3382	2284	178	3259	3481
Criteria, Total																
VOC	g/mi	0.385	0.313	0.444	0.360	1.226	1.279	1.612	—	—	0.394	0.423	0.293	0.089	0.423	0.520
CO	g/mi	1.556	1.445	1.867	1.694	2.353	3.949	4.598	—	—	1.415	1.604	1.352	1.396	1.315	1.274
NOx	g/mi	2.393	2.026	2.920	2.448	2.270	2.400	2.410	—	—	2.409	2.485	2.017	1.184	2.271	2.027
PM10 (x10)	g/mi	1.997	1.737	3.933	3.286	1.936	2.072	2.048	—	—	1.859	1.626	1.750	1.263	32.317	102.777
Criteria, Urban																
VOC	g/mi	0.141	0.118	0.145	0.121	0.126	0.127	0.133	—	—	0.126	0.106	0.131	0.125	0.125	0.105
CO	g/mi	1.009	1.008	1.010	1.009	0.915	0.916	0.924	—	—	0.850	1.014	0.893	1.156	0.856	1.032
NOx	g/mi	0.573	0.571	0.583	0.578	0.620	0.621	0.640	—	—	0.554	0.601	0.592	0.727	0.546	0.575
PM10 (x10)	g/mi	0.704	0.703	0.706	0.705	0.669	0.670	0.676	—	—	0.671	0.719	0.685	0.766	0.674	0.727
Urban Toxics, (weighted)																
Benzene	g/mi	2.3E-03	2.3E-03	—	—	—	—	—	—	—	1.8E-03	2.3E-03	—	—	—	—
1-3 Butadiene	g/mi	1.4E-03	1.3E-03	—	—	—	—	—	—	—	1.1E-03	1.4E-03	—	—	—	—
Formaldehyde	g/mi	3.6E-03	3.5E-03	—	—	—	—	—	—	—	2.7E-03	3.6E-03	—	—	—	—
Acetaldehyde	g/mi	8.0E-04	7.9E-04	—	—	—	—	—	—	—	6.1E-04	8.0E-04	—	—	—	—
Diesel PM	g/mi	2.4E+00	2.4E+00	—	—	—	—	—	—	—	2.3E+00	2.5E+00	—	—	—	—

Figure A-10. Urban Buses: All Model Years (Natural Gas, DME, Methanol, and Hydrogen)

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

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	42.73	47.17	46.90	44.95	56.21	2.23	70.80	45.01	29.44	51.51	63.46	36.85	47.02	41.98	25.21
Petroleum	MJ/mi	0.17	0.52	0.52	0.18	1.10	1.85	1.20	1.10	1.38	0.90	0.41	0.31	0.68	0.16	0.40
Natural Gas	MJ/mi	42.57	46.66	46.38	44.78	55.10	0.38	3.69	43.91	28.07	30.47	63.05	36.54	6.94	41.82	24.81
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	65.91	0.00	0.00	20.13	0.00	0.00	39.40	0.00	0.00
Non Fossil	MJ/mi	0.21	0.03	0.02	0.03	0.01	65.92	0.47	0.01	20.14	0.34	3.46	16.22	0.91	0.75	28.49
WTT	MJ/mi	4.52	8.78	8.89	6.96	20.10	32.03	35.15	17.24	21.80	24.07	42.85	28.99	23.85	18.65	29.62
TTW	MJ/mi	38.43	38.43	38.02	38.02	36.12	36.12	36.12	27.78	27.78	27.78	24.08	24.08	24.08	24.08	24.08
GHGs (weighted)																
WTT	g/mi	403	782	750	611	964	-2198	1082	808	-1759	838	3869	2222	1210	2492	2027
TTW	g/mi	2136	2136	2166	2166	2409	2409	2409	1902	1902	1902	0	0	0	0	0
TOTAL	g/mi	2540	2919	2916	2776	3373	211	3492	2710	143	2739	3869	2222	1210	2492	2027
Criteria, Total																
VOC	g/mi	1.071	1.128	1.157	1.073	3.205	0.957	1.332	0.615	0.272	0.544	0.403	0.239	0.401	0.259	0.265
CO	g/mi	4.007	4.322	4.366	4.046	4.500	4.219	3.813	1.430	1.091	0.964	0.778	0.369	0.359	0.396	0.458
NOx	g/mi	19.130	21.659	22.114	19.133	21.527	20.445	19.806	6.728	4.567	4.961	0.432	0.284	0.937	0.234	0.726
PM10 (x10)	g/mi	3.547	4.336	4.346	3.567	3.282	3.143	59.816	1.973	0.610	77.025	0.809	0.533	63.395	0.448	0.968
Criteria, Urban																
VOC	g/mi	0.813	0.812	0.814	0.810	2.857	2.911	0.809	0.311	0.350	0.309	0.008	0.005	0.001	0.005	0.052
CO	g/mi	3.678	3.676	3.668	3.662	3.692	3.898	3.685	0.762	0.912	0.778	0.214	0.009	0.054	0.074	0.151
NOx	g/mi	18.916	18.939	18.972	18.907	19.025	19.437	18.897	3.899	4.189	3.863	0.036	0.021	0.011	0.023	0.049
PM10 (x10)	g/mi	3.429	3.440	3.427	3.416	1.867	2.078	1.833	0.256	0.401	0.250	0.402	0.200	0.250	0.332	0.355
Urban Toxics, (weighted)																
Benzene	g/mi	7.9E-04	8.1E-04	2.0E-04	1.0E-03	3.3E-04	—	—	3.3E-04	—	—	1.4E-03	6.1E-04	—	3.3E-04	9.7E-04
1-3 Butadiene	g/mi	2.0E-03	2.1E-03	2.0E-04	2.0E-03	3.0E-04	—	—	2.9E-04	—	—	1.6E-03	5.4E-04	—	5.1E-04	1.2E-03
Formaldehyde	g/mi	1.2E-01	1.2E-01	1.2E-01	1.3E-01	1.2E-01	—	—	2.4E-02	—	—	1.0E-02	1.7E-03	—	2.8E-03	9.5E-03
Acetaldehyde	g/mi	2.7E-02	2.7E-02	2.7E-02	2.7E-02	2.7E-02	—	—	5.5E-03	—	—	5.2E-04	2.1E-04	—	1.2E-04	3.6E-04
Diesel PM	g/mi	1.6E+01	1.6E+01	1.6E+01	1.6E+01	8.3E+00	—	—	2.2E-01	—	—	1.1E-01	1.1E-01	—	0.0E+00	0.0E+00

Figure A-10. Urban Buses: All Model Years (continued)

Natural Gas, DME, Methanol, and Hydrogen

Scenario Year 2017: UB Vehicle Class: All Model Years (blend)

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	42.01	46.40	46.20	44.28	54.99	2.19	69.54	42.79	29.01	50.59	56.27	36.05	44.92	40.03	23.65
Petroleum	MJ/mi	0.16	0.51	0.51	0.17	1.09	1.82	1.18	1.08	1.36	0.89	0.38	0.30	0.66	0.15	0.39
Natural Gas	MJ/mi	41.85	45.89	45.69	44.11	53.90	0.37	3.42	41.71	27.65	29.86	55.89	35.75	6.06	39.88	23.26
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	64.95	0.00	0.00	19.84	0.00	0.00	38.20	0.00	0.00
Non Fossil	MJ/mi	0.24	0.04	0.02	0.03	0.01	64.95	0.54	0.01	19.65	0.39	3.24	13.13	0.98	0.73	27.53
WTT	MJ/mi	4.39	8.58	8.75	6.85	19.41	31.56	34.49	15.42	21.47	23.60	35.78	25.46	22.17	17.03	27.45
TTW	MJ/mi	37.86	37.86	37.46	37.46	35.59	35.59	35.59	27.38	27.38	27.38	23.73	23.73	23.73	23.73	23.73
GHGs (weighted)																
WTT	g/mi	391	764	739	601	926	-2167	1054	770	-1734	816	3425	2174	1132	2374	1942
TTW	g/mi	2105	2105	2134	2134	2374	2374	2374	1874	1874	1874	0	0	0	0	0
TOTAL	g/mi	2496	2869	2873	2735	3300	207	3428	2644	140	2689	3425	2174	1132	2374	1942
Criteria, Total																
VOC	g/mi	1.014	1.070	1.083	1.014	3.110	0.862	1.270	0.583	0.228	0.525	0.351	0.228	0.385	0.244	0.249
CO	g/mi	3.617	3.927	3.946	3.652	4.079	3.766	3.421	1.312	0.961	0.873	0.659	0.350	0.338	0.368	0.429
NOx	g/mi	17.229	19.718	19.963	17.196	19.539	18.179	17.869	6.215	3.911	4.529	0.340	0.234	0.901	0.210	0.687
PM10 (x10)	g/mi	3.243	4.018	4.020	3.261	3.078	2.766	58.798	1.900	0.444	75.873	0.701	0.496	61.451	0.416	0.925
Criteria, Urban																
VOC	g/mi	0.764	0.763	0.764	0.761	2.775	2.808	0.760	0.296	0.320	0.294	0.007	0.005	0.001	0.005	0.050
CO	g/mi	3.298	3.296	3.286	3.282	3.302	3.478	3.303	0.677	0.804	0.691	0.164	0.008	0.047	0.064	0.140
NOx	g/mi	17.032	17.055	17.068	17.020	17.100	17.346	17.013	3.485	3.655	3.450	0.032	0.020	0.010	0.022	0.036
PM10 (x10)	g/mi	3.136	3.149	3.136	3.127	1.702	1.814	1.683	0.234	0.308	0.227	0.347	0.194	0.238	0.315	0.336
Urban Toxics, (weighted)																
Benzene	g/mi	7.8E-04	8.0E-04	1.3E-04	9.3E-04	2.1E-04	—	—	2.1E-04	—	—	1.2E-03	4.2E-04	—	3.1E-04	9.3E-04
1-3 Butadiene	g/mi	1.9E-03	2.0E-03	1.6E-04	1.9E-03	2.3E-04	—	—	2.2E-04	—	—	1.4E-03	4.3E-04	—	4.9E-04	1.1E-03
Formaldehyde	g/mi	1.2E-01	1.2E-01	1.1E-01	1.2E-01	1.1E-01	—	—	2.3E-02	—	—	9.0E-03	1.4E-03	—	2.7E-03	9.2E-03
Acetaldehyde	g/mi	2.5E-02	2.5E-02	2.5E-02	2.5E-02	2.5E-02	—	—	5.1E-03	—	—	4.3E-04	1.4E-04	—	1.1E-04	3.4E-04
Diesel PM	g/mi	1.5E+01	1.5E+01	1.5E+01	1.5E+01	7.5E+00	—	—	1.8E-01	—	—	5.8E-02	5.8E-02	—	0.0E+00	0.0E+00

Figure A-10. Urban Buses: All Model Years (continued)

Natural Gas, DME, Methanol, and Hydrogen

Scenario Year 2022: UB Vehicle Class: All Model Years (blend)

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestrati on	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	41.40	45.51	45.36	43.48	53.18	2.16	68.48	41.67	28.64	49.82	51.41	35.11	43.18	37.97	22.17
Petroleum	MJ/mi	0.16	0.50	0.50	0.17	1.07	1.80	1.16	1.06	1.34	0.88	0.36	0.30	0.63	0.15	0.38
Natural Gas	MJ/mi	41.24	45.00	44.66	43.31	52.12	0.36	3.17	40.61	27.30	29.35	51.05	34.82	5.41	37.83	21.79
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	64.15	0.00	0.00	19.59	0.00	0.00	37.13	0.00	0.00
Non Fossil	MJ/mi	0.27	0.04	0.02	0.04	0.01	64.16	0.60	0.01	19.60	0.44	3.15	11.30	1.05	0.66	26.26
WTT	MJ/mi	4.27	8.15	8.37	6.51	18.05	31.16	33.93	14.64	21.20	23.21	31.12	22.97	20.80	15.20	24.99
TTW	MJ/mi	37.40	37.40	37.00	37.00	35.15	35.15	35.15	27.04	27.04	27.04	23.43	23.43	23.43	23.43	23.43
GHGs (weighted)																
WTT	g/mi	381	733	713	578	848	-2141	1030	750	-1713	796	3127	2118	1071	2249	1848
TTW	g/mi	2080	2080	2108	2108	2345	2345	2345	1851	1851	1851	0	0	0	0	0
TOTAL	g/mi	2460	2813	2821	2686	3193	204	3375	2601	138	2647	3127	2118	1071	2249	1848
Criteria, Total																
VOC	g/mi	0.955	1.007	1.013	0.952	3.017	0.783	1.207	0.560	0.198	0.507	0.317	0.219	0.372	0.229	0.237
CO	g/mi	3.338	3.636	3.643	3.367	3.775	3.458	3.142	1.236	0.880	0.808	0.584	0.335	0.323	0.341	0.403
NOx	g/mi	15.706	18.132	18.282	15.659	17.946	16.438	16.327	5.837	3.443	4.195	0.289	0.208	0.872	0.191	0.661
PM10 (x10)	g/mi	3.017	3.772	3.771	3.032	2.928	2.512	57.973	1.855	0.340	74.924	0.633	0.471	59.726	0.388	0.891
Criteria, Urban																
VOC	g/mi	0.710	0.709	0.709	0.707	2.695	2.716	0.706	0.282	0.297	0.280	0.007	0.005	0.001	0.005	0.049
CO	g/mi	3.025	3.023	3.013	3.010	3.025	3.186	3.030	0.618	0.735	0.631	0.134	0.008	0.042	0.055	0.129
NOx	g/mi	15.520	15.543	15.546	15.507	15.569	15.714	15.501	3.166	3.262	3.131	0.029	0.020	0.010	0.021	0.030
PM10 (x10)	g/mi	2.920	2.930	2.918	2.909	1.582	1.633	1.570	0.221	0.250	0.213	0.312	0.188	0.227	0.299	0.318
Urban Toxics, (weighted)																
Benzene	g/mi	7.7E-04	7.8E-04	8.9E-05	8.8E-04	1.4E-04	—	—	1.4E-04	—	—	1.0E-03	3.2E-04	—	3.0E-04	9.0E-04
1-3 Butadiene	g/mi	1.9E-03	2.0E-03	1.4E-04	1.9E-03	1.9E-04	—	—	1.9E-04	—	—	1.3E-03	3.8E-04	—	4.7E-04	1.1E-03
Formaldehyde	g/mi	1.1E-01	1.1E-01	1.0E-01	1.1E-01	1.0E-01	—	—	2.1E-02	—	—	8.3E-03	1.2E-03	—	2.5E-03	8.9E-03
Acetaldehyde	g/mi	2.4E-02	2.4E-02	2.3E-02	2.4E-02	2.3E-02	—	—	4.7E-03	—	—	3.8E-04	1.1E-04	—	1.1E-04	3.3E-04
Diesel PM	g/mi	1.4E+01	1.4E+01	1.4E+01	1.4E+01	7.0E+00	—	—	1.7E-01	—	—	3.4E-02	3.4E-02	—	0.0E+00	0.0E+00

Figure A-10. Urban Buses: All Model Years (concluded)

Natural Gas, DME, Methanol, and Hydrogen

Scenario Year 2030: UB Vehicle Class: All Model Years (blend)

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestrati on	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	40.94	45.00	44.85	43.00	52.59	2.13	67.72	41.21	28.32	49.26	50.84	34.72	42.70	37.55	21.92
Petroleum	MJ/mi	0.16	0.49	0.50	0.17	1.06	1.78	1.15	1.05	1.33	0.87	0.36	0.29	0.63	0.15	0.37
Natural Gas	MJ/mi	40.78	44.50	44.36	42.83	51.54	0.35	3.13	40.16	27.00	29.02	50.48	34.43	5.35	37.40	21.55
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	63.43	0.00	0.00	19.38	0.00	0.00	36.72	0.00	0.00
Non Fossil	MJ/mi	0.27	0.04	0.02	0.04	0.01	63.44	0.59	0.01	19.38	0.43	3.11	11.17	1.04	0.65	25.97
WTT	MJ/mi	4.23	8.06	8.28	6.44	17.84	30.82	33.55	14.48	20.97	22.95	30.78	22.72	20.57	15.03	24.72
TTW	MJ/mi	36.98	36.98	36.59	36.59	34.76	34.76	34.76	26.74	26.74	26.74	23.17	23.17	23.17	23.17	23.17
GHGs (weighted)																
WTT	g/mi	376	725	705	571	838	-2117	1018	742	-1694	787	3092	2095	1059	2224	1827
TTW	g/mi	2057	2057	2085	2085	2319	2319	2319	1830	1830	1830	0	0	0	0	0
TOTAL	g/mi	2433	2782	2790	2656	3158	202	3337	2572	137	2617	3092	2095	1059	2224	1827
Criteria, Total																
VOC	g/mi	0.851	0.904	0.905	0.848	2.890	0.678	1.100	0.534	0.175	0.482	0.313	0.216	0.367	0.227	0.234
CO	g/mi	2.705	2.999	3.001	2.733	3.132	2.813	2.509	1.101	0.743	0.678	0.576	0.330	0.319	0.337	0.398
NOx	g/mi	12.567	14.966	15.075	12.515	14.774	13.257	13.174	5.173	2.786	3.548	0.280	0.199	0.862	0.189	0.651
PM10 (x10)	g/mi	2.598	3.345	3.342	2.613	2.697	2.273	57.130	1.825	0.319	74.082	0.618	0.458	59.056	0.378	0.875
Criteria, Urban																
VOC	g/mi	0.610	0.608	0.608	0.606	2.571	2.591	0.605	0.260	0.274	0.258	0.007	0.005	0.001	0.005	0.048
CO	g/mi	2.396	2.394	2.383	2.381	2.393	2.549	2.400	0.490	0.602	0.502	0.132	0.008	0.042	0.054	0.127
NOx	g/mi	12.383	12.406	12.405	12.369	12.424	12.554	12.364	2.531	2.617	2.496	0.028	0.020	0.010	0.021	0.027
PM10 (x10)	g/mi	2.502	2.512	2.500	2.491	1.365	1.410	1.357	0.210	0.235	0.202	0.302	0.180	0.219	0.290	0.308
Urban Toxics, (weighted)																
Benzene	g/mi	7.5E-04	7.7E-04	7.1E-05	8.5E-04	1.1E-04	—	—	1.1E-04	—	—	9.3E-04	2.7E-04	—	2.8E-04	8.9E-04
1-3 Butadiene	g/mi	1.9E-03	2.0E-03	1.3E-04	1.8E-03	1.7E-04	—	—	1.7E-04	—	—	1.2E-03	3.5E-04	—	4.5E-04	1.1E-03
Formaldehyde	g/mi	9.4E-02	9.4E-02	8.9E-02	9.5E-02	8.9E-02	—	—	1.8E-02	—	—	7.6E-03	1.1E-03	—	2.4E-03	8.8E-03
Acetaldehyde	g/mi	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02	—	—	4.0E-03	—	—	3.4E-04	9.6E-05	—	1.0E-04	3.3E-04
Diesel PM	g/mi	1.2E+01	1.2E+01	1.2E+01	1.2E+01	5.9E+00	—	—	1.6E-01	—	—	2.3E-02	2.3E-02	—	0.0E+00	0.0E+00

Figure A-11. Urban Buses: Model Years 2010 and Newer (Natural Gas, DME, Methanol, and Hydrogen)

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

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	42.31	46.71	46.43	44.51	55.65	2.21	70.10	44.57	29.15	51.00	62.83	36.48	46.55	41.57	24.96
Petroleum	MJ/mi	0.16	0.51	0.51	0.17	1.09	1.83	1.19	1.09	1.36	0.89	0.41	0.30	0.67	0.16	0.39
Natural Gas	MJ/mi	42.15	46.19	45.92	44.33	54.55	0.38	3.65	43.47	27.79	30.17	62.43	36.18	6.87	41.41	24.56
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	65.26	0.00	0.00	19.93	0.00	0.00	39.01	0.00	0.00
Non Fossil	MJ/mi	0.21	0.03	0.02	0.03	0.01	65.27	0.47	0.01	19.94	0.34	3.43	16.06	0.90	0.74	28.20
WTT	MJ/mi	4.48	8.70	8.80	6.89	19.90	31.72	34.80	17.07	21.58	23.83	42.42	28.70	23.81	18.47	29.32
TTW	MJ/mi	38.04	38.04	37.84	37.64	35.76	35.76	35.76	27.51	27.51	27.51	23.84	23.84	23.84	23.84	23.84
GHGs (weighted)																
WTT	g/mi	399	774	743	605	954	-2177	1072	800	-1741	829	3831	2200	1198	2468	2007
TTW	g/mi	2115	2115	2144	2144	2386	2386	2386	1883	1883	1883	0	0	0	0	0
TOTAL	g/mi	2515	2890	2887	2749	3340	209	3457	2683	141	2712	3831	2200	1198	2468	2007
Criteria, Total																
VOC	g/mi	0.304	0.360	0.389	0.306	2.416	0.190	0.562	0.457	0.117	0.387	0.399	0.236	0.397	0.257	0.262
CO	g/mi	1.232	1.544	1.587	1.270	1.720	1.442	1.041	0.868	0.533	0.408	0.771	0.365	0.355	0.393	0.453
NOx	g/mi	0.900	3.404	3.854	0.902	3.272	2.201	1.569	3.053	0.913	1.304	0.428	0.281	0.928	0.232	0.718
PM10 (x10)	g/mi	0.790	1.571	1.581	0.809	1.907	1.770	57.881	1.992	0.642	76.301	0.839	0.566	62.805	0.482	0.996
Criteria, Urban																
VOC	g/mi	0.048	0.047	0.049	0.045	2.071	2.125	0.044	0.156	0.195	0.154	0.008	0.005	0.001	0.005	0.051
CO	g/mi	0.907	0.905	0.897	0.891	0.920	1.125	0.913	0.208	0.356	0.223	0.212	0.008	0.054	0.073	0.150
NOx	g/mi	0.687	0.710	0.743	0.679	0.795	1.203	0.668	0.252	0.539	0.216	0.035	0.021	0.011	0.023	0.049
PM10 (x10)	g/mi	0.672	0.683	0.670	0.660	0.506	0.715	0.473	0.291	0.435	0.286	0.436	0.236	0.286	0.367	0.390
Urban Toxics, (weighted)																
Benzene	g/mi	7.9E-04	8.1E-04	2.0E-04	1.0E-03	3.3E-04	---	---	3.3E-04	---	---	1.4E-03	6.0E-04	---	3.2E-04	9.6E-04
1-3 Butadiene	g/mi	1.9E-03	2.0E-03	2.0E-04	2.0E-03	3.0E-04	---	---	2.9E-04	---	---	1.6E-03	5.4E-04	---	5.1E-04	1.2E-03
Formaldehyde	g/mi	1.2E-02	1.2E-02	6.6E-03	1.3E-02	6.8E-03	---	---	1.8E-03	---	---	9.9E-03	1.7E-03	---	2.8E-03	9.5E-03
Acetaldehyde	g/mi	1.7E-03	1.8E-03	1.5E-03	1.8E-03	1.5E-03	---	---	4.0E-04	---	---	5.1E-04	2.1E-04	---	1.2E-04	3.5E-04
Diesel PM	g/mi	2.1E+00	2.2E+00	2.3E+00	2.2E+00	1.3E+00	---	---	2.2E-01	---	---	1.1E-01	1.1E-01	---	0.0E+00	0.0E+00

Figure A-11. Urban Buses: Model Years 2010 and Newer (continued)

Natural Gas, DME, Methanol, and Hydrogen

Scenario Year 2017: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	41.38	45.71	45.51	43.62	54.17	2.16	68.51	42.15	28.57	49.84	55.43	35.51	44.25	39.44	23.30
Petroleum	MJ/mi	0.16	0.50	0.50	0.17	1.07	1.80	1.16	1.06	1.34	0.88	0.37	0.30	0.65	0.15	0.38
Natural Gas	MJ/mi	41.22	45.21	45.01	43.45	53.10	0.36	3.37	41.09	27.24	29.42	55.06	35.22	5.97	39.28	22.91
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	63.98	0.00	0.00	19.54	0.00	0.00	37.63	0.00	0.00
Non Fossil	MJ/mi	0.24	0.04	0.02	0.03	0.01	63.99	0.53	0.01	19.55	0.38	3.19	12.94	0.96	0.72	27.12
WTT	MJ/mi	4.32	8.45	8.62	6.75	19.12	31.09	33.98	15.20	21.15	23.25	35.25	25.08	21.84	16.78	27.04
TTW	MJ/mi	37.30	37.30	36.91	36.91	35.06	35.06	35.06	26.97	26.97	26.97	23.37	23.37	23.37	23.37	23.37
GHGs (weighted)																
WTT	g/mi	385	753	728	592	912	-2135	1039	759	-1708	803	3374	2142	1115	2338	1913
TTW	g/mi	2074	2074	2103	2103	2339	2339	2339	1846	1846	1846	0	0	0	0	0
TOTAL	g/mi	2460	2827	2830	2694	3251	204	3378	2605	138	2649	3374	2142	1115	2338	1913
Criteria, Total																
VOC	g/mi	0.294	0.349	0.362	0.294	2.359	0.145	0.546	0.433	0.084	0.376	0.345	0.224	0.379	0.240	0.246
CO	g/mi	1.302	1.607	1.626	1.336	1.757	1.449	1.109	0.840	0.494	0.407	0.649	0.344	0.333	0.363	0.423
NOx	g/mi	0.812	3.264	3.504	0.781	3.087	1.748	1.442	2.890	0.621	1.229	0.335	0.231	0.888	0.207	0.677
PM10 (x10)	g/mi	0.775	1.538	1.540	0.792	1.845	1.537	56.736	1.917	0.482	74.789	0.735	0.534	60.581	0.454	0.956
Criteria, Urban																
VOC	g/mi	0.048	0.047	0.047	0.044	2.028	2.061	0.043	0.151	0.174	0.149	0.007	0.005	0.001	0.005	0.049
CO	g/mi	0.987	0.985	0.976	0.972	0.991	1.165	0.993	0.215	0.340	0.228	0.162	0.008	0.047	0.063	0.138
NOx	g/mi	0.618	0.640	0.653	0.606	0.684	0.927	0.599	0.201	0.368	0.166	0.031	0.020	0.010	0.022	0.036
PM10 (x10)	g/mi	0.671	0.682	0.669	0.660	0.489	0.599	0.471	0.275	0.348	0.269	0.387	0.236	0.279	0.355	0.376
Urban Toxics, (weighted)																
Benzene	g/mi	7.7E-04	7.9E-04	1.2E-04	9.1E-04	2.0E-04	—	—	2.0E-04	—	—	1.2E-03	4.1E-04	—	3.1E-04	9.2E-04
1-3 Butadiene	g/mi	1.9E-03	2.0E-03	1.6E-04	1.9E-03	2.2E-04	—	—	2.2E-04	—	—	1.4E-03	4.3E-04	—	4.8E-04	1.1E-03
Formaldehyde	g/mi	1.2E-02	1.2E-02	6.5E-03	1.2E-02	6.6E-03	—	—	1.6E-03	—	—	8.9E-03	1.3E-03	—	2.6E-03	9.1E-03
Acetaldehyde	g/mi	1.7E-03	1.7E-03	1.4E-03	1.8E-03	1.5E-03	—	—	3.6E-04	—	—	4.2E-04	1.4E-04	—	1.1E-04	3.4E-04
Diesel PM	g/mi	2.1E+00	2.2E+00	2.3E+00	2.1E+00	1.2E+00	—	—	1.8E-01	—	—	5.7E-02	5.7E-02	—	0.0E+00	0.0E+00

Figure A-11. Urban Buses: Model Years 2010 and Newer (continued)

Natural Gas, DME, Methanol, and Hydrogen

Scenario Year 2022: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestration	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	40.88	44.94	44.79	42.94	52.52	2.13	67.62	41.15	28.28	49.20	50.77	34.67	42.64	37.50	21.89
Petroleum	MJ/mi	0.16	0.49	0.49	0.17	1.05	1.78	1.15	1.05	1.32	0.87	0.35	0.29	0.63	0.15	0.37
Natural Gas	MJ/mi	40.72	44.44	44.30	42.77	51.47	0.35	3.13	40.10	26.96	28.98	50.41	34.38	5.35	37.35	21.52
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	63.35	0.00	0.00	19.35	0.00	0.00	36.67	0.00	0.00
Non Fossil	MJ/mi	0.27	0.04	0.02	0.04	0.01	63.36	0.59	0.01	19.36	0.43	3.11	11.16	1.04	0.65	25.93
WTT	MJ/mi	4.22	8.05	8.27	6.43	17.82	30.77	33.50	14.46	20.94	22.92	30.74	22.69	20.54	15.01	24.68
TTW	MJ/mi	36.93	36.93	36.54	36.54	34.71	34.71	34.71	26.70	26.70	26.70	23.14	23.14	23.14	23.14	23.14
GHGs (weighted)																
WTT	g/mi	376	724	704	571	837	-2114	1017	741	-1691	786	3088	2092	1057	2221	1825
TTW	g/mi	2054	2054	2082	2082	2316	2316	2316	1828	1828	1828	0	0	0	0	0
TOTAL	g/mi	2430	2778	2786	2653	3153	202	3333	2569	136	2614	3088	2092	1057	2221	1825
Criteria, Total																
VOC	g/mi	0.289	0.341	0.347	0.287	2.326	0.119	0.539	0.422	0.065	0.370	0.313	0.216	0.367	0.226	0.234
CO	g/mi	1.303	1.597	1.605	1.332	1.735	1.422	1.110	0.822	0.470	0.400	0.577	0.331	0.319	0.337	0.398
NOx	g/mi	0.757	3.153	3.302	0.711	2.969	1.480	1.371	2.814	0.450	1.192	0.286	0.205	0.861	0.189	0.653
PM10 (x10)	g/mi	0.766	1.512	1.511	0.781	1.810	1.399	56.169	1.881	0.386	74.040	0.675	0.515	59.032	0.433	0.930
Criteria, Urban																
VOC	g/mi	0.048	0.046	0.046	0.044	2.007	2.028	0.043	0.148	0.163	0.146	0.007	0.005	0.001	0.005	0.048
CO	g/mi	0.994	0.993	0.983	0.980	0.994	1.154	0.999	0.212	0.327	0.224	0.132	0.008	0.042	0.054	0.127
NOx	g/mi	0.574	0.596	0.599	0.561	0.622	0.766	0.555	0.176	0.271	0.141	0.028	0.020	0.010	0.021	0.030
PM10 (x10)	g/mi	0.670	0.681	0.668	0.660	0.480	0.531	0.469	0.268	0.297	0.260	0.358	0.236	0.274	0.345	0.364
Urban Toxics, (weighted)																
Benzene	g/mi	7.6E-04	7.7E-04	8.8E-05	8.7E-04	1.4E-04	—	—	1.4E-04	—	—	1.0E-03	3.2E-04	—	2.9E-04	8.9E-04
1-3 Butadiene	g/mi	1.9E-03	2.0E-03	1.4E-04	1.8E-03	1.9E-04	—	—	1.8E-04	—	—	1.2E-03	3.7E-04	—	4.7E-04	1.1E-03
Formaldehyde	g/mi	1.2E-02	1.2E-02	6.4E-03	1.2E-02	6.5E-03	—	—	1.5E-03	—	—	8.2E-03	1.2E-03	—	2.5E-03	8.8E-03
Acetaldehyde	g/mi	1.7E-03	1.7E-03	1.4E-03	1.8E-03	1.5E-03	—	—	3.3E-04	—	—	3.7E-04	1.1E-04	—	1.1E-04	3.3E-04
Diesel PM	g/mi	2.1E+00	2.2E+00	2.3E+00	2.1E+00	1.2E+00	—	—	1.6E-01	—	—	3.4E-02	3.4E-02	—	0.0E+00	0.0E+00

Figure A-11. Urban Buses: Model Years 2010 and Newer (concluded)

Natural Gas, DME, Methanol, and Hydrogen

Scenario Year 2030: UB Vehicle Class: Model Year Start 2010 (new)

WTT Case ID		C1	C2	L3	L1	DM1	DM3	DM5	M1	M3	M5	H2	H3	H4c	H11	H23
WTT Description		CNG, NA Natural Gas	CNG, LNG, Remote NG	LNG, Remote NG	LNG, Pipeline Liquefier	DME, Remote NG	DME, CA Poplar	DME, Coal CCS	Methanol, Remote NG	Methanol, CA Poplar	Methanol, Coal CCS	H2, NG SR, LH2	H2, NG SR, LH2, Ren Power	H2, Coal, Sequestrati on	H2, Onsite NG SR	H2, 70% Renewable, Electrolysis
Vehicle Type		CNG	CNG	LNG	LNG	DME	DME	DME	Methanol	Methanol	Methanol	H2FCV	H2FCV	H2FCV	H2FCV	H2FCV
Vehicle Technology		ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	ICEV	FCV	FCV	FCV	FCV	FCV	FCV	FCV	FCV
Fossil	MJ/mi	40.48	44.49	44.35	42.51	52.00	2.11	66.95	40.75	28.00	48.71	50.27	34.33	42.22	37.13	21.68
Petroleum	MJ/mi	0.16	0.49	0.49	0.17	1.04	1.76	1.14	1.04	1.31	0.86	0.35	0.29	0.62	0.14	0.37
Natural Gas	MJ/mi	40.32	44.00	43.86	42.35	50.96	0.35	3.10	39.70	26.69	28.69	49.91	34.04	5.29	36.98	21.31
Coal	MJ/mi	0.00	0.00	0.00	0.00	0.00	0.00	62.72	0.00	0.00	19.16	0.00	0.00	36.31	0.00	0.00
Non Fossil	MJ/mi	0.26	0.04	0.02	0.04	0.01	62.73	0.59	0.01	19.17	0.43	3.08	11.04	1.03	0.64	25.67
WTT	MJ/mi	4.18	7.97	8.19	6.37	17.64	30.47	33.17	14.32	20.73	22.70	30.43	22.46	20.34	14.86	24.44
TTW	MJ/mi	36.56	36.56	36.18	36.18	34.37	34.37	34.37	26.44	26.44	26.44	22.91	22.91	22.91	22.91	22.91
GHGs (weighted)																
WTT	g/mi	372	717	697	565	829	-2093	1007	734	-1675	778	3057	2071	1047	2199	1807
TTW	g/mi	2034	2034	2061	2061	2293	2293	2293	1810	1810	1810	0	0	0	0	0
TOTAL	g/mi	2406	2751	2759	2626	3122	200	3300	2543	135	2588	3057	2071	1047	2199	1807
Criteria, Total																
VOC	g/mi	0.268	0.319	0.321	0.264	2.284	0.096	0.514	0.414	0.058	0.362	0.309	0.213	0.363	0.224	0.231
CO	g/mi	1.328	1.619	1.620	1.355	1.750	1.435	1.134	0.819	0.466	0.401	0.569	0.326	0.316	0.334	0.393
NOx	g/mi	0.764	3.136	3.244	0.712	2.946	1.446	1.364	2.782	0.423	1.176	0.277	0.197	0.852	0.187	0.644
PM10 (x10)	g/mi	0.808	1.546	1.544	0.822	1.815	1.396	55.635	1.862	0.373	73.306	0.668	0.510	58.450	0.431	0.922
Criteria, Urban																
VOC	g/mi	0.029	0.027	0.027	0.025	1.968	1.988	0.024	0.142	0.156	0.140	0.007	0.005	0.001	0.005	0.048
CO	g/mi	1.022	1.020	1.010	1.007	1.019	1.173	1.027	0.215	0.326	0.227	0.131	0.008	0.041	0.053	0.125
NOx	g/mi	0.582	0.604	0.603	0.568	0.622	0.751	0.563	0.170	0.255	0.136	0.028	0.019	0.009	0.020	0.027
PM10 (x10)	g/mi	0.713	0.723	0.711	0.702	0.498	0.542	0.490	0.265	0.289	0.257	0.356	0.236	0.274	0.344	0.362
Urban Toxics, (weighted)																
Benzene	g/mi	7.4E-04	7.6E-04	7.1E-05	8.4E-04	1.1E-04	—	—	1.1E-04	—	—	9.2E-04	2.7E-04	—	2.8E-04	8.8E-04
1-3 Butadiene	g/mi	1.8E-03	1.9E-03	1.3E-04	1.8E-03	1.7E-04	—	—	1.7E-04	—	—	1.1E-03	3.5E-04	—	4.5E-04	1.1E-03
Formaldehyde	g/mi	8.6E-03	8.7E-03	3.6E-03	9.4E-03	3.6E-03	—	—	8.9E-04	—	—	7.6E-03	1.1E-03	—	2.4E-03	8.7E-03
Acetaldehyde	g/mi	1.1E-03	1.1E-03	8.0E-04	1.1E-03	6.2E-04	—	—	2.0E-04	—	—	3.3E-04	9.5E-05	—	1.0E-04	3.2E-04
Diesel PM	g/mi	2.3E+00	2.5E+00	2.5E+00	2.3E+00	1.3E+00	—	—	1.6E-01	—	—	2.3E-02	2.3E-02	—	0.0E+00	0.0E+00

APPENDIX B. GENERAL RESPONSE TO COMMENTS ON THE DRAFT FULL FUEL CYCLE ASSESSMENT REPORTS

Many alternative fuels technologies stakeholders, environmental groups, industry organizations, university representatives, and regulatory agencies offered in-depth comments on the drafts of the three major reports that were the products of the full fuel cycle assessment (FFCA) of alternative fuels production, distribution, and use. The depth of these comments reflects the importance of this topic to California's energy future. We thank all those who provided such detailed review of the reports and provided comments. All comments received were carefully considered and appropriately addressed in the revised reports issued. Comments received can be generally grouped into three categories. These categories and our responses are summarized as follows:

- Report errors. In documenting the results of an effort of the magnitude captured in the draft reports, the occurrence of typographical errors, the unintentional use of outdated data, inconsistencies, and inadvertent factual errors are unavoidable. We attempted to correct all these, resolve inconsistencies, and include clarification where possible.

- Questions regarding the validity of many of the assumptions made in coming to assessment results. Again, in completing an analysis as detailed and comprehensive as that undertaken in the FFCA, a large number of assumptions regarding analysis parameter values and the details of the evaluation cases considered were required. Many reviewers noted that alternate assumptions and approach details could have been considered. We took all these comments and suggestions into careful consideration, but elected to remain with our original approach. In many of these instances, we attempted to offer clarifying discussion regarding why our approach was selected, acknowledging that alternate assumptions are possible, but that those adopted were reasonable.

- Assessment omissions. Many reviewers noted that several aspects of the assessment attempted were omitted or insufficiently discussed. For example:

  - The sensitivity of assessment results to the choice of assumptions made was not carefully considered nor explained
  - The importance of land use considerations as they affect assessment results was not carefully considered nor explained
  - Many alternative fuel production, distribution, and use pathways that may be of critical importance to the ultimate use of assessment findings were not evaluated

  We attempted to address these omissions to the best of our ability within the intended scope of the effort. For example:

- Sensitivity analyses were performed and discussed where possible, again within the intended scope of the analysis
- Land use impacts were indeed not considered in the assessment; clarifying discussion to emphasize this point has been added
- Many additional alternative fuel pathways were evaluated in preparing this revised set of reports, and appropriate discussion of these and their evaluation results incorporated

Again, we thank all those who offered careful review and comment on the draft assessment reports. Attempts have been made to both consider and address all comments received. We hope that these reviewers will continue to offer their support to the AB 1007 Alternative Fuels Plan Proceeding as it progresses.

APPENDIX C. RESPONSES TO SPECIFIC COMMENTS ON THE DRAFT FULL FUEL CYCLE ASSESSMENT REPORTS