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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 H_2, H_2 Highway, AB1493, AB2076, AB1007

Fuel Pathways

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

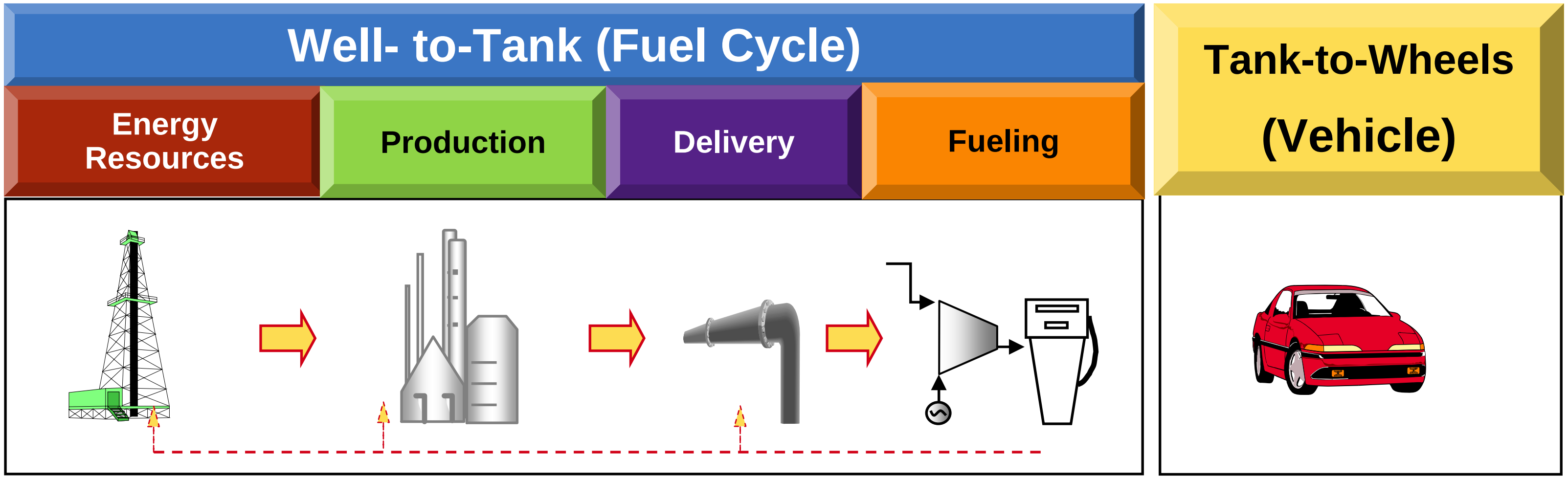
Vehicles

- 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

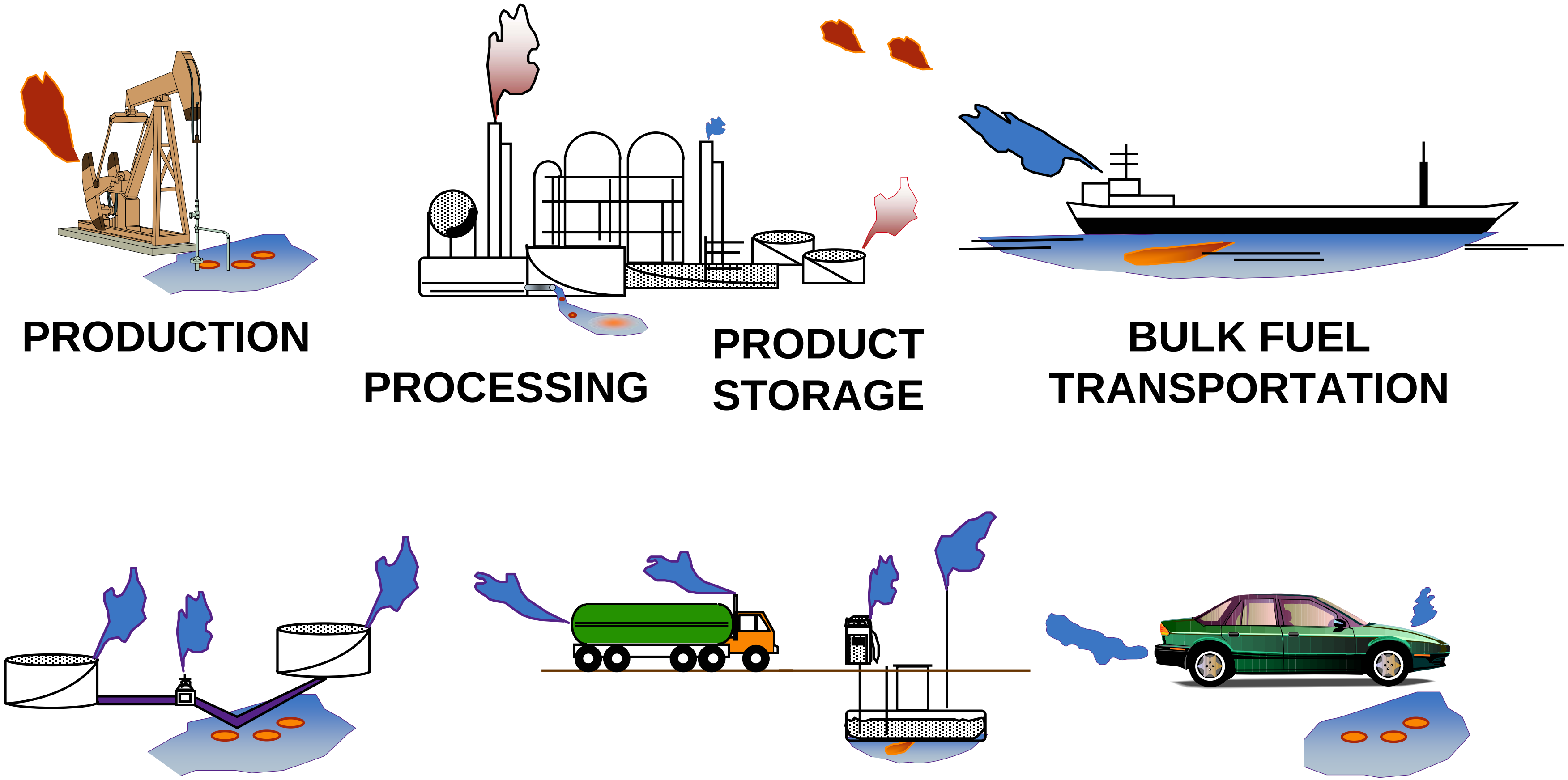
- Local requirements affect criteria pollutants, toxics, and water impacts
- Location of sources, CA ARB regulations, BACT, offset requirements
- Global GHG emissions

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.



PRODUCTION

PROCESSING

PRODUCT STORAGE

BULK FUEL TRANSPORTATION

BULK STORAGE

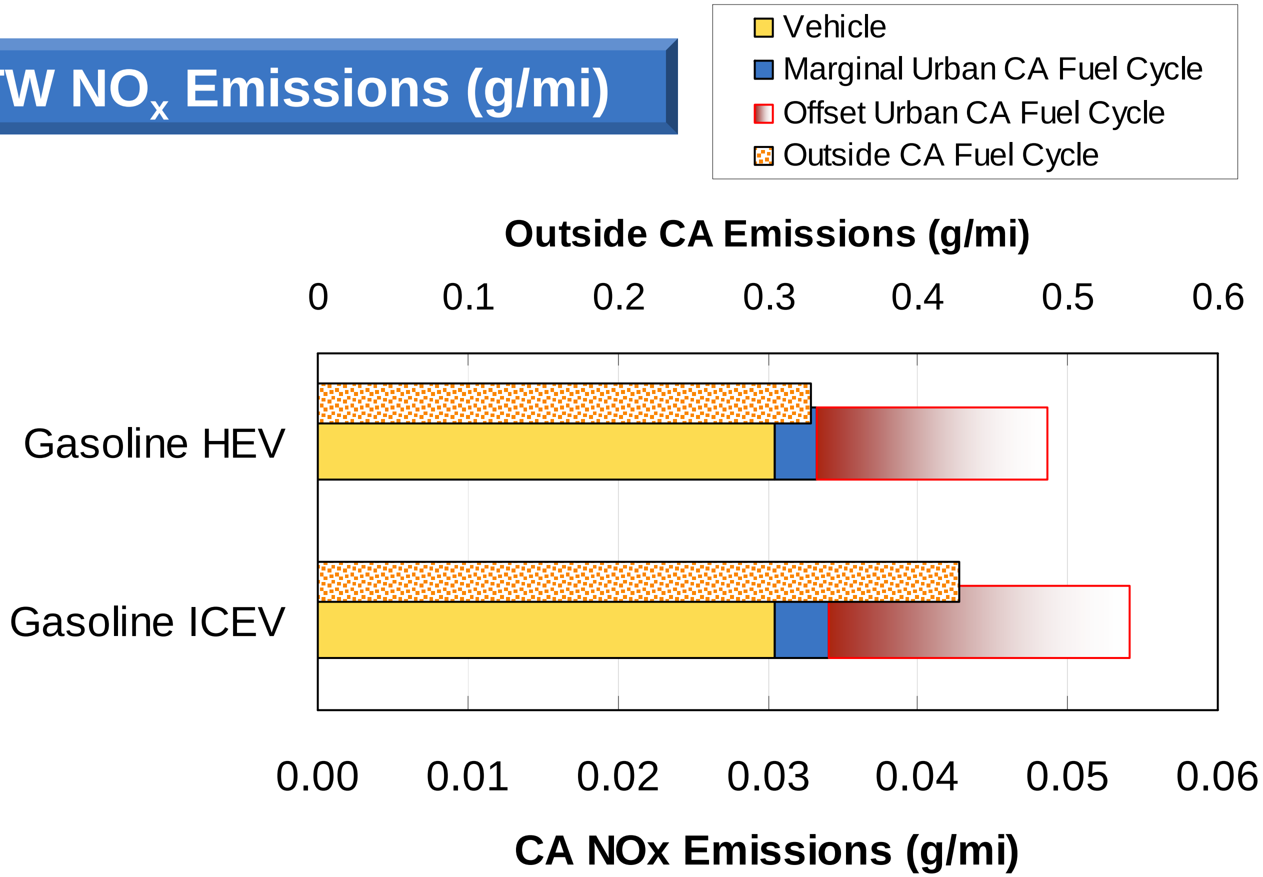
TRANSPORTATION AND DISTRIBUTION

VEHICLE

Out of CA Emissions
Offset CA Emissions
Marginal CA Emissions
CA Water Impacts

WTW emissions include the vehicle plus the fuel cycle. Fuel cycle emissions are grouped by region.

WTW NO_x Emissions (g/mi)



Prior fuel cycle studies focused on a range of fuels and boundaries.

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

🟦	Marginal CA Emissions
🟥	Average Emissions

The full fuel cycle analysis will consider a range of feedstocks and fuels.

Fuels	Primary Feedstock	Other Feedstocks
RFG – E0	Petroleum	
RFG — E5.7		
RFG — E10		
Diesel		
LPG		Natural Gas
CNG	Natural Gas	LFG, LNG
LNG		Biomass Coal
Methanol		
Dimethyl ether		
FT blends		
Ethanol — E85	Corn	Sugar Cane Biomass
E-diesel		
Biodiesel (thermal)	Biomass	
Biodiesel (vegetable)	Soy Bean Oil	Palm Oil
Electricity	NG/20% RP	Various
Hydrogen	Natural Gas	Various

The analysis will be configured for different vehicle applications.

Vehicle	Class	GVW
Passenger Car	LDA	3750
Light Truck	LDT1, LDT2	3750, 6000
Delivery Truck	MDV	14,000
Long Haul Truck	HHDT	80,000
Garbage Truck	HHDT	80,000
School Bus 88 passenger	SBUS	40,000
Transit Bus 40 ft	UB	40,000
Off Road Vehicles	TBD	TBD

Vehicle/fuel combinations that appear likely for the application will be presented in the report.

Year	Introduced
2012	**New 2010[1], All**
2017	
2022	
2030	

Fuel	LD Car[2]	Transit Bus
RFG — E0	x	
RFG — E5.7	x, HEV, PHEV	HEV
RFG — E10	**x[3]**	—
Diesel	x	x, HEV
LPG	x	—
CNG	x	x
LNG	—	x
Methanol	—	FC
DME	—	x
FT blends	**x**	x
Ethanol — E85	**x, PHEV**	**—**
E-diesel	—	**x**
BD (thermal)	**x**	**x**
BD (vegetable)	**x**	**x**
Electricity	PHEV, **EV**	—
Hydrogen	x, FC	x, FC

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**

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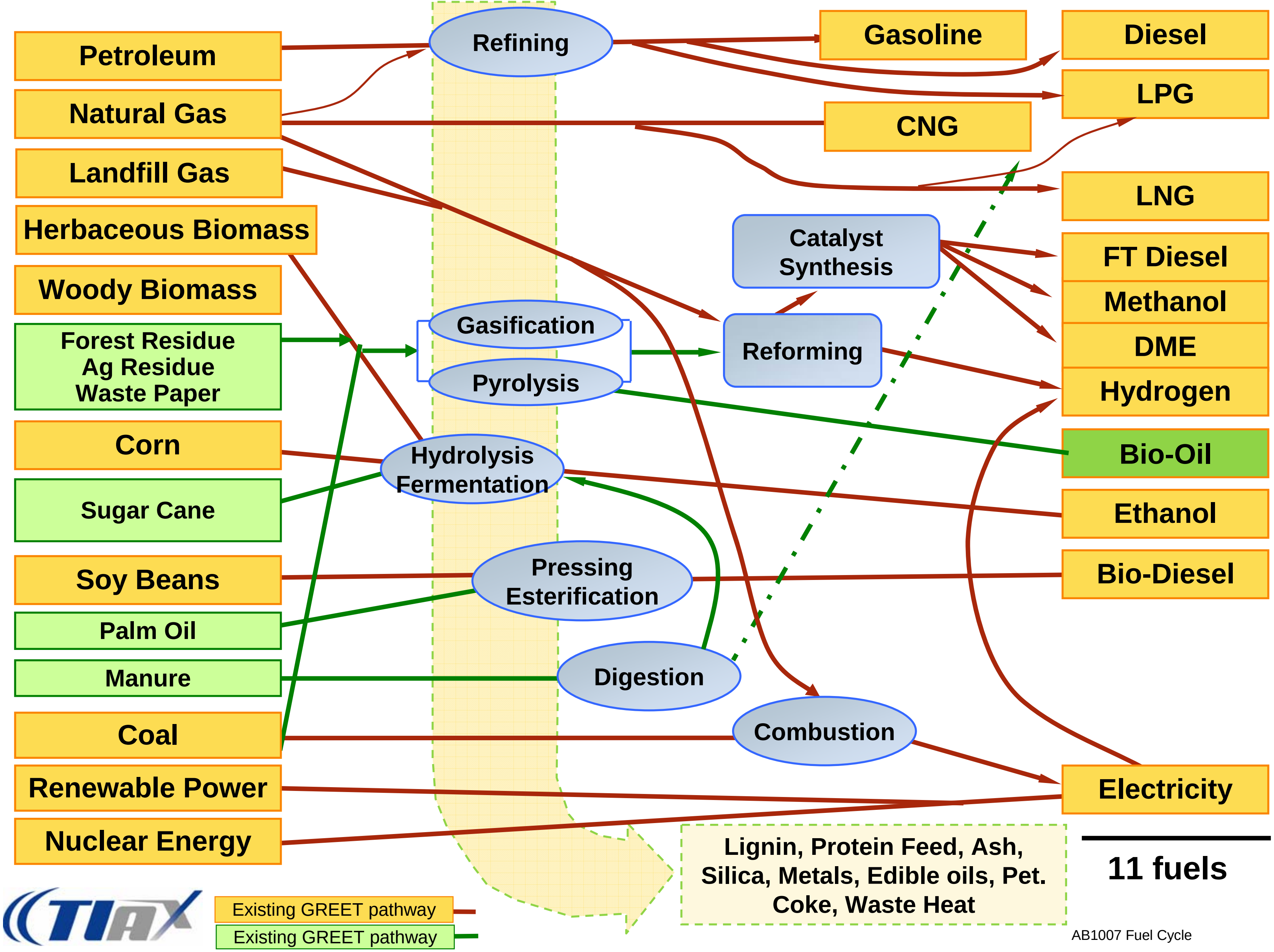
Alternative Fuel Production Processes — “Well-to-Tank”

- 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

CNG

Diesel

LPG

LNG

FT Diesel

Methanol

DME

Hydrogen

Bio-Oil

Ethanol

Bio-Diesel

Electricity

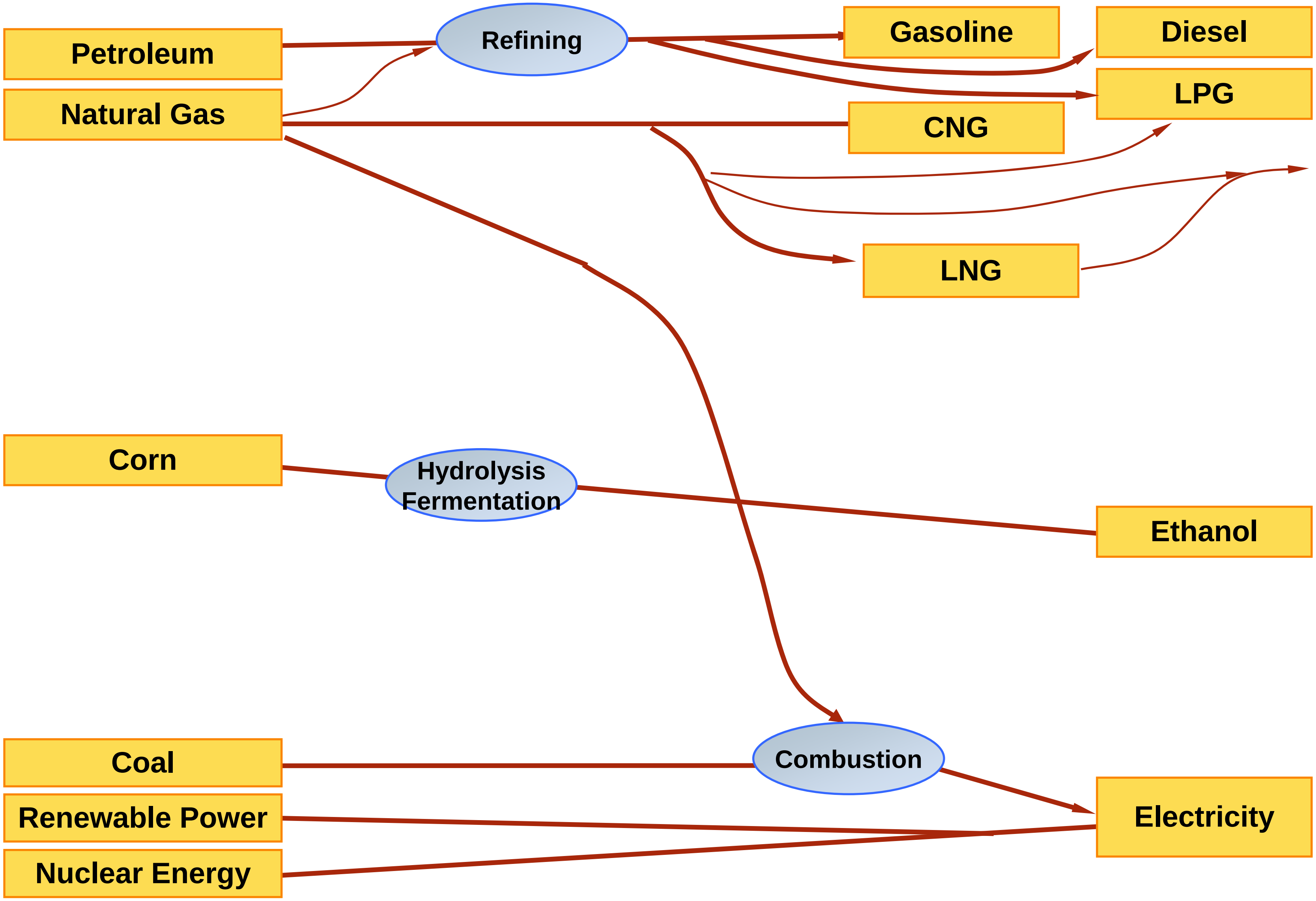
Lignin, Protein Feed, Ash, Silica, Metals, Edible oils, Pet. Coke, Waste Heat

11 fuels

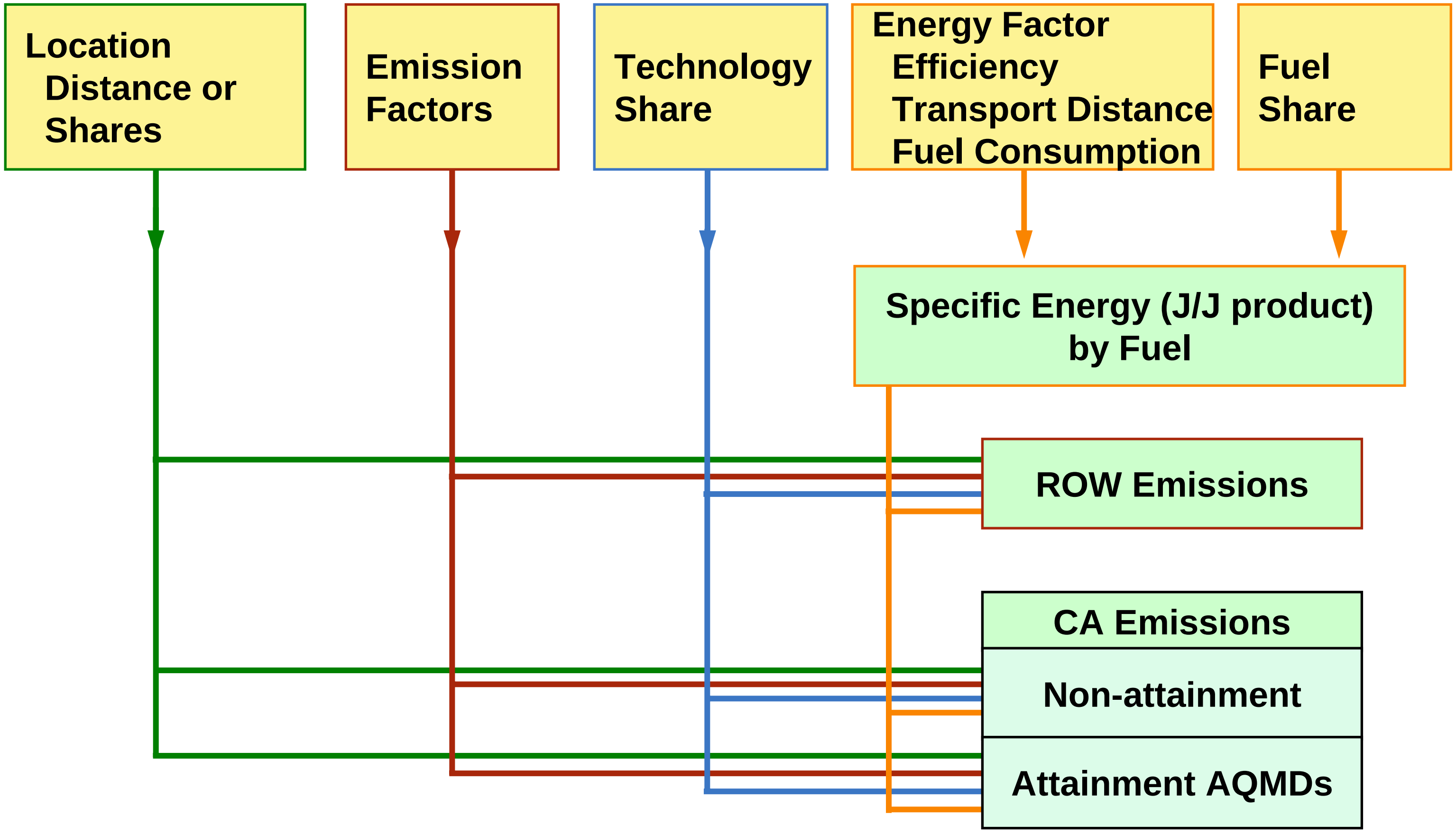
Existing GREET pathway

Existing GREET pathway

Analysis Scope Fuel Pathways *Primary Fuels*



Fuel cycle model inputs need to capture California boundaries.



Location
Distance or Shares

Emission Factors

Technology Share

Energy Factor
Efficiency
Transport Distance
Fuel Consumption

Fuel Share

Specific Energy (J/J product) by Fuel

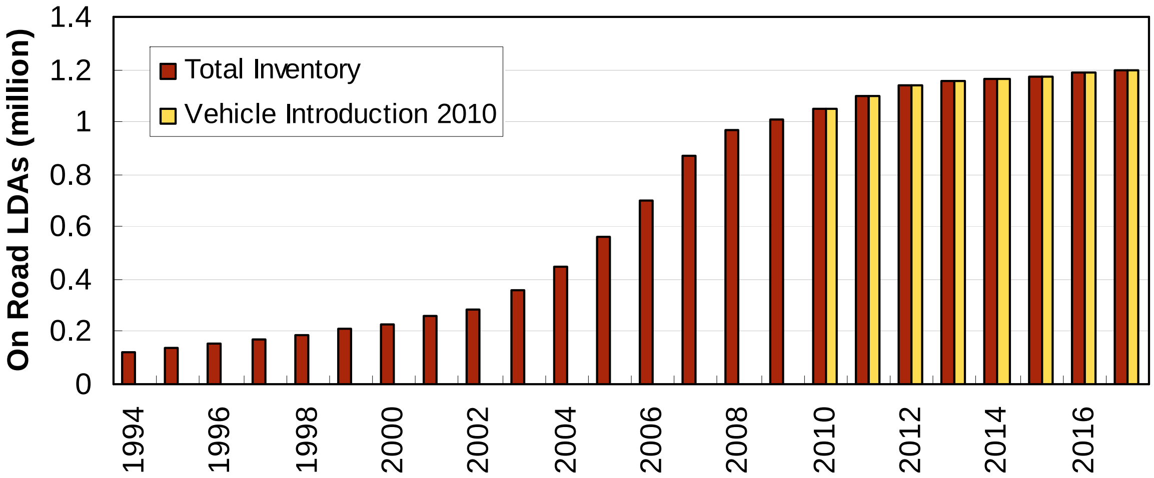
ROW Emissions

CA Emissions
Non-attainment
Attainment AQMDs

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.

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 alterative fuel
  - Adjustment factors in GREET
  - Additional emission test data



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

Toxic Contaminant	Sources		
	Fuel	Engines	Facilities
Benzene	💧	🚌	🏭 💧
1,3 butadiene	💧	🚌	💧
Formaldehyde		🚌	🏭
Acetaldehyde		🚌	🏭
Diesel PM		🚌	
Metals		💧	🏭

Calculation Method

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

Toxic	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde
Running Exhaust	2.64%	0.55%	1.70%	0.24%

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

Water Pollutant	Sources		
	Fuel	Engines	Facilities
Hydrocarbons	💧	🚌	🏭
Alcohols	💧		🏭
Metals		🚌	🏭
Salts			🏭
Sulfates		🚌	🏭
Nitrates		🚌	🏭
Water use			🏭

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

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 alterative 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

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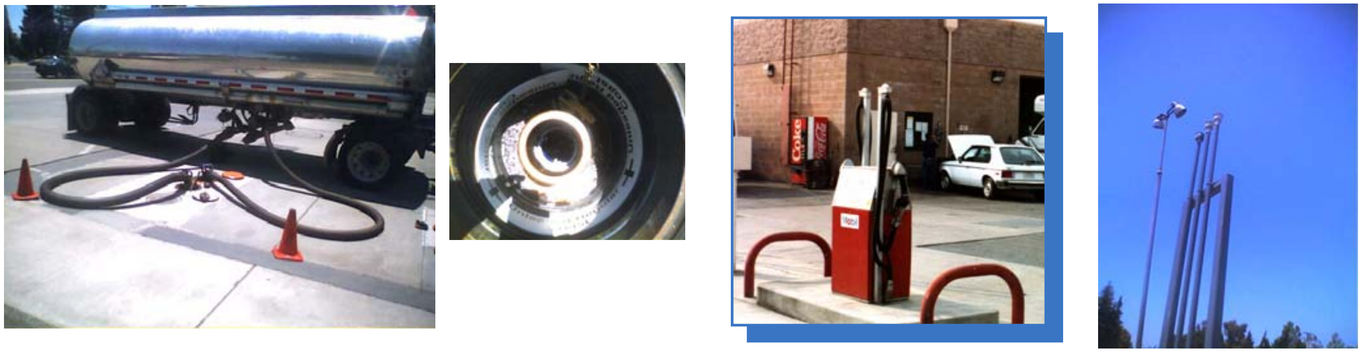
- **Assumptions**
- Sensitivity Results
- Conclusions

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.

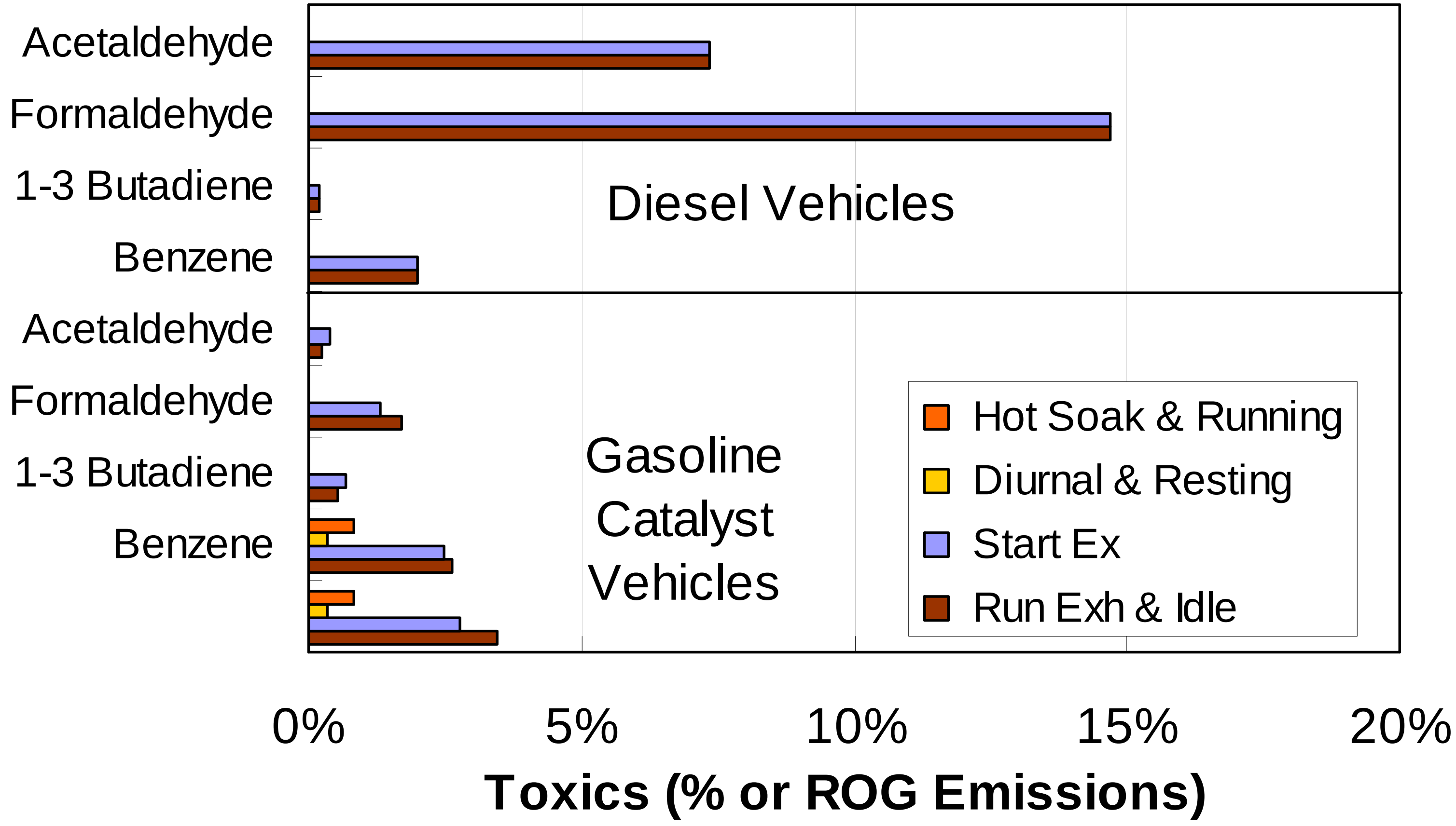
	Emission Factor (lb/1000 gal)		
Source	**Uncontrolled**	**W. control**	**W. defect rate**
Tank truck spillage	0.07	—	—
UG tank working loss	8.4	0.42	0.42
UG tank breathing loss	0.84	0.1	0.1
Vehicle fueling vapor loss	8.4	0.42	0.115
Vehicle fueling spillage	0.64	0.42	0.42



ARB inventory values except for tank truck spillage. 95% control efficiency for vapor working losses. 10% defect rate and fueling station vapor controls.

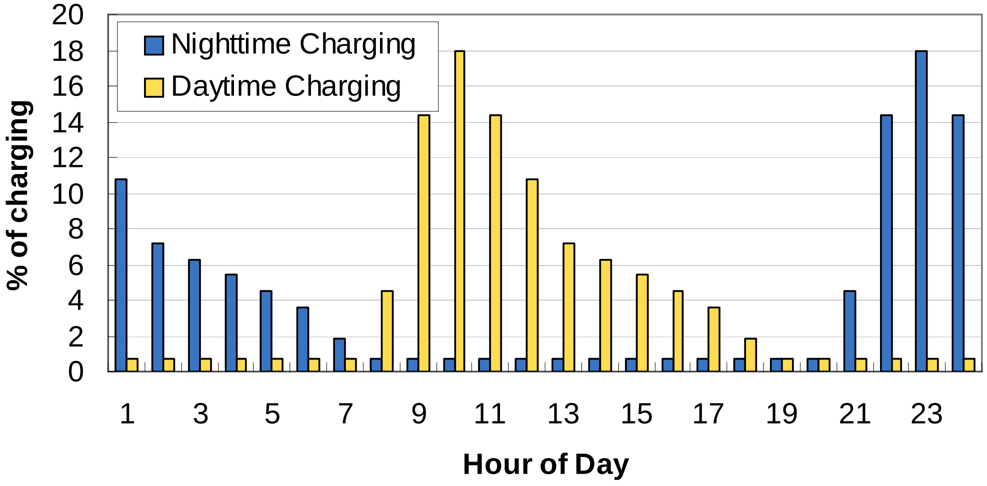
ARB's speciation database was used to determine the fraction of toxics in ROG emissions.

Toxics from Vehicle Emissions (% of ROG)



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 an heat rate

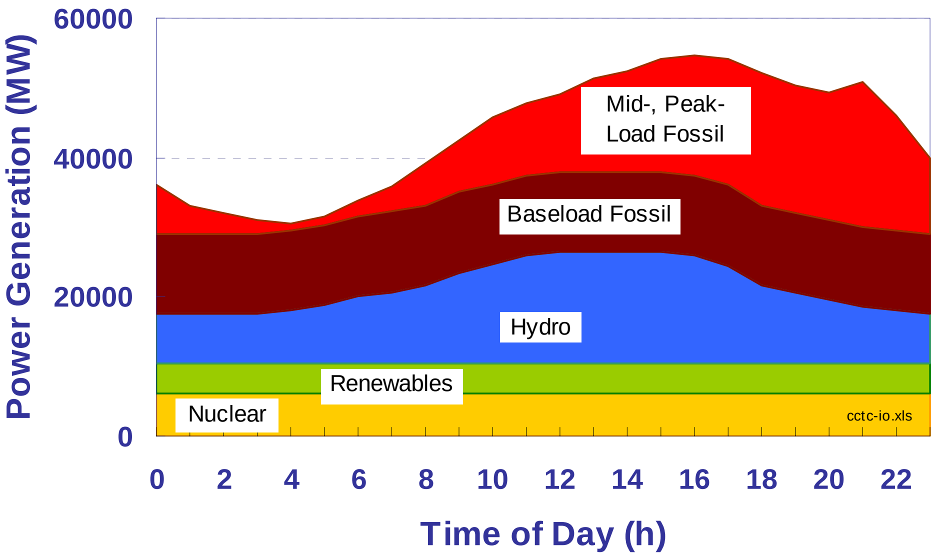


Scenario	Profile	Time	GWh/y	Application
1	24-hr Marginal - N Cal	15-Oct-17	400	Fuel production
2	24-hr Marginal - S Cal	15-Oct-17	400	Fuel production
3	Night-time OFF70%s22h	15-Oct-17	1000	Battery Charging
4	Night-time OFF55%s18h	15-Oct-17	1000	Battery Charging
5	Day-Time OFF30%s08h	15-Oct-17	1000	Battery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

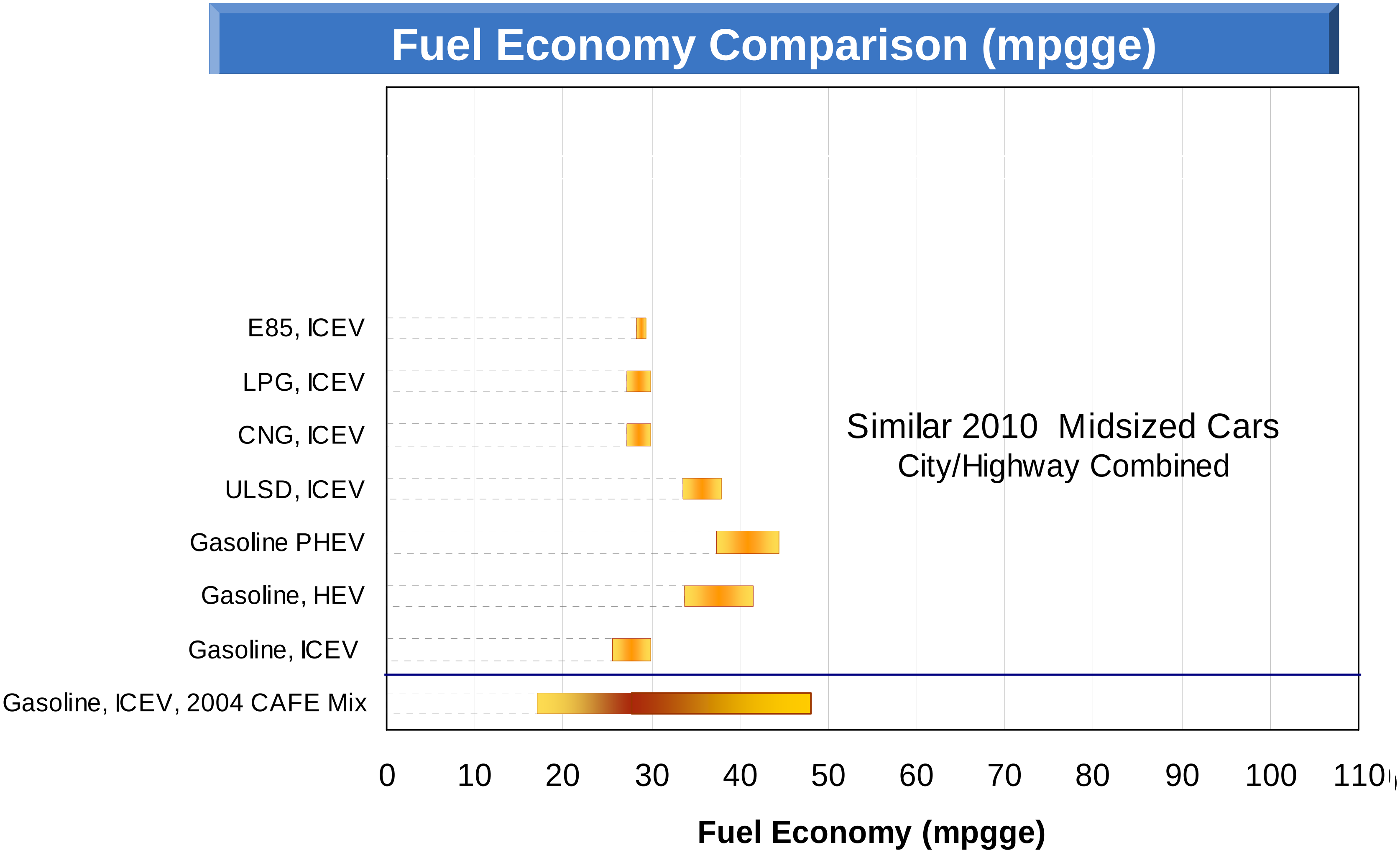
Battery charging, OFF70%s22h refers to 70% of power from off peak according to charging profile and CA ISO definition of off peak. Charging timed to start at 10 pm.

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

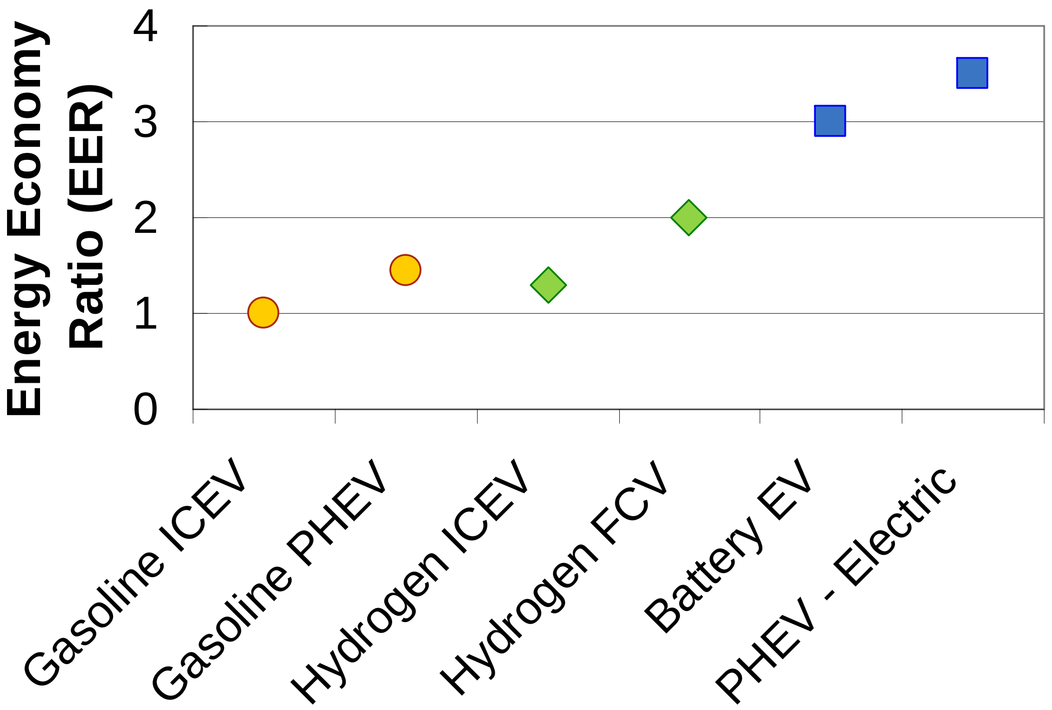


Fuel economy estimates have been made for comparable gasoline and alternative fueled vehicles.



Baseline fuel economy for alternative drive train technologies.

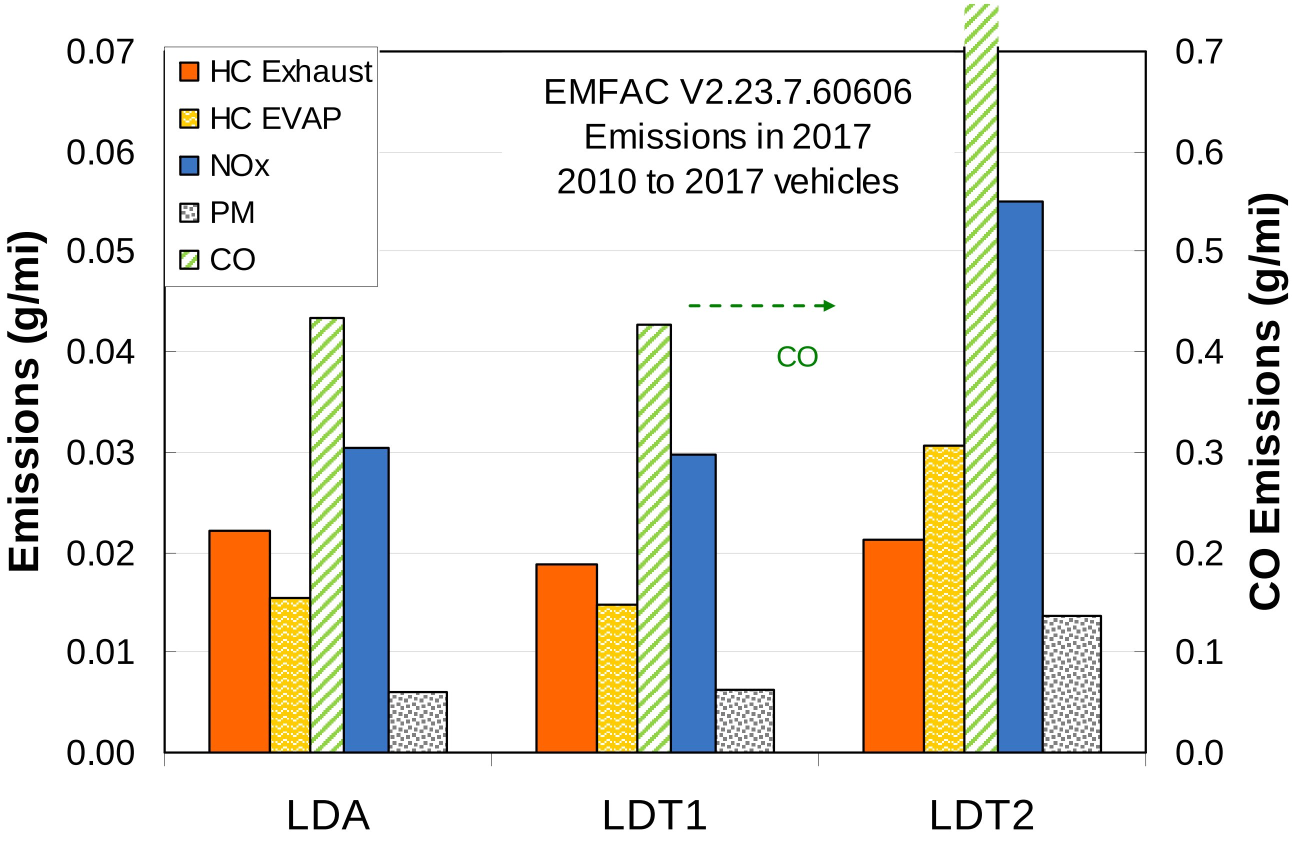
Energy Economy Ratio, EER (J $_{\text{gasoline}}$/J $_{\text{alt fuel}}$)



Stakeholder continue to debate benchmark for fuel economy. Base policy on actual vehicle performance.

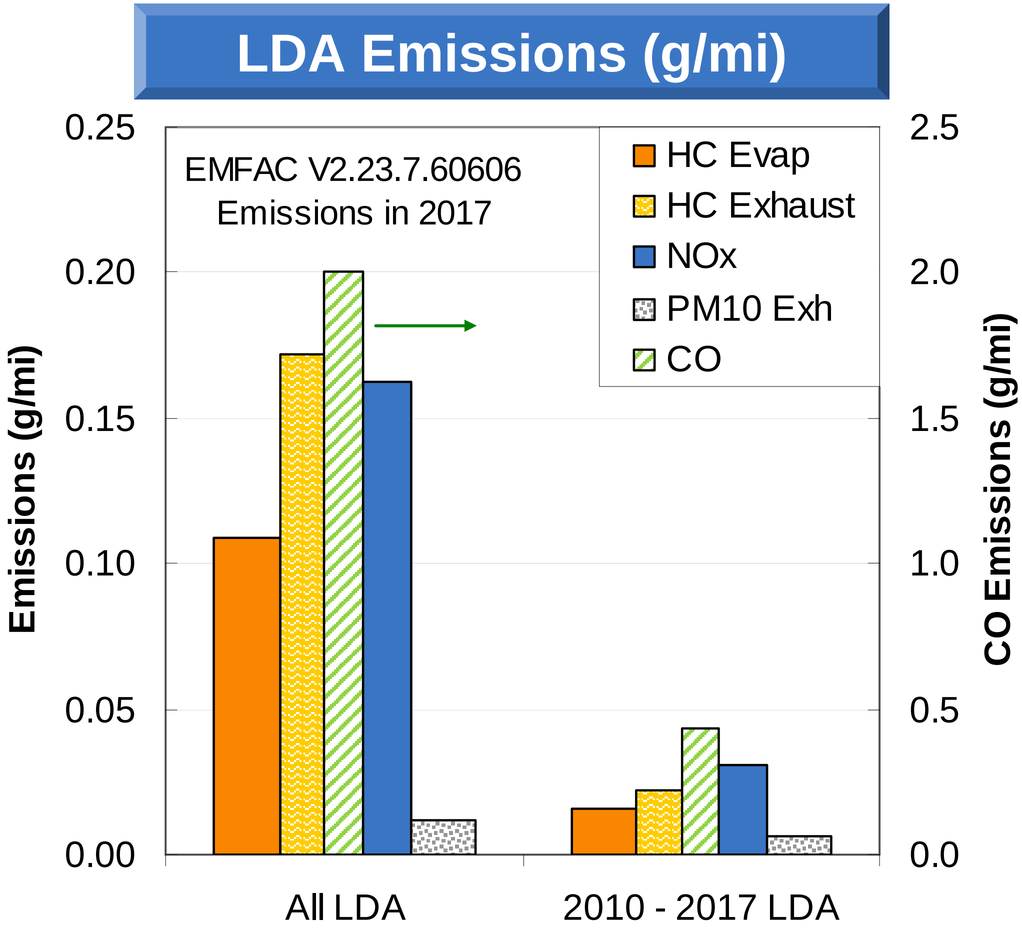
EMFAC model outputs representing a mix of vehicle technologies, driving patterns, and other assumptions are represented on a per mile basis.

Vehicle Emissions (g/mi)



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

	CARFG	E10	CNG	LPG	E85 FFV	H2 ICEV	H2 FCV	Battery EV
FE Gasoline mpgge	100%	100%	100%	100%	103%	130%	200%	300%
Exhaust VOC	100%	100%	90%	90%	100%	0%	0%	0%
Evaporative VOC	100%	100%	10%	10%	85%	0%	0%	0%
CO	100%	100%	100%	100%	100%	0%	0%	0%
NO_x	100%	100%	100%	100%	100%	75%	0%	0%
Exhaust PM10	100%	100%	100%	100%	100%	0%	0%	0%
Brake and Tire Wear PM10	100%	100%	100%	100%	100%	100%	100%	100%
CH_4	100%	100%	200%	100%	100%	10%	0%	0%
N_2O	100%	100%	100%	100%	100%	75%	0%	0%

Values adjusted from GREET input assumptions

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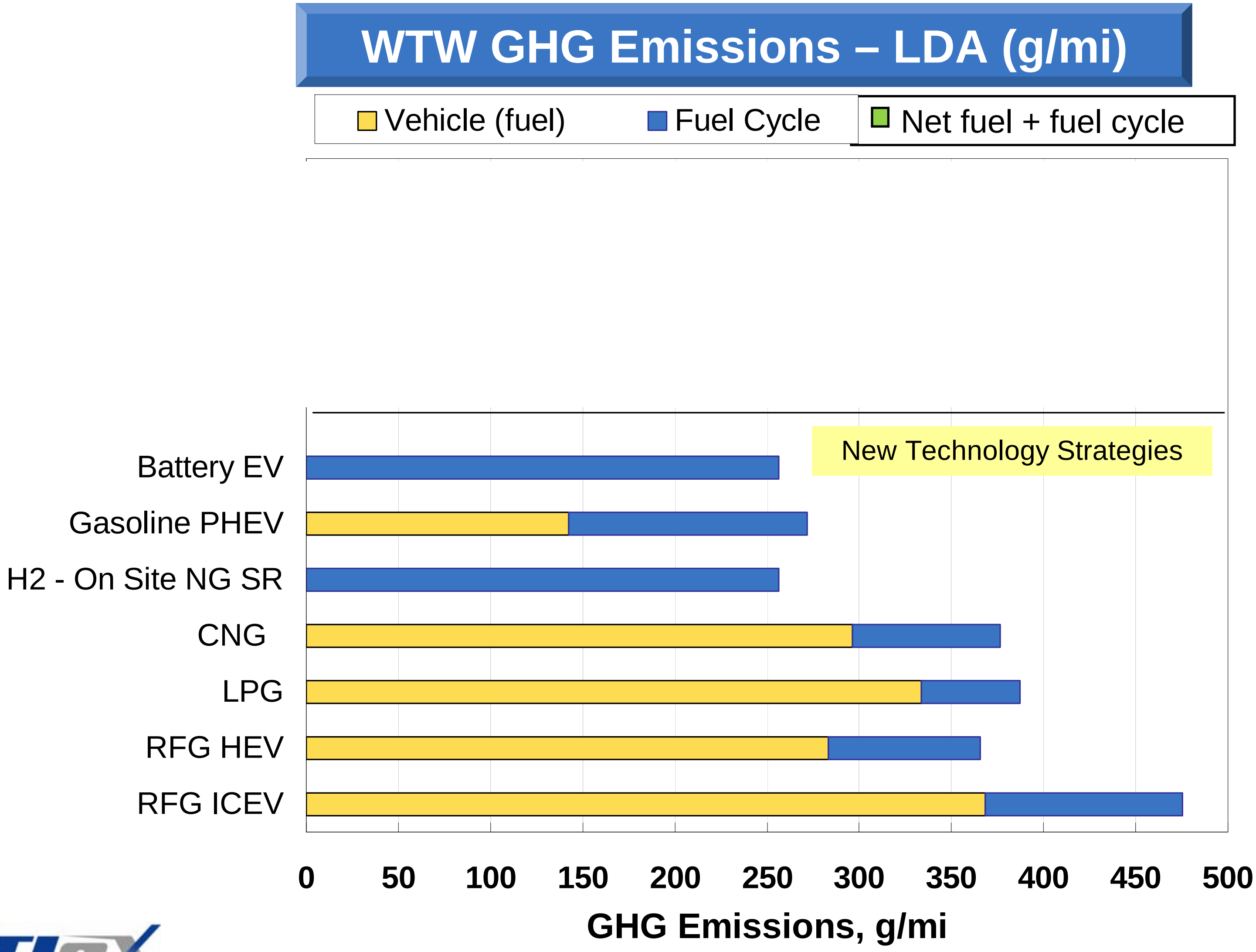
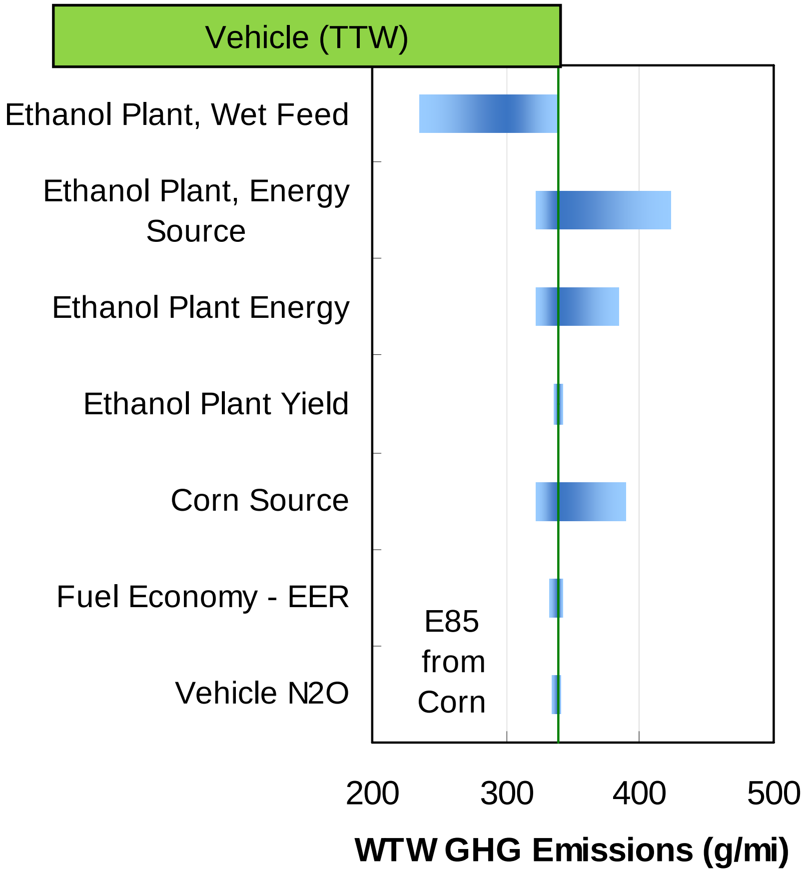
Alternative technologies offer the potential for GHG emission reductions.



Ethanol plant energy inputs and source of processing energy have a significant impact on E85 from corn..

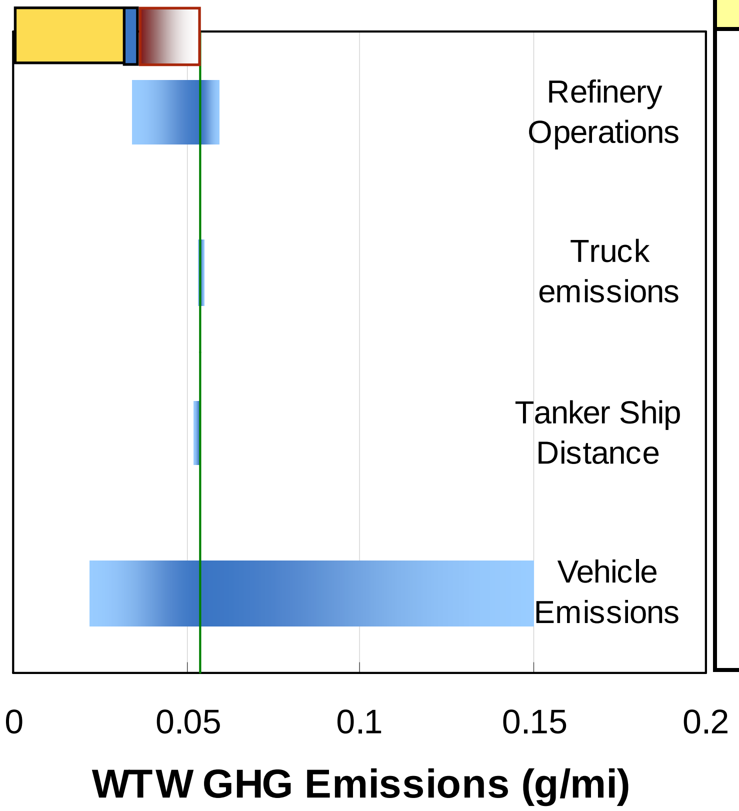


Min	Base	Max
Digester gas	Wet Feed	Base Case
20/80	26/74	75/25
36000	39000	49500
2.6	2.71	2.8
Higher Yield	Average	Marginal
1.05	1.03	1.02
1.5	2	2.5

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_x – 2017 LDA (g/mi)



Min	Base	Max
100% Offset	Avg Est.	High Est.
25 mi	HHDT 50 mi	7 g/mi
26 mi	200 mi	
PZEV	New 2010	2017 inventory

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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_2O – 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