Full Fuel Cycle Analysis Assessment

Joint Workshop on
Increasing the Use of Alternative Transportation Fuels
California Energy Commission
Sacramento, California

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Outline

Background
Approach
Assumptions
Sensitivity Results
Summary
A full fuel cycle analysis provides a basis for determining the energy inputs and emissions from various fuel and vehicle options.

Objectives

- Compare fuel options based on impacts of fuel production and vehicle operation
- Applications: ARB ZEV, DOE H₂, H₂ Highway, AB1493, AB2076, AB1007

Fuel Pathways

- Petroleum, natural gas, coal, biofuels, renewable power

Vehicles

- Light-, medium-, and heavy-duty vehicles, off-road vehicles
- Emissions occurring in 2012, 2017, 2022, and 2030
- New vehicle and blended fuel strategies (E10, biodiesel, FT fuels)

Emission Sources and Boundaries

- Local requirements affect criteria pollutants, toxics, and water impacts
- Location of sources, CA ARB regulations, BACT, offset requirements
- Global GHG emissions
**Background**  Fuel Cycle Analysis

**Well-to-Wheels/ Full Fuel Cycle Emission Steps**

- Full fuel cycle emissions correspond to resource extraction, fuel production, delivery, and vehicle exhaust, running/evaporative
- Includes combustion, fugitive, and spillage emissions, water discharges
- Emissions from facility and vehicle manufacturing are not included (LCA)
- Energy inputs for fuel cycle energy inputs and losses are also included
Boundary definitions affect how emissions are determined.
WTW emissions include the vehicle plus the fuel cycle. Fuel cycle emissions are grouped by region.
**Prior fuel cycle studies focused on a range of fuels and boundaries.**

<table>
<thead>
<tr>
<th>Study, Year</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA H2 Highway, 2005</td>
<td>Hydrogen production and vehicle analysis. Assessment of renewable power for transportation fuels. Apply analysis to CA instead of SoCAB.</td>
</tr>
</tbody>
</table>

Marginal CA Emissions
Average Emissions
The full fuel cycle analysis will consider a range of feedstocks and fuels.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Primary Feedstock</th>
<th>Other Feedstocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFG – E0</td>
<td>Petroleum</td>
<td></td>
</tr>
<tr>
<td>RFG — E5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFG — E10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td>Natural Gas</td>
</tr>
<tr>
<td>CNG</td>
<td></td>
<td>LFG, LNG</td>
</tr>
<tr>
<td>LNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>Natural Gas</td>
<td>Biomass</td>
</tr>
<tr>
<td>Dimethyl ether</td>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td>FT blends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol — E85</td>
<td>Corn</td>
<td>Sugar Cane</td>
</tr>
<tr>
<td>E-diesel</td>
<td></td>
<td>Biomass</td>
</tr>
<tr>
<td>Biodiesel (thermal)</td>
<td>Biomass</td>
<td></td>
</tr>
<tr>
<td>Biodiesel (vegetable)</td>
<td>Soy Bean Oil</td>
<td>Palm Oil</td>
</tr>
<tr>
<td>Electricity</td>
<td>NG/20% RP</td>
<td>Various</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Natural Gas</td>
<td>Various</td>
</tr>
</tbody>
</table>
The analysis will be configured for different vehicle applications.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Class</th>
<th>GVW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Car</td>
<td>LDA</td>
<td>3750</td>
</tr>
<tr>
<td>Light Truck</td>
<td>LDT1, LDT2</td>
<td>3750, 6000</td>
</tr>
<tr>
<td>Delivery Truck</td>
<td>MDV</td>
<td>14,000</td>
</tr>
<tr>
<td>Long Haul Truck</td>
<td>HHDT</td>
<td>80,000</td>
</tr>
<tr>
<td>Garbage Truck</td>
<td>HHDT</td>
<td>80,000</td>
</tr>
<tr>
<td>School Bus 88 passenger</td>
<td>SBUS</td>
<td>40,000</td>
</tr>
<tr>
<td>Transit Bus 40 ft</td>
<td>UB</td>
<td>40,000</td>
</tr>
<tr>
<td>Off Road Vehicles</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Vehicle/fuel combinations that appear likely for the application will be presented in the report.

<table>
<thead>
<tr>
<th>Year</th>
<th>Introduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>New 2010¹, All</td>
</tr>
<tr>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
</tr>
</tbody>
</table>

1. Example for 2017 LDA vehicles this presentation
2. Light Duty Vehicles (LDA) (<3,750 GVW)  
   - x = IC engine vehicle  
   - HEV = hybrid electric vehicle,  
   - PHEV = plug in hybrid electric vehicles,  
   - EV = Battery Electric Vehicle  
   - FC = fuel cell vehicle
3. Blended fuel options = x

<table>
<thead>
<tr>
<th>Fuel</th>
<th>LD Car²</th>
<th>Transit Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFG — E0</td>
<td>x</td>
<td>HEV</td>
</tr>
<tr>
<td>RFG — E5.7</td>
<td>x, HEV, PHEV</td>
<td>—</td>
</tr>
<tr>
<td>RFG — E10</td>
<td>x³</td>
<td>—</td>
</tr>
<tr>
<td>Diesel</td>
<td>x</td>
<td>x, HEV</td>
</tr>
<tr>
<td>LPG</td>
<td>x</td>
<td>—</td>
</tr>
<tr>
<td>CNG</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>LNG</td>
<td>—</td>
<td>x</td>
</tr>
<tr>
<td>Methanol</td>
<td>—</td>
<td>FC</td>
</tr>
<tr>
<td>DME</td>
<td>—</td>
<td>x</td>
</tr>
<tr>
<td>FT blends</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Ethanol — E85</td>
<td>x, PHEV</td>
<td>—</td>
</tr>
<tr>
<td>E-diesel</td>
<td>—</td>
<td>x</td>
</tr>
<tr>
<td>BD (thermal)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>BD (vegetable)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electricity</td>
<td>PHEV, EV</td>
<td>—</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>x, FC</td>
<td>x, FC</td>
</tr>
</tbody>
</table>
Alternative Fuel Production Processes — “Well-to-Tank”

- **CNG, LPG**
  - *Natural Gas Production ➔ Compression ➔ CNG*
  - *Natural Gas Production ➔ Refining ➔ LPG*

- **Synthetic Fuels**
  - *NG Production ➔ Steam Reforming ➔ Methanol, DME, FT Fuels*
  - *Biomass ➔ Gasification ➔*

- **Ethanol**
  - *Harvest Crop ➔ Fermentation ➔ Distillation ➔ Distribution ➔ Ethanol*
  - *Collect Biomass ➔ Hydrolysis ➔ Fermentation ➔ Distillation ➔ Ethanol*

- **Hydrogen**
  - *NG Production ➔ Steam Reforming ➔ Compression ➔ cH2*

- **Battery Electric**
  - *Natural Gas Production ➔ Electric Power Plant + RPS ➔ Charger*
Analysis Scope  Fuel Pathways  Multiple Pathways

- Petroleum
- Natural Gas
- Landfill Gas
- Herbaceous Biomass
- Woody Biomass
- Forest Residue
- Ag Residue
- Waste Paper
- Corn
- Sugar Cane
- Soy Beans
- Palm Oil
- Manure
- Coal
- Renewable Power
- Nuclear Energy

- Refining
- Gasification
- Pyrolysis
- Hydrolysis
- Fermentation
- Pressing
- Esterification
- Digestion
- Combustion
- Catalyst Synthesis
- Reforming

- Gasoline
- Diesel
- LPG
- CNG
- LNG
- FT Diesel
- Methanol
- DME
- Hydrogen
- Bio-Oil
- Ethanol
- Bio-Diesel
- Electricity

11 fuels

Coke, Waste Heat

Existing GREET pathway

AB1007 Fuel Cycle
Analysis Scope  Fuel Pathways  Primary Fuels

- Petroleum
- Natural Gas
- Corn
- Coal
- Renewable Power
- Nuclear Energy
- Refining
- Gasoline
- Diesel
- LPG
- CNG
- LNG
- Hydrolysis
- Fermentation
- Ethanol
- Combustion
- Electricity
- Nuclear Energy
Fuel cycle model inputs need to capture California boundaries.

GREET 1.7 is used to calculate well to tank (WTT) or fuel cycle emissions. Several GREET models are configured with different regional emission assumptions. A WTT factor for each fuel is based on the composite of regional WTT results.
Approach | Vehicle Analysis Inputs

Vehicle emissions are based on EMFAC model runs for different scenario years.

- New Vehicle Strategies
  - Run model for introduction date through scenario year

- Blend Fuels
  - Run model for all vehicles on the road (total inventory)

- Alternative Fuels
  - Adjust baseline vehicle emissions for alternative fuel
  - Adjustment factors in GREET
  - Additional emission test data

![Graph showing On Road LDAs (million) from 1994 to 2016](image)
Emissions of toxics occur from fuel, engine exhaust, and fuel production/processing facilities.

Toxic Contaminants
- State of California Listed Toxics
- ROG and exhaust sources in the fuel cycle
- Fuel spills, vapor losses, vehicle and engine exhaust, production facilities

Calculation Method
- Toxics = Source x Speciation
- $T_a = S_1 \times \chi_{a1} + S_2 \times \chi_{a2}$
- Example for gasoline vehicle:

<table>
<thead>
<tr>
<th>Toxic Contaminant</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel</td>
</tr>
<tr>
<td>Benzene</td>
<td>⚠️</td>
</tr>
<tr>
<td>1,3 butadiene</td>
<td>⚠️</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>![Car]</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>![Car]</td>
</tr>
<tr>
<td>Diesel PM</td>
<td>![Car]</td>
</tr>
<tr>
<td>Metals</td>
<td>![Car]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Toxic</th>
<th>Benzene</th>
<th>1-3 Butadiene</th>
<th>Formaldehyde</th>
<th>Acetaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running Exhaust</td>
<td>2.64%</td>
<td>0.55%</td>
<td>1.70%</td>
<td>0.24%</td>
</tr>
</tbody>
</table>
Water impacts will be determined from spills and fuel transport as well as fuel production.

**Fuel sources**
- Tanker ships
- Pipelines
- Underground tanks
- Fuel processing facilities
- Vehicle fueling

**Engines**
- Motor oil
- Nitrates and sulfates from exhaust

**Facilities**
- Water use and discharges from processing plants
- Oil and gas field
- Agricultural run off

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**Water Pollutant** | **Sources** | **Fuel** | **Engines** | **Facilities**
--- | --- | --- | --- | ---
Hydrocarbons | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)
Alcohols | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)
Metals | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)
Salts | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)
Sulfates | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)
Nitrates | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)
Water use | ![Fuel](https://via.placeholder.com/15) | ![Engines](https://via.placeholder.com/15) | ![Facilities](https://via.placeholder.com/15)

Fuel transport losses based on summary in AB2076 report. Data from water discharges from permit applications, and data from CA Department of Water Resources and CA Water Resources Control Board.

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A spreadsheet database provides the results for numerous scenario options.

**Well to Tank**
- GREET analysis for different regions
- Alternative fuels results from a composite of GREET runs
- Toxics based on ARB speciation data
- Water impacts from available data on production facilities

**Tank to Wheels**
- EMFAC runs for scenario and introduction years
- Adjustment factors for alternative fuels
- Toxics based on ROG emissions and speciation data
- Baseline values for relative fuel economy (EER)
- Water impacts from fuel distribution chain and engine oil

**Full Fuel Cycle (Well to Wheels)**
- Spreadsheet data base to combine scenario, vehicle, and fuel options
Outline

- Background
- Approach
- Assumptions
- Sensitivity Results
- Conclusions
Several key assumptions affect the analysis results.

- **Facility Location**
  - *Marginal sources for fossil fuels*
  - *Analyze CA facilities with BACT, Show offset emissions*
  - *Worldwide GHG emissions with region specific assumptions*

- **Fuel transportation**
  - *Tanker truck transport (50 mi one way), average HDDT, 40 ton GVW*
  - *Tanker ship, 200 mi in CA, in port emissions*

- **Hydrocarbon Losses**
  - *BACT for bulk storage tanks*
  - *Fuel transfer based on vapor pressure and control efficiency*
  - *10% defect rate for fuel station vapor recovery*

- **Electric Power**
  - *Marginal generation mix plus renewable portfolio standard*

- **Fuel Economy**
  - *Analyze “comparable” vehicles*
The wide range of estimates of fugitive emissions has a significant impact on the fuel cycle analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncontrolled</th>
<th>W. control</th>
<th>W. defect rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank truck spillage</td>
<td>0.07</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>UG tank working loss</td>
<td>8.4</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>UG tank breathing loss</td>
<td>0.84</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Vehicle fueling vapor loss</td>
<td>8.4</td>
<td>0.42</td>
<td>0.115</td>
</tr>
<tr>
<td>Vehicle fueling spillage</td>
<td>0.64</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

ARB inventory values except for tank truck spillage. 95% control efficiency for vapor working losses. 10% defect rate and fueling station vapor controls.
ARB’s speciation database was used to determine the fraction of toxics in ROG emissions.

![Toxics from Vehicle Emissions (% of ROG) diagram]

**Assumptions**

- Toxics
- Vehicle Emissions

**Toxics from Vehicle Emissions (% of ROG)**

<table>
<thead>
<tr>
<th>Toxics</th>
<th>Diesel Vehicles</th>
<th>Gasoline Catalyst Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3 Butadiene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3 Butadiene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Hot Soak & Running**
**Diurnal & Resting**
**Start Ex**
**Run Exh & Idle**
Assumptions Power Generation

 Dispatch models have been used to determine marginal generation emissions.

• Scenarios
  – Fuel production process power
  – EV/PHEV charging at night

• Scope
  – Analysis days
  – Typical incremental load

• Issues
  – Out of state resource mix and heat rate

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Profile</th>
<th>Time</th>
<th>GWh/y</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24-hr Marginal - N Cal</td>
<td>15-Oct-17</td>
<td>400</td>
<td>Fuel production</td>
</tr>
<tr>
<td>2</td>
<td>24-hr Marginal - S Cal</td>
<td>15-Oct-17</td>
<td>400</td>
<td>Fuel production</td>
</tr>
<tr>
<td>3</td>
<td>Night-time OFF70%s22h</td>
<td>15-Oct-17</td>
<td>1000</td>
<td>Battery Charging</td>
</tr>
<tr>
<td>4</td>
<td>Night-time OFF55%s18h</td>
<td>15-Oct-17</td>
<td>1000</td>
<td>Battery Charging</td>
</tr>
<tr>
<td>5</td>
<td>Day-Time OFF30%s08h</td>
<td>15-Oct-17</td>
<td>1000</td>
<td>Battery Charging</td>
</tr>
<tr>
<td>6</td>
<td>CA Average Mix</td>
<td>15-Oct-17</td>
<td>240000</td>
<td>For Reference</td>
</tr>
</tbody>
</table>

Battery charging, OFF70%s22h refers to 70% of power from off peak according to charging profile and CAISO definition of off peak. Charging timed to start at 10 pm.
Load growth for production will likely come from new fossil generation.

- Marginal power is from fossil fuel generation
  - Assume production from natural gas combined cycle
  - Apply applicable RPS requirement to mix (20% in 2020)
  - EV/PHEV charging profiles

- Hydropower and nuclear capacity
  - No new capacity due to load growth
  - These resources are not on the margin

- Dedicated renewables
  - Solar PV homes own REC
  - Option to buy RECs
Fuel economy estimates have been made for comparable gasoline and alternative fueled vehicles.

**Fuel Economy Comparison (mpgge)**

- Battery EV
- Hydrogen FC PHEV
- Hydrogen FCV/FCHEV
- Hydrogen ICEV/ICHEV
- E85, ICEV
- LPG, ICEV
- CNG, ICEV
- ULSD, ICEV
- Gasoline PHEV
- Gasoline, HEV
- Gasoline, ICEV
- Gasoline, ICEV, 2004 CAFE Mix

**Range**

Similar 2010 Midsized Cars City/Highway Combined
Baseline fuel economy for alternative drive train technologies.

Stakeholder continue to debate benchmark for fuel economy. Base policy on actual vehicle performance.
EMFAC model outputs representing a mix of vehicle technologies, driving patterns, and other assumptions are represented on a per mile basis.

**Assumptions**  
Vehicle Emissions

**EMFAC Emissions**

EMFAC V2.23.7.60606  
Emissions in 2017  
2010 to 2017 vehicles
The baseline for new vehicle strategies can be significantly lower than the average vehicle in the inventory.

- Introduction scenario affects displaced gasoline or diesel vehicle
- New vehicle strategies and blend fuel strategies require separate treatment
### Fuel economy values used in this analysis.

#### Alternative Fuel Emission Adjustment

<table>
<thead>
<tr>
<th></th>
<th>CARFG</th>
<th>E10</th>
<th>CNG</th>
<th>LPG</th>
<th>B35 FFV</th>
<th>H2 ICEV</th>
<th>H2 FCV</th>
<th>Battery EV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FE Gasoline mpgge</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>103%</td>
<td>130%</td>
<td>200%</td>
<td>300%</td>
</tr>
<tr>
<td><strong>Exhaust VOC</strong></td>
<td>100%</td>
<td>100%</td>
<td>90%</td>
<td>90%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Evaporative VOC</strong></td>
<td>100%</td>
<td>100%</td>
<td>10%</td>
<td>10%</td>
<td>85%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>NOx</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>75%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Exhaust PM10</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Brake and Tire Wear PM10</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>CH4</strong></td>
<td>100%</td>
<td>100%</td>
<td>200%</td>
<td>100%</td>
<td>100%</td>
<td>10%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>N2O</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>75%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Values adjusted from GREET input assumptions
Outline

- Background
- Approach
- Assumptions
- Sensitivity Results
- Summary
Alternative technologies offer the potential for GHG emission reductions.

WTW GHG Emissions – LDA (g/mi)

- E85 - CA Sugar Cane
- E85 - Corn
- Diesel
- RFG ICEV
- Battery EV
- Gasoline PHEV
- H2 - On Site NG SR
- CNG
- LPG
- RFG HEV
- RFG ICEV

GHG Emissions, g/mi
Ethanol plant energy inputs and source of processing energy have a significant impact on E85 from corn.

Changes in land use may also have a significant impact for biofuels.
Local NMOG in the fuel cycle are primarily due to fuel and vapor losses.

Urban CA NO\textsubscript{x} – 2017 LDA (g/mi)

<table>
<thead>
<tr>
<th>Min</th>
<th>Base</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Offset</td>
<td>Avg Est.</td>
<td>High Est.</td>
</tr>
<tr>
<td>25 mi</td>
<td>HHDT 50 mi</td>
<td>7 g/mi</td>
</tr>
<tr>
<td>26 mi</td>
<td>200 mi</td>
<td></td>
</tr>
<tr>
<td>PZEV</td>
<td>New 2010</td>
<td>2017 inventory</td>
</tr>
</tbody>
</table>

WTW GHG Emissions (g/mi)
Prior studies and models provide a basis for the full cycle assessment. However, we need stakeholder input to better reflect California specific vehicles and fuel options.

**Energy Inputs**
- California specific fuel production options
- Energy consumption and growth projections

**GHG Emissions**
- Limited uncertainty in WTT for fossil fuels
- Review land use impacts for biofuels

**Criteria Pollutants**
- Identify available information for CA fuel production facilities

**Water Impacts**
- Identify available information on fuel production facilities
- Collect information from Department of Water Resources and Water Resources Control Board

**Fuel Economy**
- Examine input from developers and vehicle operators
The following acronyms are among those used in this presentation.

- BACT – best available control technology (for stationary emission sources)
- CH$_4$ – methane
- CNG – compressed natural gas
- E5.7, E10, E85 – ethanol/gasoline fuel (ethanol volume%)
- EMFAC – ARB’s vehicle emission factor model
- LCA – life cycle analysis (environmental)
- LDA, LDT – light-duty automobile, light-duty truck
- LNG – liquefied natural gas
- NMOG – non methane organic gases (HCs, alcohols, aldehydes)
- N$_2$O – nitrous oxide, a greenhouse gas (dentist’s anesthetic)
- NO$_x$ – oxides of nitrogen
- PM – particulate matter
- RFG – reformulated gasoline
- RP – renewable power
- RPS - renewable portfolio standard
- ROG – reactive organic gases (HCs - methane)
- SOx – sulfur oxides
- TTW – tank to wheel
- WTT - well to tank
- WTW – well to wheel