Transportation Fuels
ARB Technology Assessment

September 3, 2014

California Environmental Protection Agency
Air Resources Board

Issues to be Evaluated

1. Can biofuels be the only solution for our 2050 GHG targets?
2. What is the relative emission benefit of switching to alternative transportation fuels and technologies?
3. What is the impact of methane leakage from the natural gas distribution system on established emission rates?
4. What infrastructure improvements are needed to facilitate the use of emerging fuels?

Overview – Fuel Policies

Federal Fuel Policies

- Renewable Fuels Standards (RFS)
  - Expansion of renewable fuel production from 9 billion gallons in 2008 to 36 billion gallons in 2022
  - Minimum Well to Tank (WTT) greenhouse gas (GHG) emissions reductions from gasoline and diesel baselines required:

Fuel	Min. Percent Reduction in WTT GHG emissions
Advanced Biofuels	50
Biomass-Based Diesel	50
Renewable Fuel	20
Cellulosic Biofuel	50

California Fuel Policies

- Assembly Bill 32—CA Global Warming Solutions Act of 2006
  - Sets GHG target in 2020 as 1990 emission levels
  - Cap/Trade program adopted – regulates fuel providers among others
    - CA fuel facility GHG emissions under compliance today
    - Carbon content of fuels sold have compliance requirements beginning Jan 2015
- CA Executive Order S-03-05
  - Sets GHG target in 2050 as 80% below 1990 levels

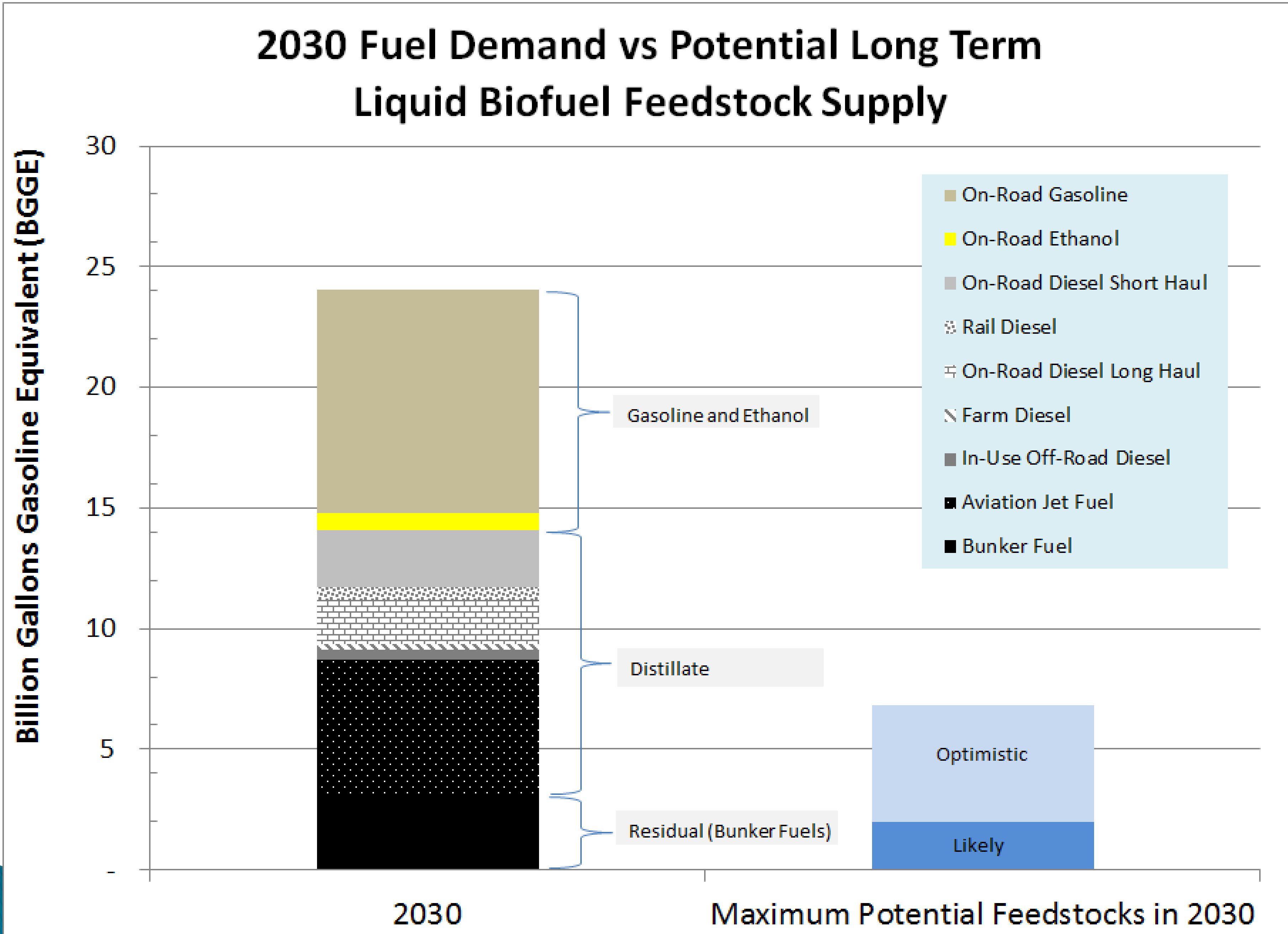
California Fuel/Energy Standards

- **Low Carbon Fuel Standard (LCFS)**
  - Requires fuel regulated parties to reduce the carbon intensity of their products 10 % by 2020
- **California Renewable Portfolio Standard (RPS)**
  - Requires all CA retail sellers of electricity to serve 33 % of their load with renewable energy by 2020
  - Jointly administered by CPUC and CEC
- **California Senate Bill 1505**
  - Requires 33 % of hydrogen (H_2) produced in CA be derived from renewable feedstock

California Alternative and Renewable Fuel Incentives

- Assembly Bill (AB) 118—CA Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007
  - Provides $150 million annually to fund air quality improvement projects and develop and deploy technology and alternative and renewable fuels until 2015
  - AB 8 extends AB 118 funding through 2023

1. Can Biofuels Be a Primary Solution for our 2050 GHG Targets?


2030 Fuel Demand vs Potential Long Term
Liquid Biofuel Feedstock Supply
Billion Gallons Gasoline Equivalent (BGGE)
30
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On-Road Gasoline
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On-Road Diesel Short Haul
Rail Diesel
On-Road Diesel Long Haul
Farm Diesel
In-Use Off-Road Diesel
Aviation Jet Fuel
Bunker Fuel
Gasoline and Ethanol
Distillate
Residual (Bunker Fuels)
Optimistic
Likely
2030
Maximum Potential Feedstocks in 2030

Outline

- Baseline fuel demand projections
- Biofuel availability projections
    - Review of literature and expert analysis
- Comparison of biofuels supply over time to demand projections

Baseline Fuel Demand

- 2012 base year fuel demand from the Energy Information Administration (EIA)
- Future year fuel demand:
  - Growth from EMFAC for on-road
  - Growth for off-road sectors from ARB inventories
- Projections for baseline (existing policies):
  - 2014: 24.7 billion gallons liquid fuels (gas, dsl, jet)
  - 2030: 24.2 billion gallons
  - 2050: 32.1 billion gallons

Biofuel Supply Challenges

- Today, California consumes ~1.5 billion gallons of corn-based ethanol for gasoline blends.
  - U.S. demand for ethanol = 43% of corn crop (2014)
  - Distribution networks separate from petroleum fuels
- Need new renewable "drop-in" fuels (gas, dsl)
  - Move to non-food feedstocks for sustainability
  - Limited by land area and waste streams
  - Requires large sector expansion in new market
- Sustainability factors to consider:
  - Indirect land-use change (iLUC) carbon emissions
  - Water consumption
  - Fertilizer input and nitrogen run-off

Projected Biofuel Supply

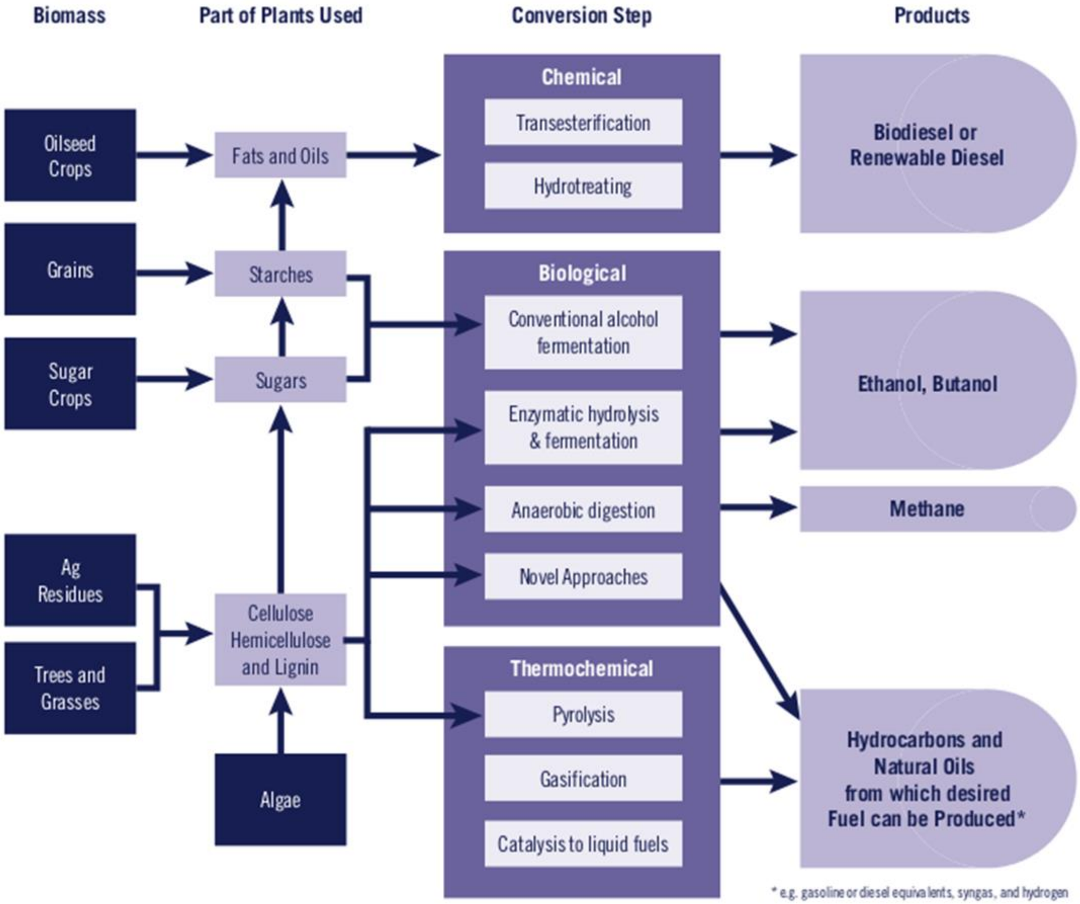
Reference Studies Reviewed

1. 2014 CEC Advanced Fuel Production Technology Market Assessment
2. UC Davis Bioenergy Webinar (May 17, 2013)
3. DOE/ORNL Billion Ton Update (Aug 2011)
4. CA Council on Science & Technology (CCST) CA's Energy Future Biofuels report (May 2013)

Acronyms:

- BG = billion gallons; bgge = billion gallons gasoline equivalent
- MGPY = million gallons per year
- BCF = billion standard cubic feet (natural gas)
- BDT = bone dry tons of biomass (raw feedstock)

Biomass Conversion Pathways



From Biofuels for Transportation: A Climate Perspective, Pena, 2007.

2014 CEC Technology Assessment

Today's Potential Supply of CA Biomass Resources

- Lignocellosic Biomass
  - 26 million tons/year = **~2.2 bgge**
  - Ref: 24.7 BG, 2014 CA
- Fats, Oils, Grease (FOG)
  - 595,711 tons/year = **~0.05 bgge**
- Biogas
  - 2 million tons or 102 BCF
  - Reference: 15.5 BCF in transportation in 2012

Biomass Resource	Tons/year
Lignocellulosic Biomass	
Crop residues (field and seed crops)	2,000,000
Crop residues (vegetable crops)	128,000
Rice hulls	297,000
Cotton gin trash	103,000
Almond shells	496,000
Walnut shells	199,000
Logging slash	4,300,000
Forest thinnings	4,100,000
Sawmill residues	3,300,000
Shrub or chaparral	2,600,000
Orchard and vineyard pruning	1,700,000
MSW (brown material)	6,898,664
Total Lignocellulosic Biomass	***26,121,664***
FOG	
Cottonseed oil	85,000
Safflower oil	14,151
Sunflower oil	7,900
Waste oils (yellow and brown grease	389,000
Beef tallow	47,000
Lard	38,000
Chicken fat	14,660
Total FOG	***595,711***
Methane	
LFG	1,400,000
Dairy Farms	341,000
WWTP	198,000
Food Processing waste	159,000
Total Methane	***2,098,000***

Add URL at bottom

UC Davis Bioenergy Webinar

Estimated Fuel Potential from California biomass residues*

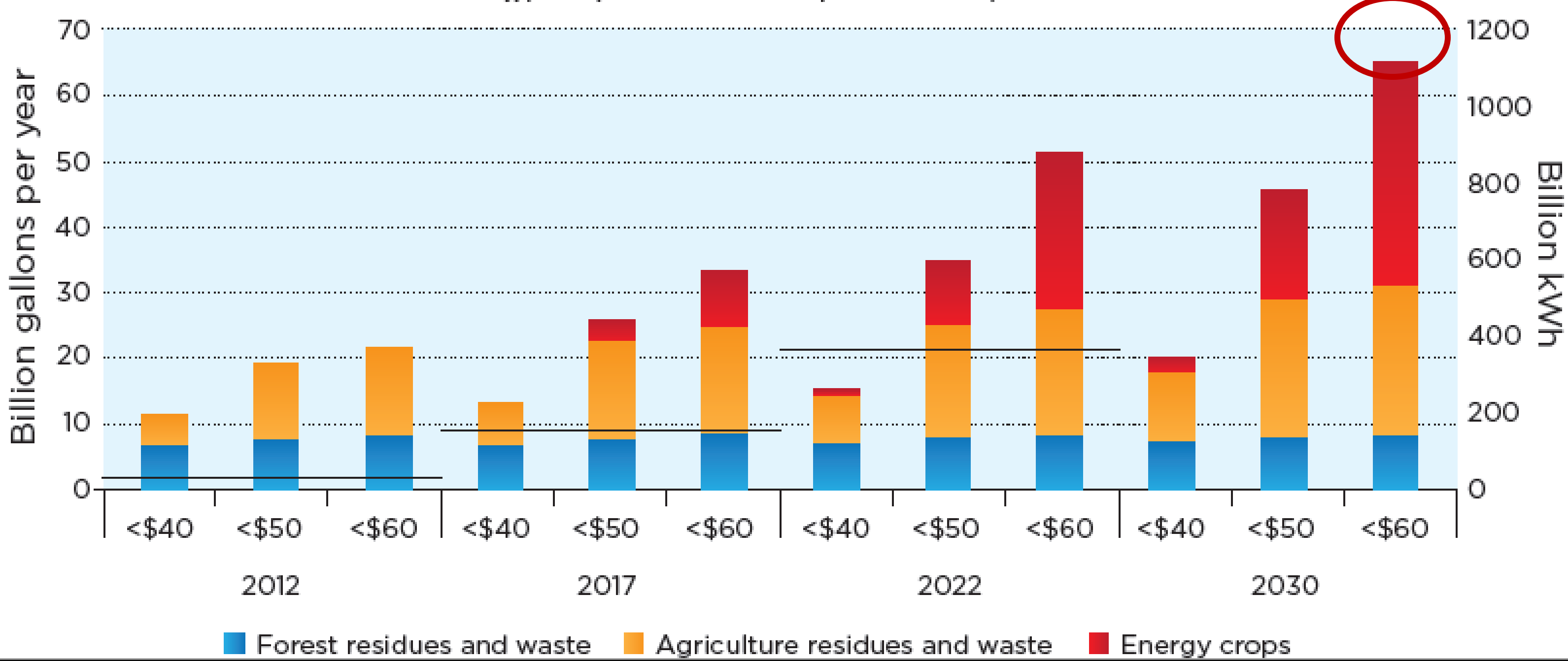
Feedstock	Amount Technically Available	Biomethane Potential (billion cubic feet)	Biofuel Potential (million gge)
Agricultural Residue (Lignocellulosic)	3.5 M BDT[a]	-	175[h]
Animal Manure	3.8 M BDT[a]	14.6[a]	125[i]
Fats, Oils and Greases	207,000 tons[b]	(assume conversion to biodiesel)	56[j]
Forestry and Forest Product Residue	14.2 M BDT[a]	-	710[h]
Landfill Gas	110 BCF[a]	55[f]	474[i]
Municipal Solid Waste (food waste fraction)	1.2 M BDT[c]	13.1[g]	113[i]
Municipal Solid Waste (lignocellulosic fraction)	9.5 M BDT[d]	-	475[h]
Waste Water Treatment Plants	9.6 BCF (gas)[e]	4.8[f]	41[i]
Total			**2,169**

Source: http://policyinstitute.ucdavis.edu/informing-policy-3/webinars/bioenergy-webinar/session-one/

National DOE/ORNL BTS Update

- CA supply apportioned by its share of US fuel usage (**10.4%**) = 2.0-6.8 bgge under varying biomass price scenario (2030)

Figure 6.1 Summary of potential bioenergy supply from forest and agriculture residues and wastes and energy crops at selected prices and years under baseline assumptions



CCST California's Energy Future

- 3.3 – 9.8 bgge supply from CA feedstocks in 2050 (range of technical potential)
- Value used in study: 7.5 bgge

Table 2. California in-state biomass availability and associated fuel production potential in 2050.

	Baseline Scenario		Optimistic Scenario	
	Biomass (million tons/yr)	**Fuel (bgge)**	**Biomass (million tons/yr)**	**Fuel (bgge)**
Energy Crops	4.5	0.4	43	3.4
Residual Biomass*	36	2.9	80	6.4
Total	41	3.3	123	9.8
Percent BAU Liquid Fuel Demand		7.5%		22%
Meets S-06-06 goal?		**No**		**No**

Summary – Biofuel Technical Potential Projections for California

Today

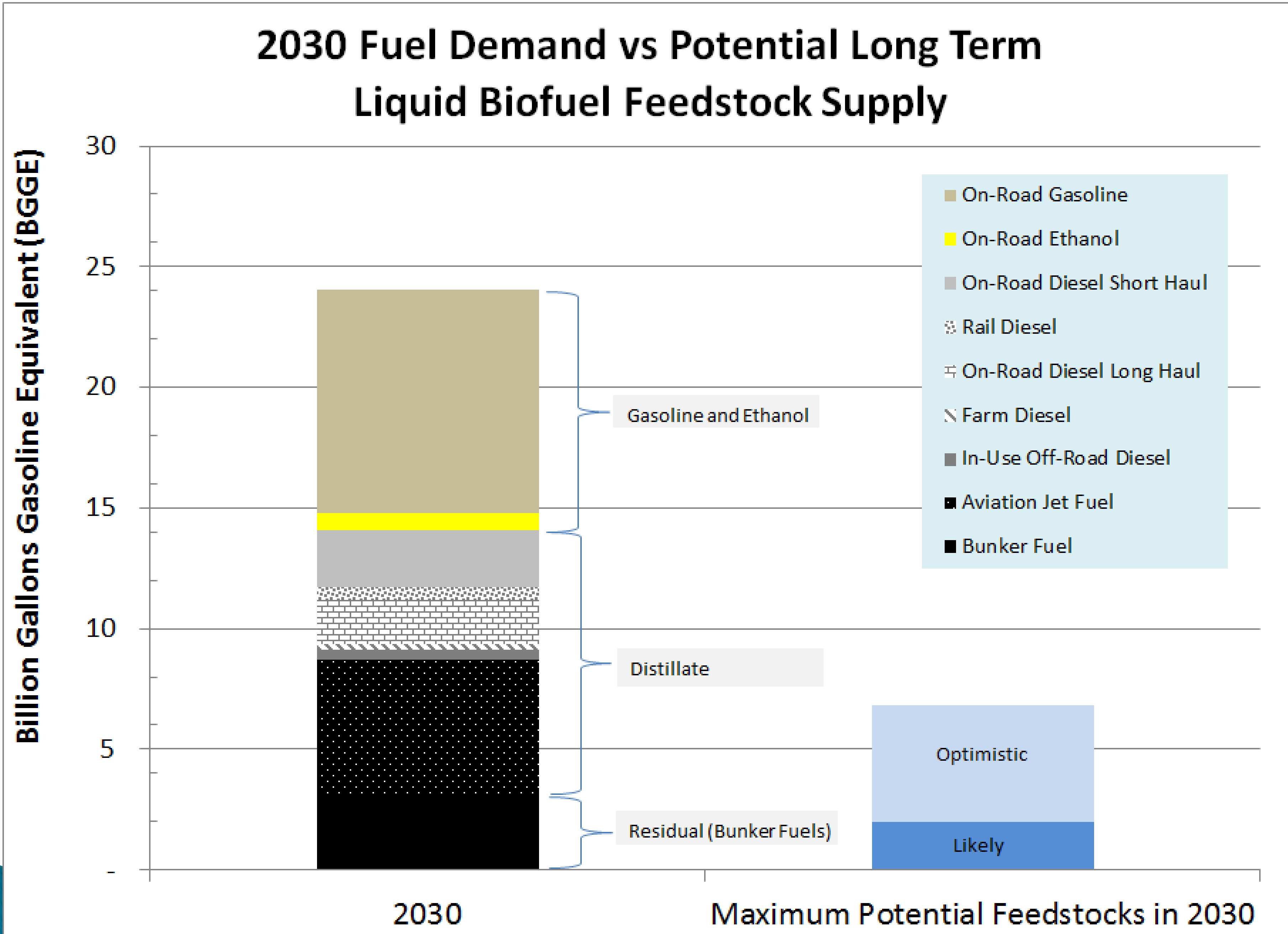
- CEC Technology Assessment:
  - Current technical potential from CA biomass: **~2.2 bgge**
- UC Davis bioenergy webinar:
  - Current technical potential from CA biomass: **~2.1 bgge**

2030 *

- U.S. DOE “Billion Ton Study Update”:
  - 2.0 – 6.8 bgge supply for CA (fraction of US energy use)
  - This is maximum feasible by 2030 under varying biomass $

2050

- CCST California’s Energy Future study:
  - 3.3-9.8 bgge production potential in CA
  - 7.5 bgge value used in scenario study (CA supply)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Aviation Jet Fuel
Bunker Fuel
Gasoline and Ethanol
Distillate
Residual (Bunker Fuels)
Optimistic
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Maximum Potential Feedstocks in 2030

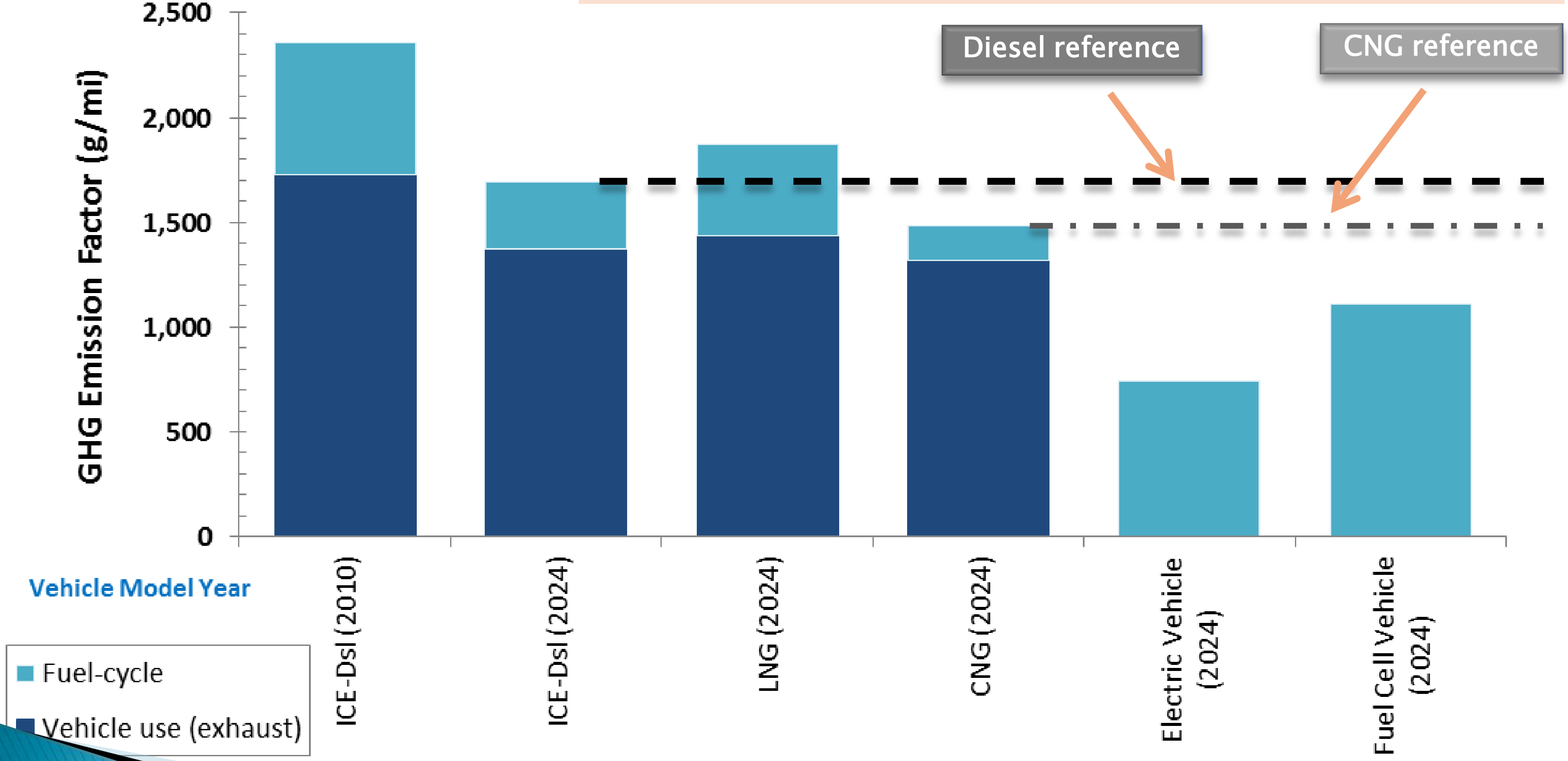
Key Observations

- Biofuel supply not expected to accommodate long-term fuel demand across heavy-duty sectors (for 2050 GHG targets)
- Need to maximize efficiency of current technology engines and vehicles in all sectors
- Need electrification for heavy-duty sectors:
    - Technology used in limited applications today
    - Need to expand to other applications (longer range and heavier uses)

2. What is the relative emission benefit of switching to alternative transportation fuels and technologies?

Well to Wheel: HHD Truck
GHG Emission Factors

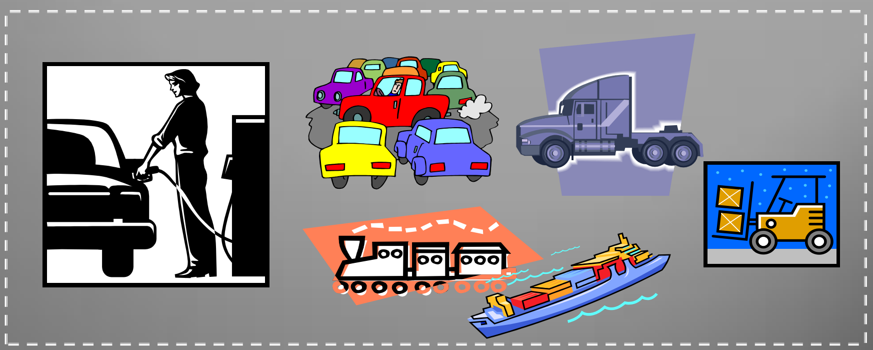
Note: Analysis uses draft LCFS CA-GREET 2.0 carbon intensities and assumptions as presented during the August 22, 2014 workshop. Updates to LCFS pathways are ongoing.



Outline

- Scope and Objectives
- Definition of Well to Wheel (WTW)
- Emissions Factor Methodology
- 2020 Fuel Blend
- NOx, GHG WTW Results for HHD Trucks
- Key Observations

Well to Wheel (WTW): Emission Factors



WTW Emission Factors: Scope

- Sector-based <u>new</u> vehicle performance
  - Reflects a model year vehicle, not the in-use fleet
  - HHD Truck emission factor (EF) comparisons discussed
- Environmental metric for comparing new vehicle and fuel alternatives
- Accounts for emissions associated with production, transport, and consumption of fuels in a vehicle

WTW Emission Factors: Objectives

- Simple tool to vary fuel-vehicle combinations and study emission factor impacts

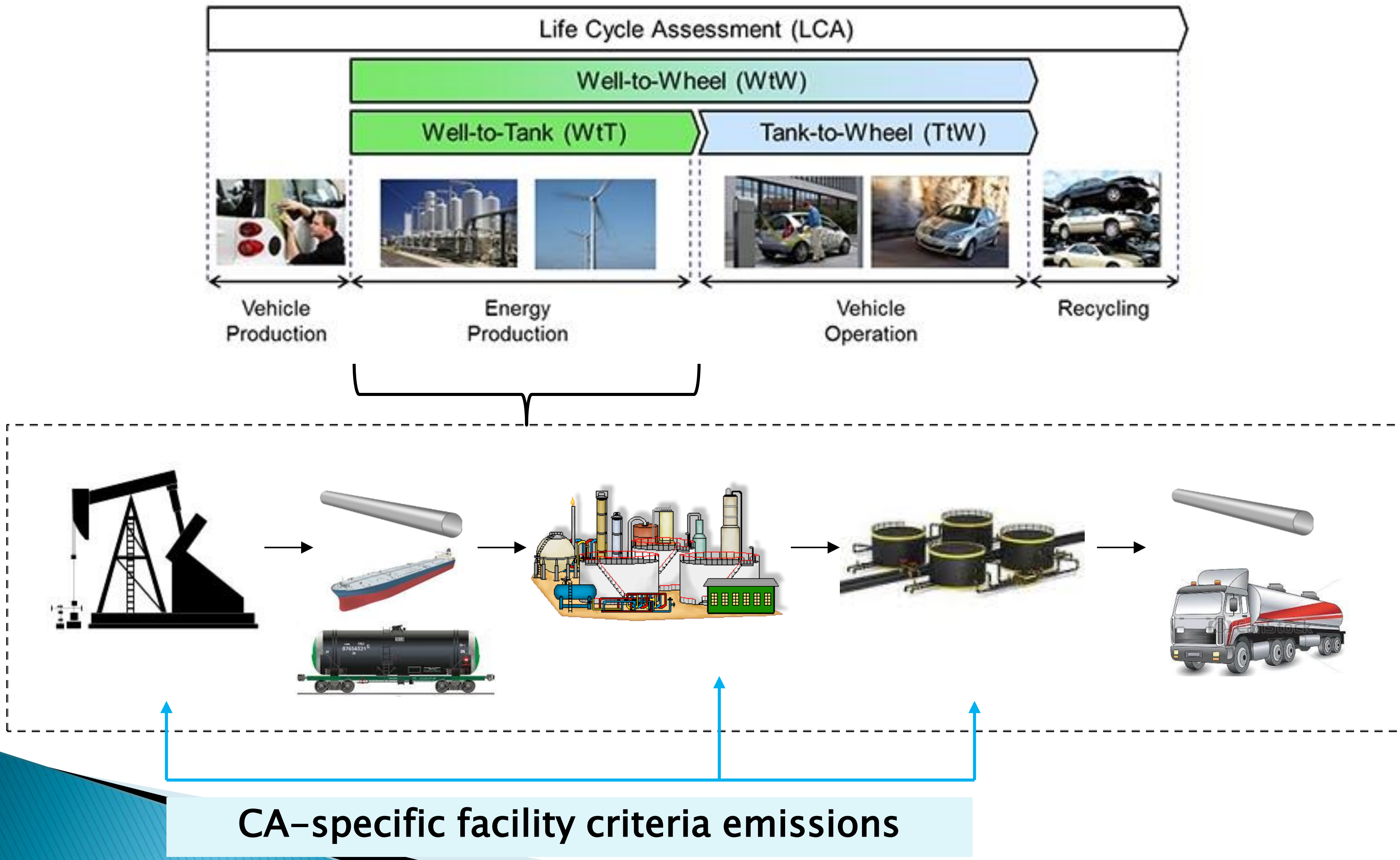
Criteria Emissions

- Develop new criteria emission factors for upstream fuel production (CA-specific)
  - Differences in global vs. in-state boundary
  - Post-2020 clean fuel assumptions (renewable electricity and hydrogen)

GHG Emissions

- Project post-2020 clean fuel combinations with LCFS pathways
  - Biofuel blending, renewable electricity & hydrogen

What is Well to Wheel?



WTW EFs: Methodology

Well to Tank Emission Factors

- Criteria pollutant EFs using:
  - CA-specific facility emissions
  - GREET 2013 national averages for non-facility processes
- GHG EFs using LCFS Carbon Intensities
  - Draft CI from August 22, 2014 LCFS workshop

Vehicle Characteristics

- Fuel efficiency/ consumption
- All vehicle efficiencies represent "new vehicle" performance

Tank to Wheel

- All vehicle criteria emissions represent "new vehicle" standards or targets
- GHG emission factors based on LCFS CI

WTT: Fuel Production Emission Factors

[grams/mmbtu, grams/gallon etc.]

(LCFS,GREET, ARB EI)

Vehicle Characteristics

[MPG, kWh/mi, miles/kg H2, gallon/bhp hr etc.]

(Staff analysis)

TTW: Vehicle Tailpipe Emission Factors

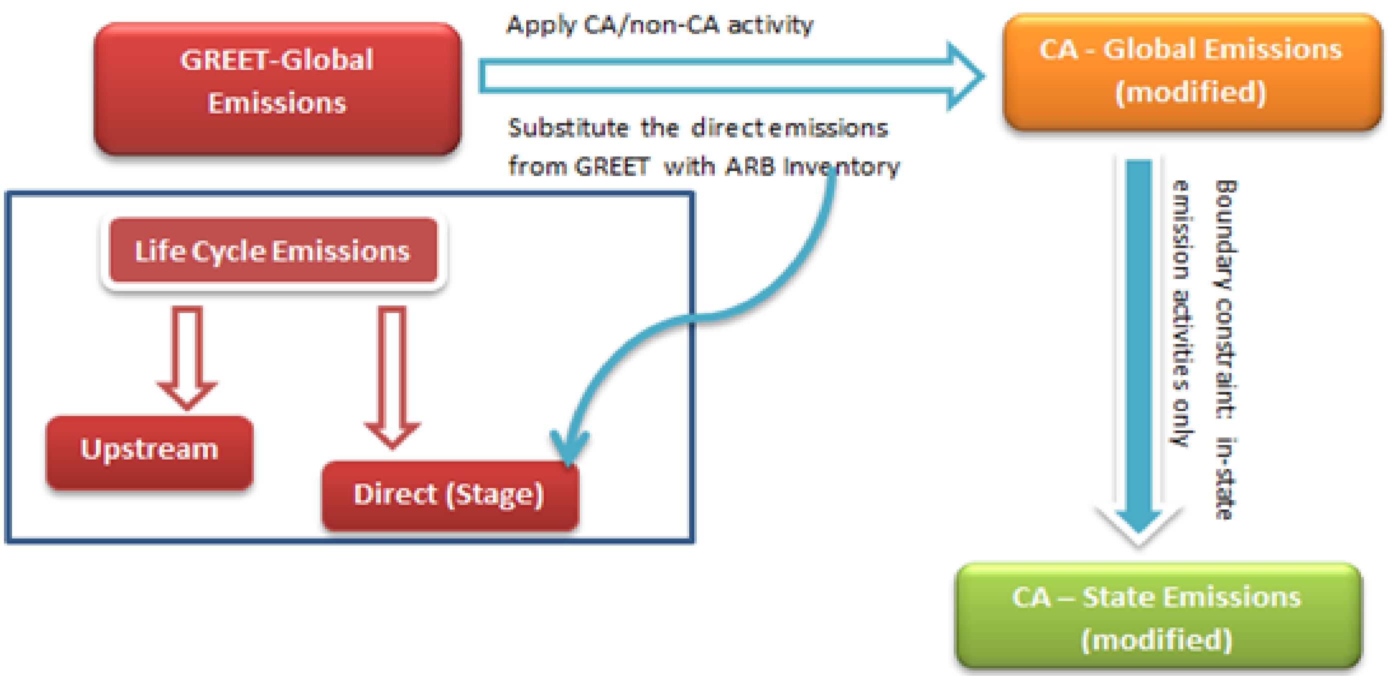
[grams/mi, grams/bhp hr etc.]

(LCFS, EMFAC, Staff analysis)

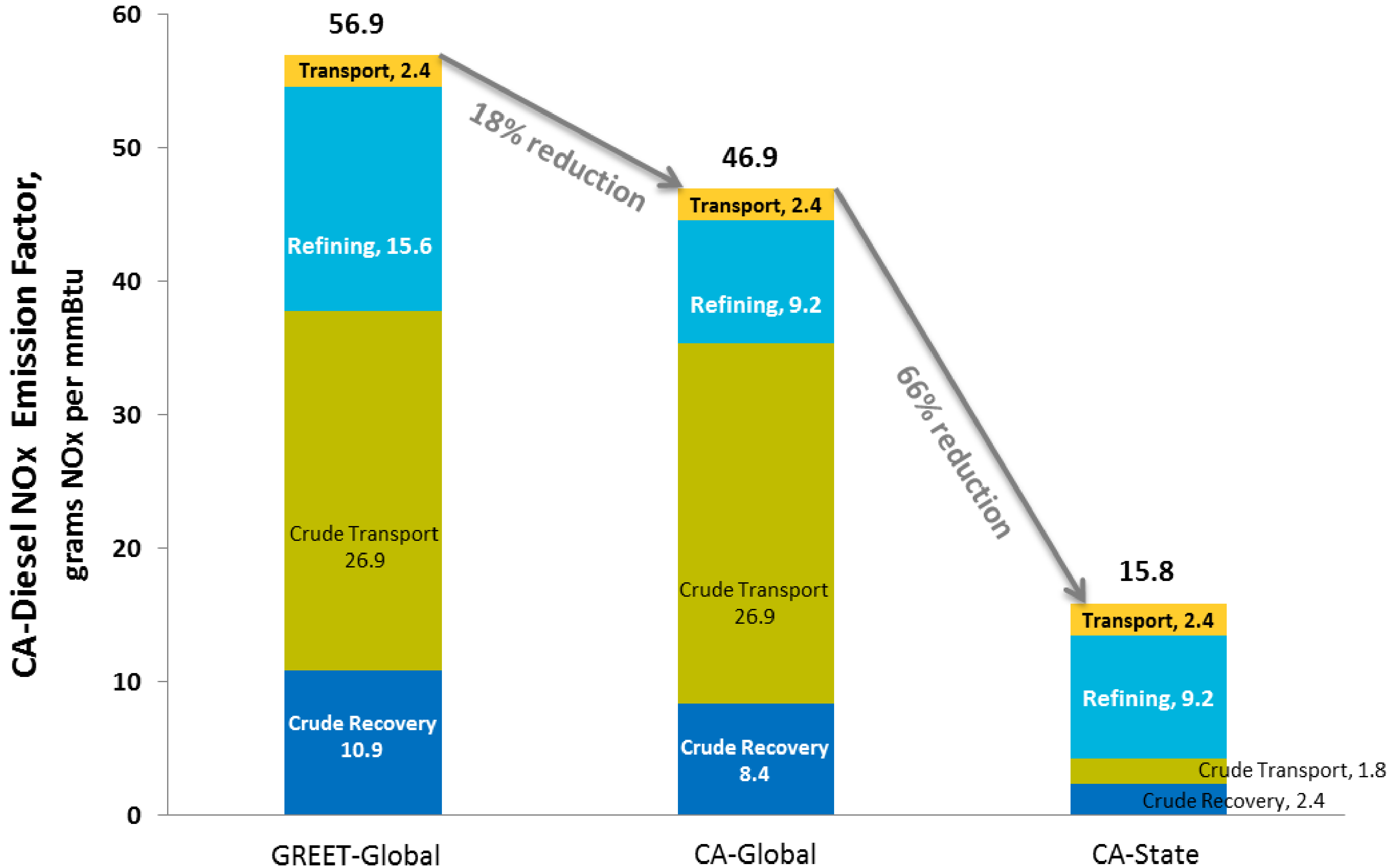
WTT Criteria EFs: Spatial Boundary Considerations

- **CA-Global:** Reflects CA-specific facility emissions
- **CA-State**: Constrained to in-state emissions

Methodology: Highly Simplified Schematic



WTT NOx Emission Factors: Spatial Boundary Effects

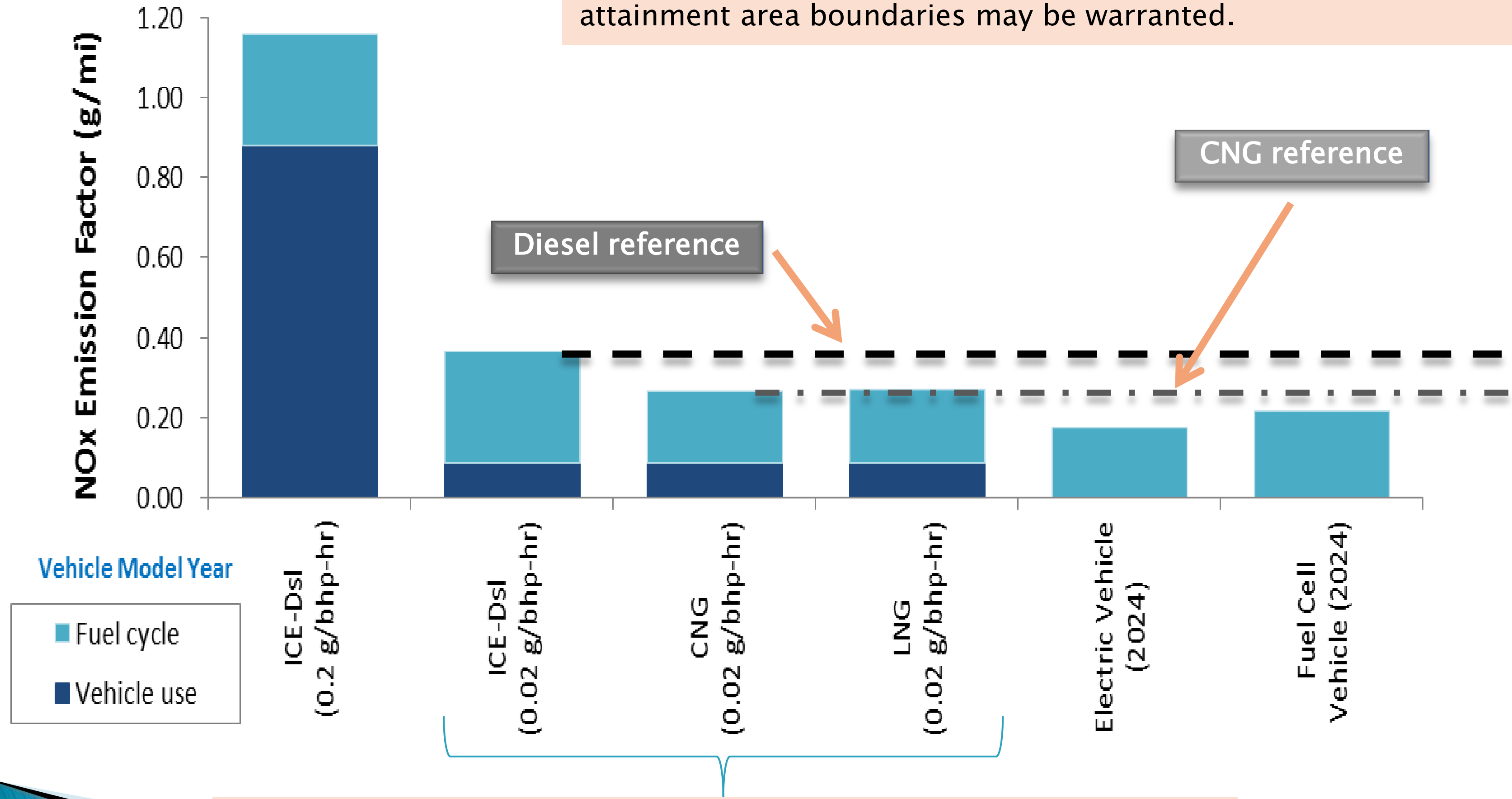


2020 Fuel Blend Assumptions

Gasoline, Diesel, NG (2020)	Assumes a mix of low-carbon biofuels to create an "LCFS Compliance" fuel Simulated with -10% CI value WTW (applied as a reduction on the WTT only)
Electricity (2020)	Electricity = LCFS "marginal" at 67% of mix + 33% renewables Assumes same ratio of in-state vs. import from today's grid
Hydrogen (2020)	Renewable onsite H2 from landfill gas (33% under SB1505) Central NG hydrogen delivered as liquid (50%) Onsite NG hydrogen delivered as gas (17%)
NG methane leakage	Argonne National Lab GREET 2013 leakage rate @ 1.27%

Well to Wheel: HHD Truck
NOx Emission Factors

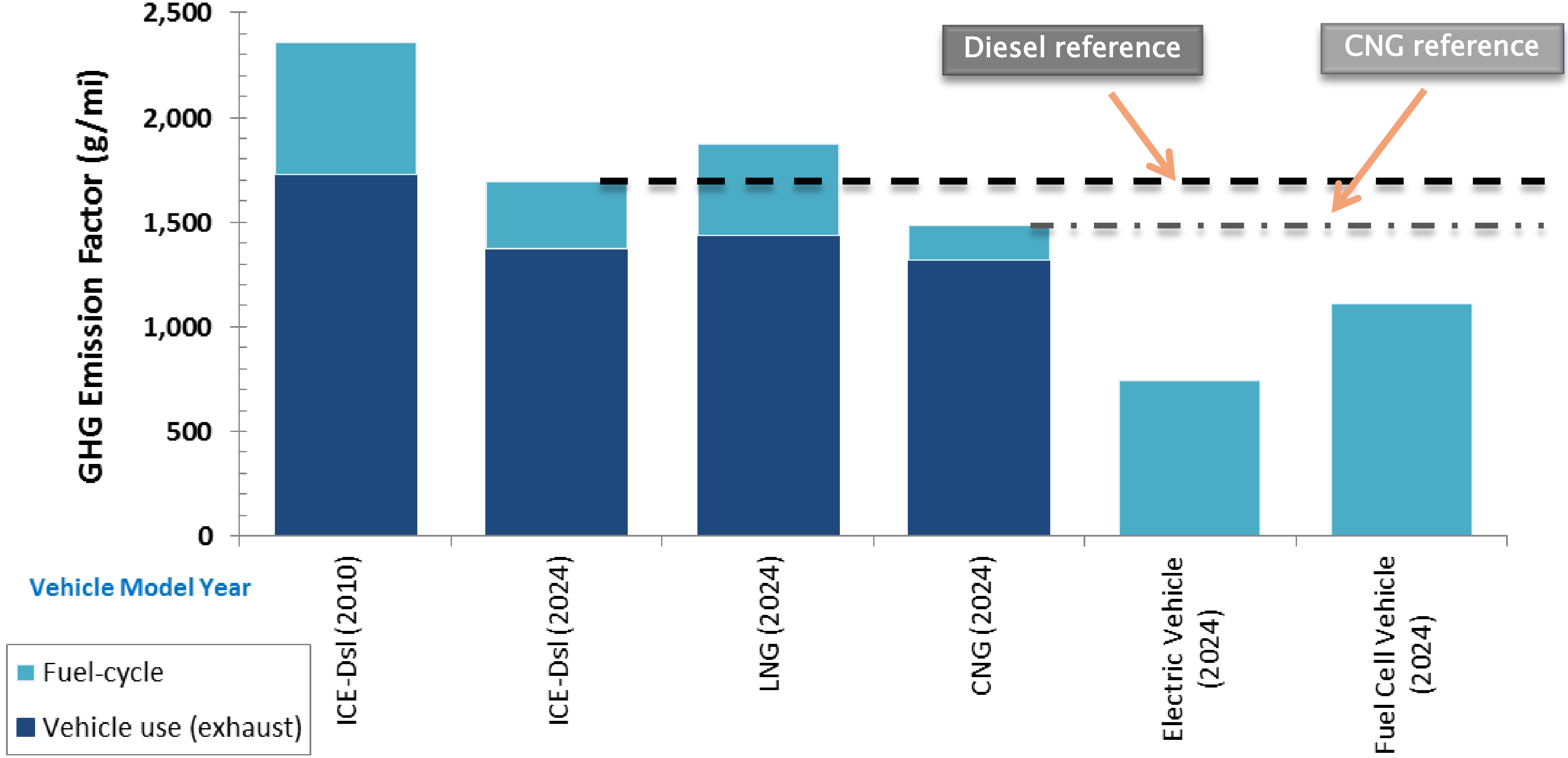
Note: Analysis presents state average criteria pollutant well-to-wheel emission factors at a state-level geography. Analysis at specific non-attainment area boundaries may be warranted.



TTW with engine certification 90% below 2010 standards

Well to Wheel: HHD Truck
GHG Emission Factors

Note: Analysis uses draft LCFS CA-GREET 2.0 carbon intensities and assumptions as presented during the August 22, 2014 workshop. Updates to LCFS pathways are ongoing.



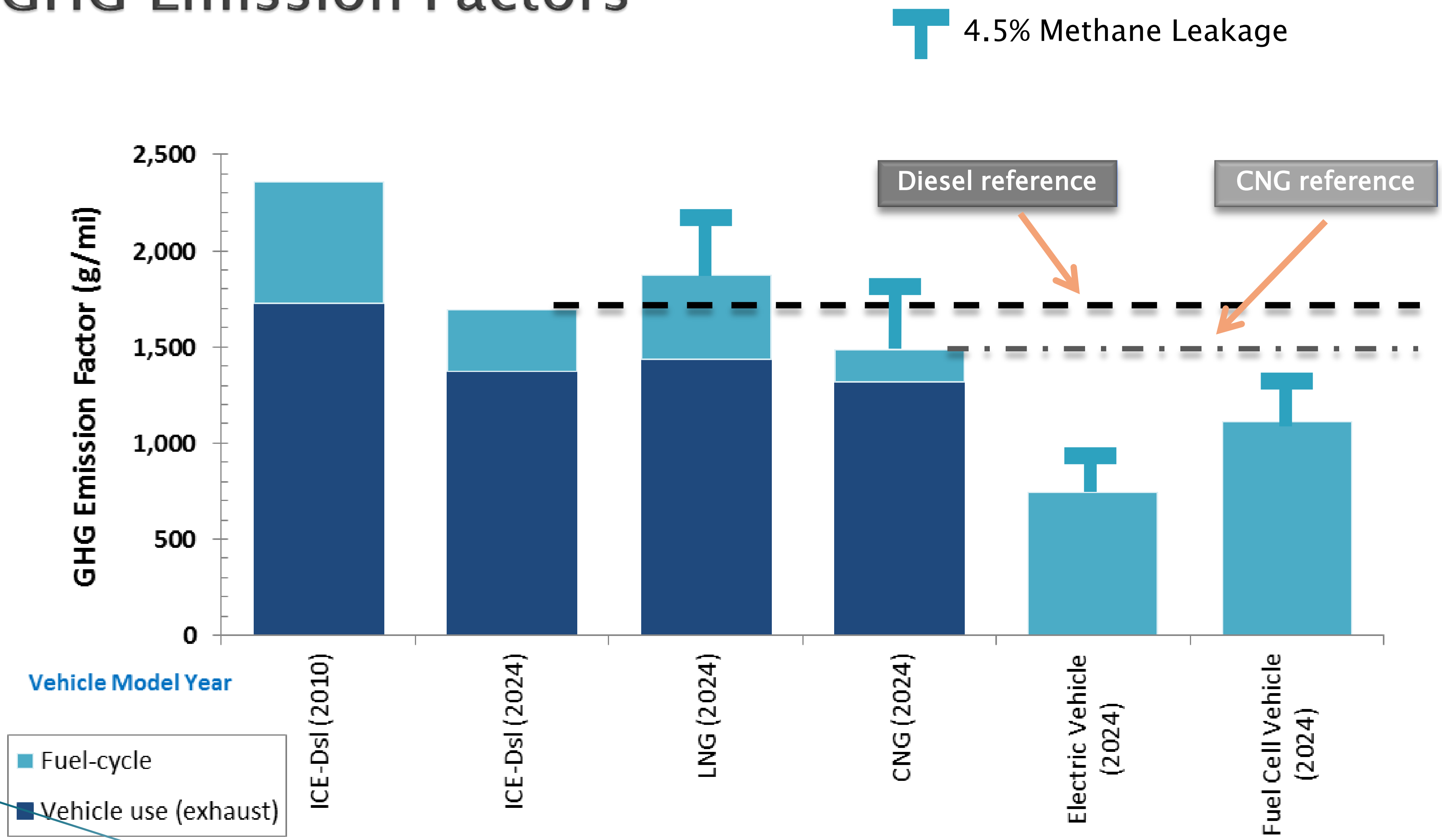
Key Observations

- Individual program decision on which WTW boundary is applicable
  - For example: “State” EFs for criteria emissions; “Global” EFs for GHG emissions
- WTW EFs lower for electric and FCVs vs. baseline
  - All sectors in GHG and criteria emission factors
- With cleaner HHD NOx engines, upstream criteria EFs becomes a significant fraction of full WTW
- Natural gas HHD trucks show NOx benefits compared to clean diesel trucks (both rated at 0.02 g NOx/bhp-hr)
  - Location of NOx reductions matter (non-attainment areas)
  - Tailpipe NOx emissions are equivalent for diesel and NG vehicles
- WTT EFs from hydrogen production higher than electricity
  - Energy demand for liquefaction and delivery
  - Larger portion of WTT NOx expected to be local for H2 vs. elec.

3. What is the impact of methane leakage from the natural gas system on established emission rates?

Well to Wheel: HHD Truck

GHG Emission Factors



* Analysis uses draft LCFS CA GREET 2.0 carbon intensities and assumptions as presented during the August 22, 2014 workshop. Updates to LCFS pathways are ongoing.

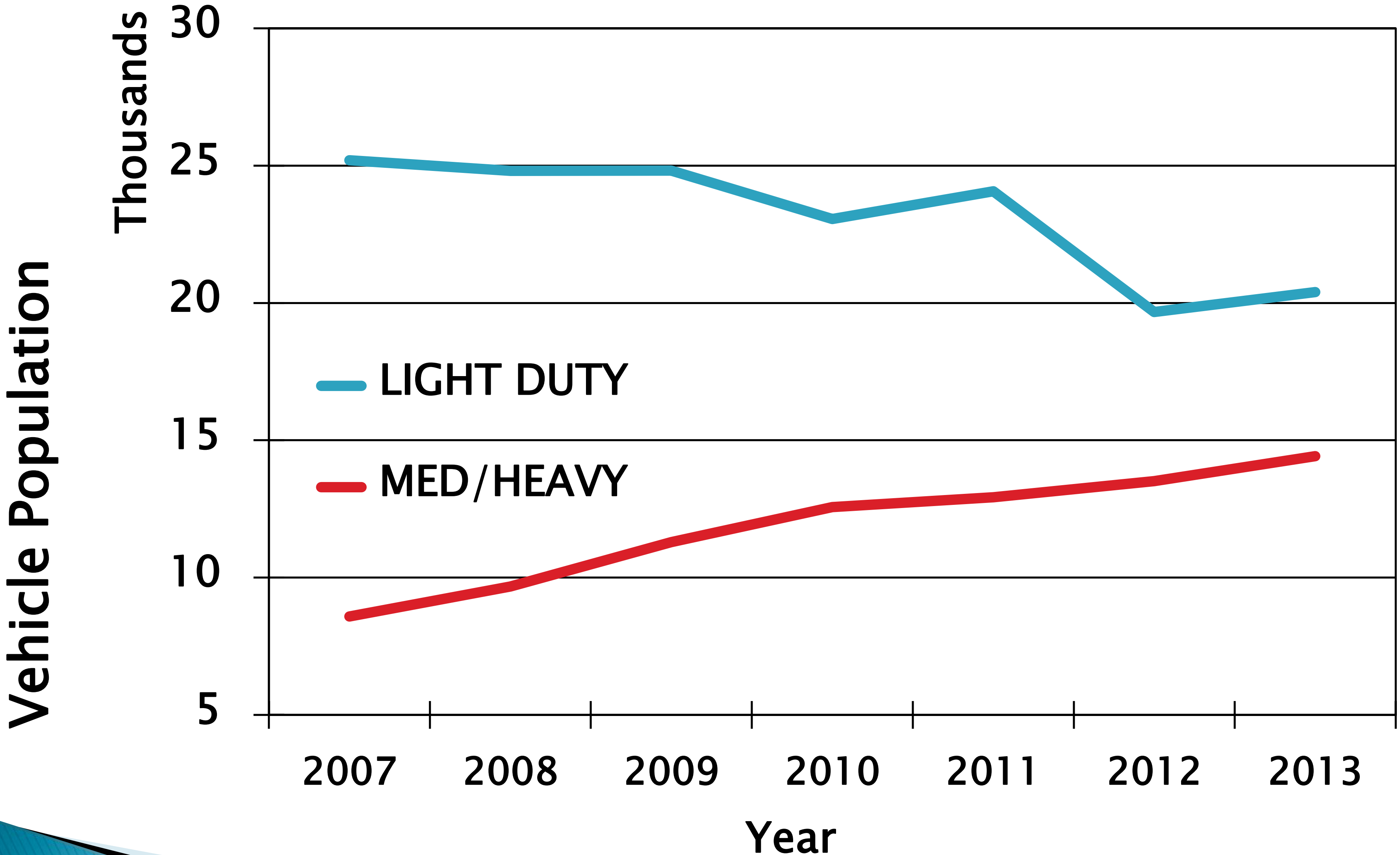
Outline

- Methane Leakage
- US Emissions, Studies, and Leakage Rates
- CA Emissions, Studies, and Leakage Rates
- Ongoing Studies
- Mitigation Ongoing and Potential
- Mitigation Strategies and Costs
- Summary and Next Steps
- Impact on Emission Rates

Methane Leakage

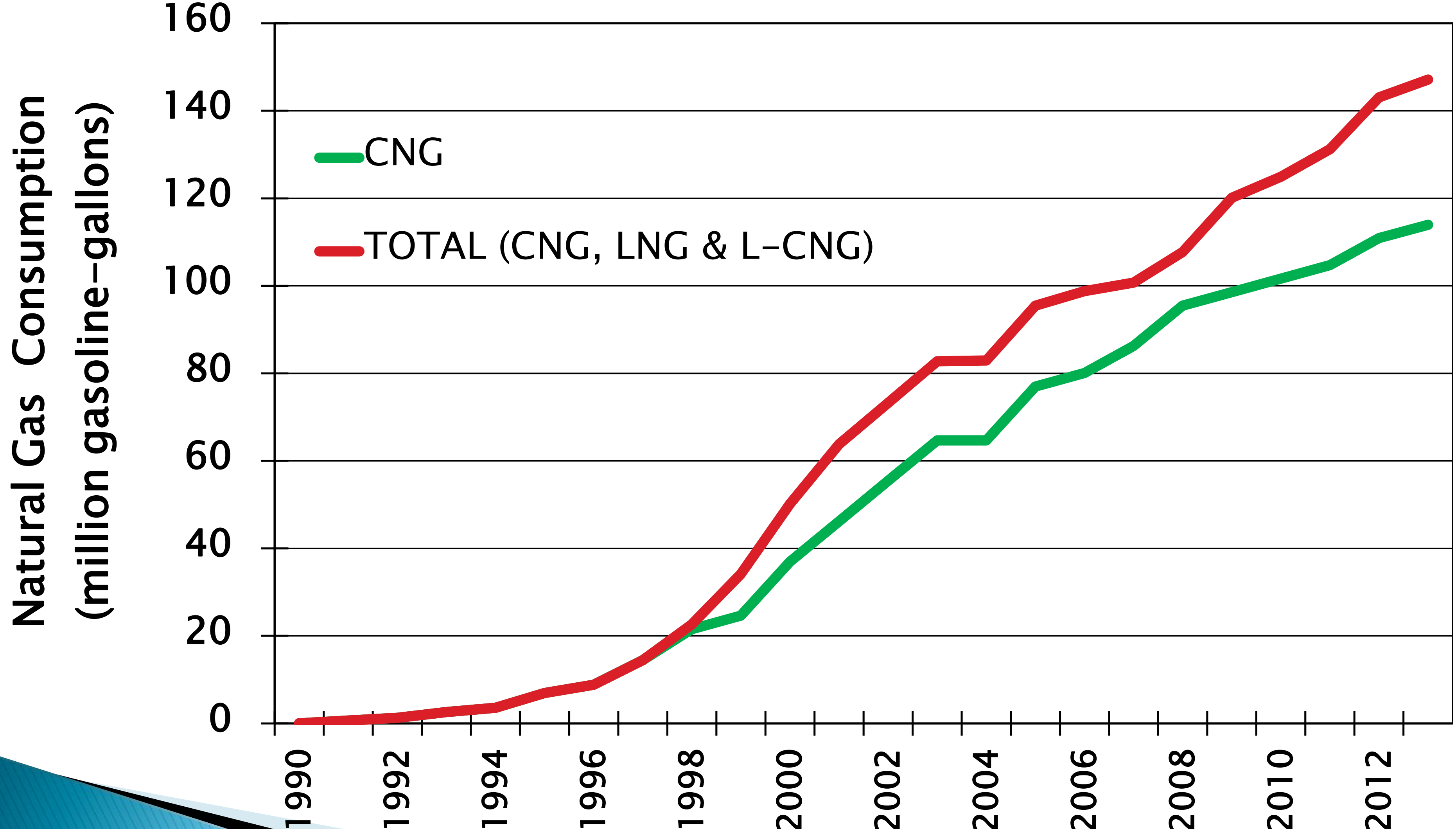
- WTW analysis considers all upstream activity as well as downstream activity
- Upstream activity includes methane leakage from the NG system – from production through distribution
- This discussion summarizes the recent studies on methane leakage and mitigation measures

Natural Gas Vehicle Trends

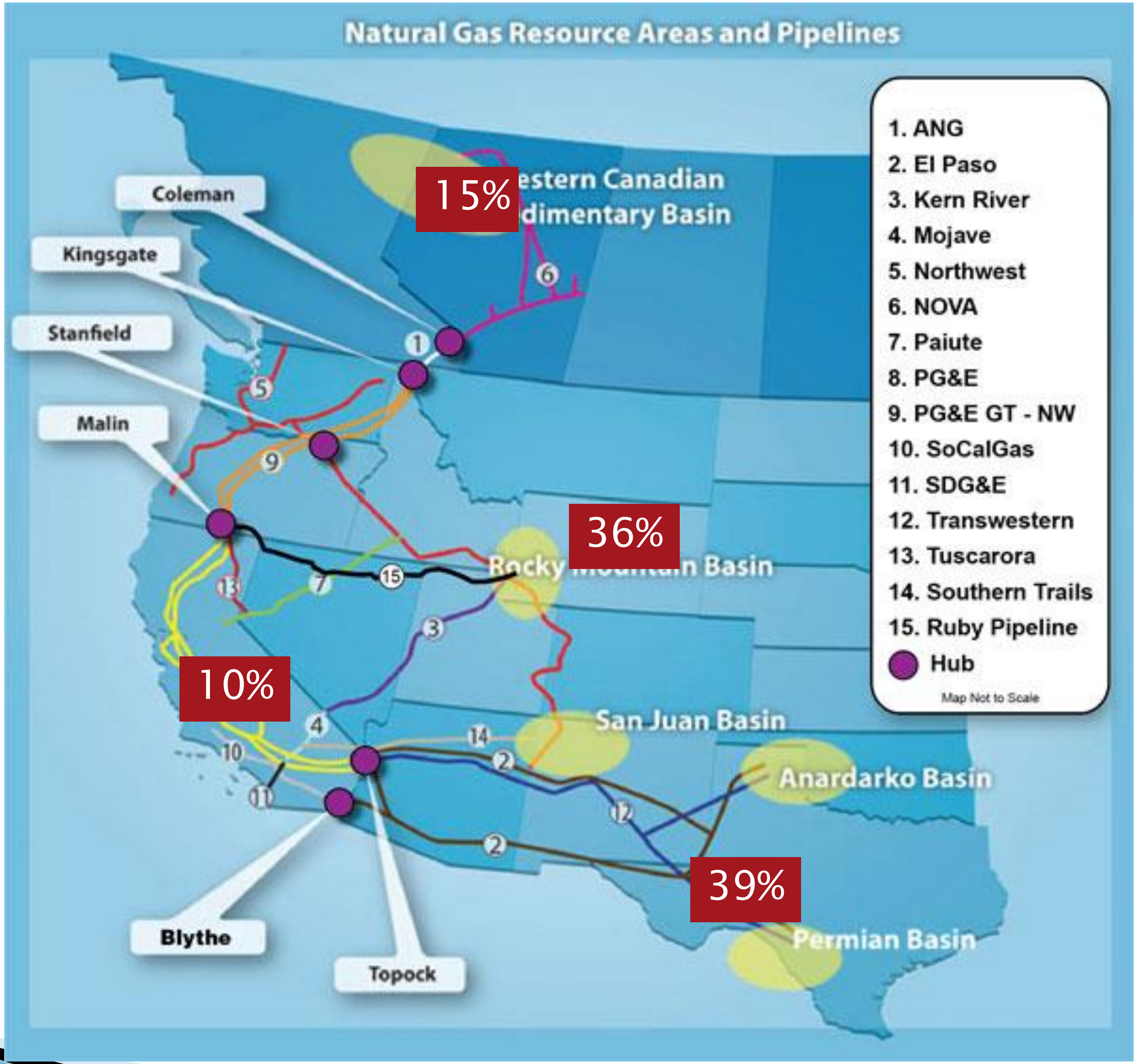


Source: CEC, Energy Analysis Office, July 2014

Natural Gas Usage in Vehicles



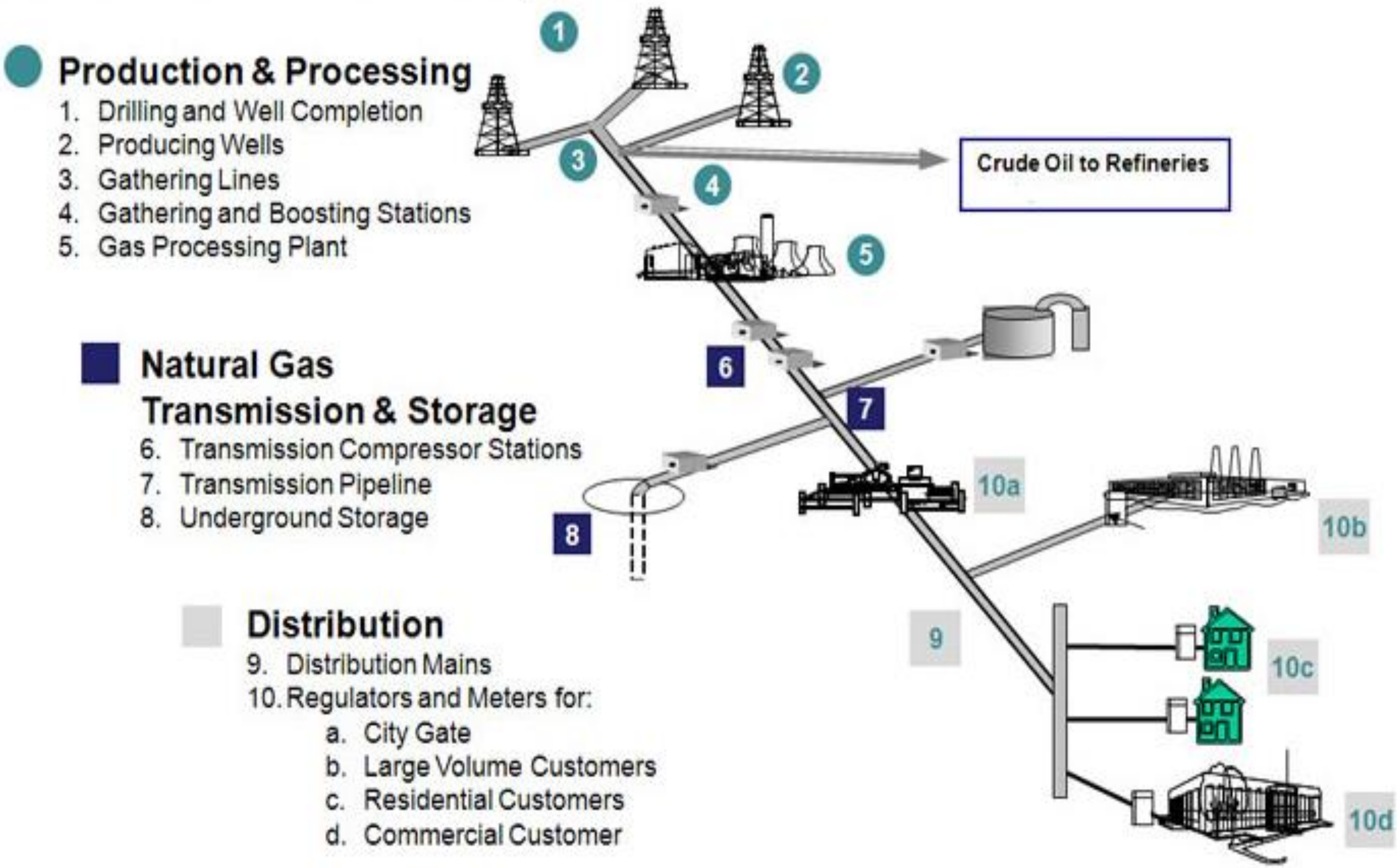
Source: CEC, Energy Analysis Office, July 2014



Source: CEC, Energy Almanac, 2014

Natural Gas Infrastructure

Natural gas systems encompass wells, gas gathering and processing facilities, storage, and transmission and distribution pipelines.

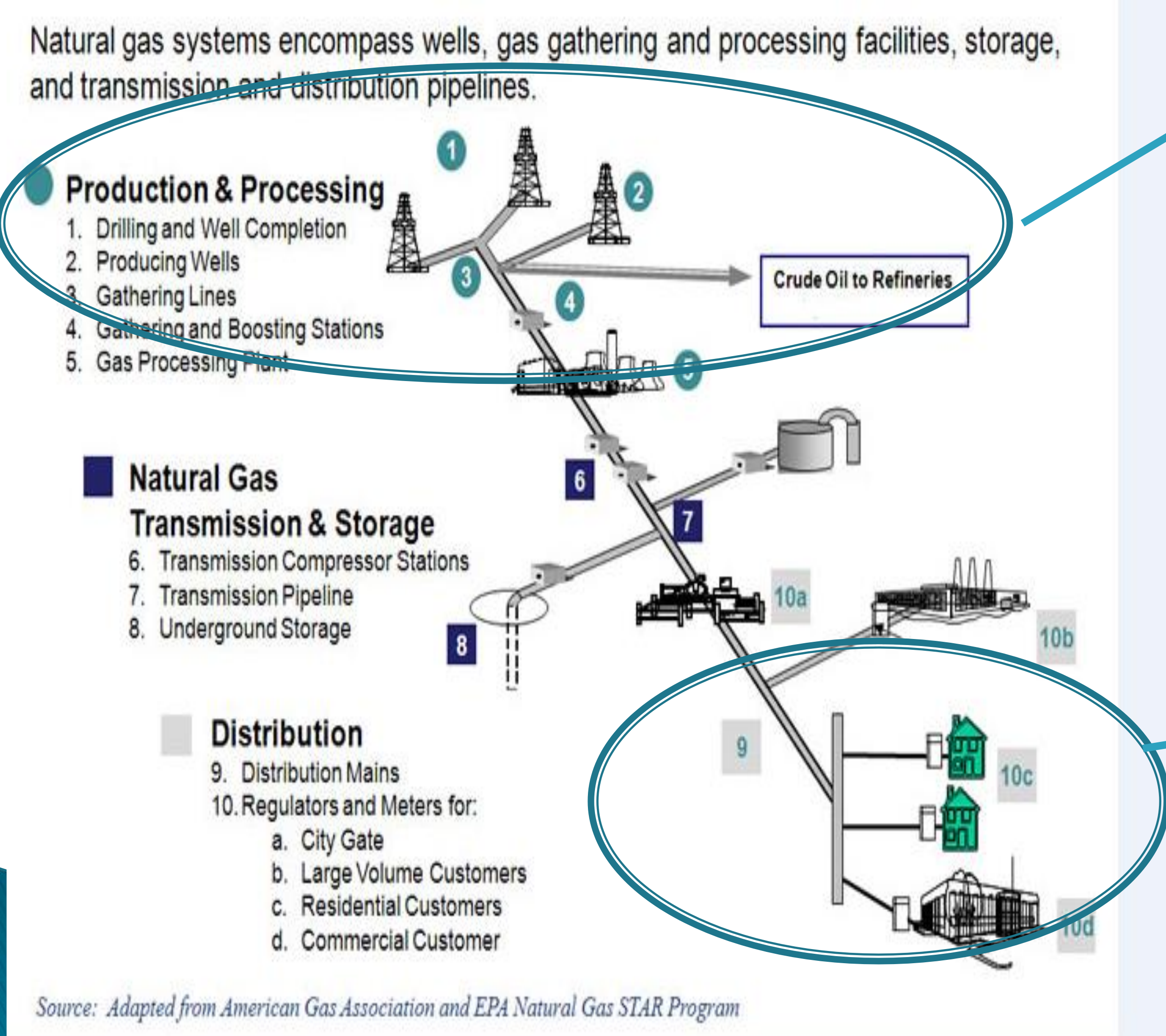


Source: Adapted from American Gas Association and EPA Natural Gas STAR Program

Calculating Leakage

- What is considered leakage?
  - Emissions from fugitives and venting
  - Methane related to combustion treated differently across studies
- How is leakage measured?
  - Estimate vented and fugitive methane emissions
    - Ambient measurements or inventory development
  - Divide emissions by a metric
    - Methane production or throughput (total or by stage),
    - NG production or throughput (total or by stage)
  - Different studies use different metrics
- **No standardization of methodology**

Attribution and Calculation Issues



NG produced with oil – how to attribute "leakage" emissions?

Are NG fueling stations close to transmission lines? If so, how should distribution leakage be treated?

Emissions Estimation Methods

- Inventory methods
  - Sum of emissions from individual sources
  - More disaggregated data is better. Example of Hierarchy
    1. Continuous source level measurements
    2. Population counts * emission factor
    3. NG production * emission factor
  - Generally: Activity Data *Emission Factor
- Ambient measurement studies
  - Depend on other assumptions
  - Limitations and uncertainties in source attribution
    - Model Inputs
    - Natural Sources

U.S Emissions, Studies, and Leakage Rates

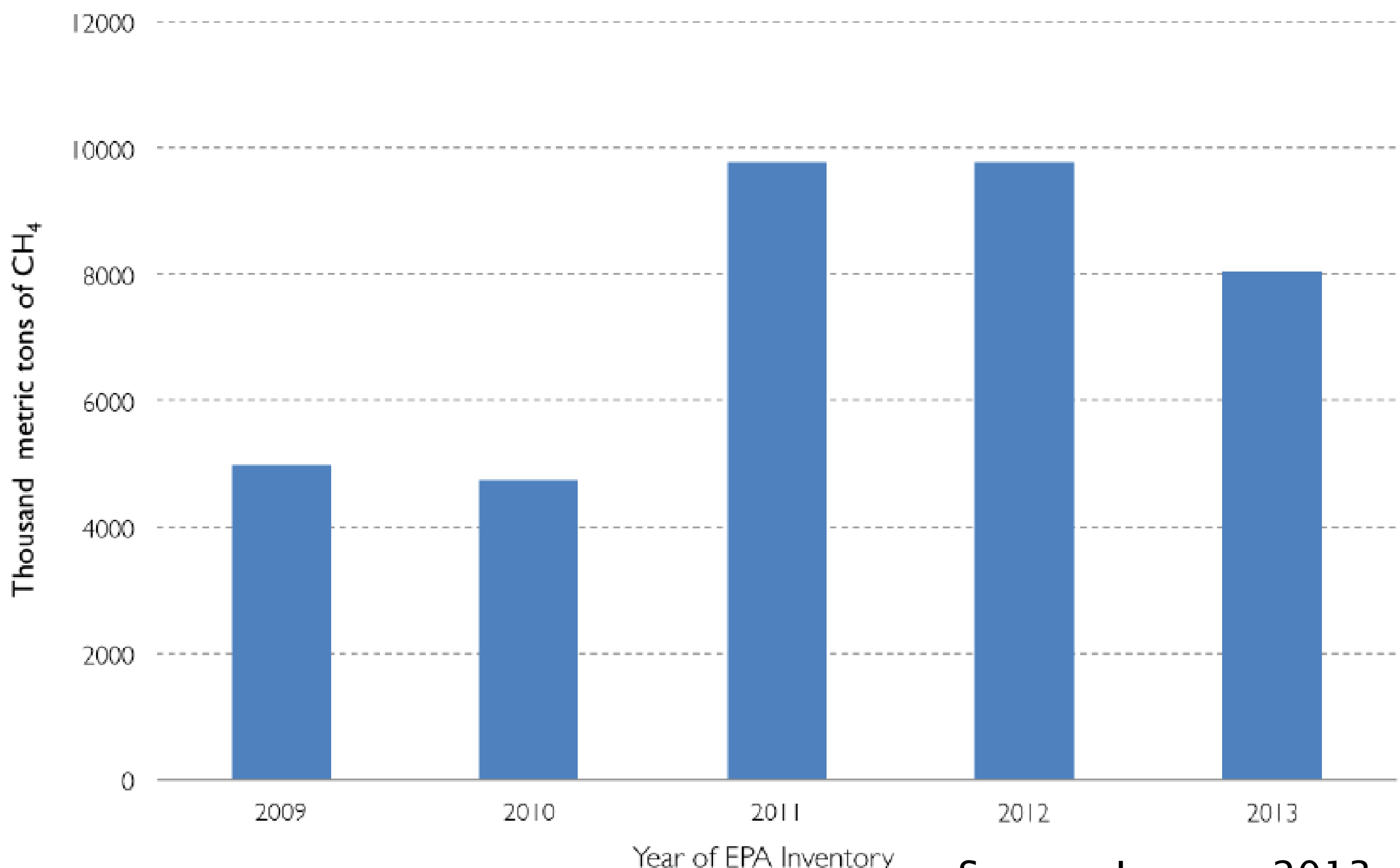
USEPA Inventory of GHG for Natural Gas Systems

	2011 CH_4 Emissions (Gg) (EPA 2013)	Percent Leakage (CH_4 emissions/ CH_4 withdrawn)	2012 CH_4 Emissions (Gg) (EPA 2014)	Percent Leakage (CH_4 emissions/ CH_4 withdrawn)
Field Production	2545	0.55%	1992	0.42%
Processing	932	0.20%	892	0.19%
Transmission & Storage	2087	0.45%	2071	0.44%
Distribution	1329	0.29%	1231	0.26%
Total	6893	**1.50%**	6186	**1.31%**

*Note: The national inventory does not include end use losses

(Source: USEPA GHG 3 and 2014 and EIA, Natural Gas Summary downloaded 05/30/2014)

Uncertainty in Emissions – EPA estimates for 2007 over 5 Inventories



Source: Larson, 2013

Comparison of EPA Leak Rates using Different Methods – 2011 Emissions

	CH_4 Emissions/NG throughput by stage (%)			NG emissions/ NG throughput by stage (%)	CH_4 emissions/ CH_4 withdrawn	NG Emissions/ NG total through-put (end-use)
		GREET 2013 Shale				
	0.34	0.58	0.49			
	0.18	0.18	0.18	0.34	0.20	0.25
Distribution						

Note that leakage rates calculated by stage throughput are not additive
GREET 2013 is being proposed to be used for LCFS

EPA Leak Rates using Different Methods- Brandt 2014

EPA 2011 NG Emissions	0.405 TCF Natural Gas 6893 Gg Methane
Volumetric Leakage Rate	
% of end-use plus net storage	1.78% TCF/TCF
% of gross withdrawals	1.42% TCF/TCF
Mass-based Leakage Rate	
% of gross CH4 withdrawals	1.50% Gg/Gg

Methodological Implications

- Leakage rates are difficult to compare
  - No standardization

- Can get more than 3 different rates with the same emissions data depending on your methodology

- Emission estimates have changed over the last few years at the national level so rate uncertain

Methane Leakage Studies

- Multi paper analyses
- Very recent studies
- CA studies

Weber and Clavin Study, 2012

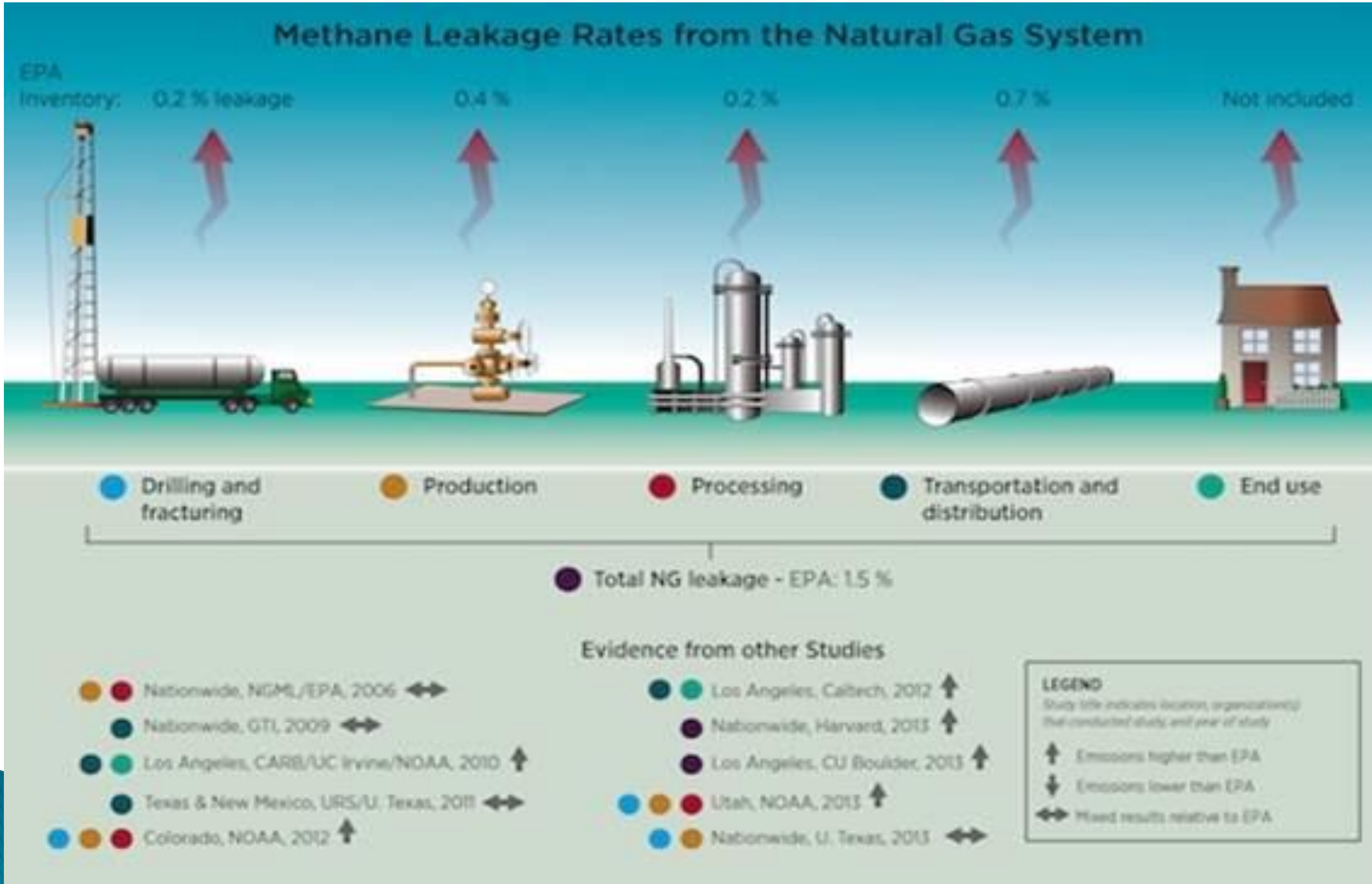
National Upstream Methane Leakage (% CH_4 withdrawals)
Excluding Distribution System

	Jiang		NETL		Hultman	Stephenson		Burnham		Howarth		Best		EPA
	Conv	Shale	Conv	Shale	Shale	Conv	Shale	Conv	Shale	Conv	Shale	Conv	Shale	All
	Methane leakage (percentage of methane production)													
Production	1.2	1.0	1.7	1.5	2.2	0.3	0.6	2.2	1.3	1.1	3.0	1.4	1.1	1.37
Processing	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.4	0.4	0.19
Transmission	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.2	1.4	1.4	0.4	0.4	0.48
TOTAL	**1.9**	**1.7**	**2.4**	**2.2**	**2.7**	**0.7**	**1.0**	**2.5**	**1.7**	**2.6**	**4.5**	**2.1**	**1.9**	**2.02**

–Academic studies were published in 2011
–EPA based on 2012 GHG Inventory for year 2010
–Adapted by Larson from Weber and Clavin data, 2013

(Source: Larson, Climate Central, 2013)

Leakage Summary, Brandt 2014



Brandt et al, 2014

	Author	Source	Study Region	Emissions Normalized to GHGI (g/g)
*	Miller et al. (2013)	All sources	National	1.5
	Miller et al. (2013)	NG+ Petrol	South Central US, Oil & Gas	1.5
	Miller et al. (2013)	All sources	South Central US	1.8
*	Kort et al. (2008)	All sources	US and Canada	1.5
*	Katzenstein et al. (2003)	All sources	South Central US	2.0
	Wang et al. (2004)	Energy	National	1.6
*	Xiao et al. (2008)	Energy	National	1.3
	Petron et al. (2012)	NG+ Petrol	Denver-Julesberg Basin	2.9
	Levi et al. (2012)	NG+ Petrol	Denver-Julesberg Basin	1.2
	Hsu et al. (2010)	urban CH4 fluxes	LA County	0.8
	Wunch et al. (2009)	All sources	SoCAB	1.6
	Wunch et al. (2009)	All sources	SoCAB	1.1
	Wennberg et al. (2012)	All sources	SoCAB	1.2
	Peischl et al. (2013)	NG + Petrol	SoCAB	1.8
	Peischl et al. (2013)	All sources	SoCAB	1.2
	Karion et al. (2013)	NG operations	Uintah Basin, UT	6.8

* Were used to estimate national number

Brandt concluded measurements were 1.25-1.75 X EPA GHGI

Brandt et al, 2014

- Translates to a national leakage rate of 1.87 – 2.62%
- Excess leakage above EPA GHGI not attributed entirely to NG sources and infrastructure
  - Any other CH_4 sources in EPA GHGI could be underestimated (e.g. landfills, livestock, etc.)
  - Could also include sources not estimated (e.g. seepage and abandoned wells)
- Concluded high leakage rates in recent studies are unlikely to be representative
- Hydraulic fracturing not a significant source of methane leakage

Very Recent Academic Studies

Study	Source	Leakage Rate
Allen et al (Aug 2013)	Well drilling	0.53% of gross methane production
Petron et al (June 2014)	NG + Petroleum Denver-Julesburg Basin, CO	4% of gross methane production
Caulton et al, (Mar 2014)	Marcellus shale formation	2.8-17.3% of gross methane production

California Emissions, Studies and Leakage Rates

CA Emissions Development

- Surveys conducted for year 2007 covering production, transmission, and distribution
  - Production survey
    - Covered 97% of production
    - Final report Oct 2013
  - Transmission and Distribution Survey
    - Mailed survey to over 20 natural gas companies
    - Survey focused on fugitive emissions
    - 100% response
- Survey results: Emissions are 5.2 $MMTCO_2E$
- Work ongoing to incorporate survey into ARB GHG inventory estimates
    - Current GHG inventory estimates are approximately 2.4 MMTCO2E

Considerations for California Leakage Rate

- Approximately 75% of NG production occurs with petroleum production (Associated Gas)

- How do you apportion methane emissions between NG and Oil production when co-occur?
  - Energy Content?
  - Mass or volume of production based?
  - All to NG?
  - This can change leakage rate for NG significantly

- WTW leakage rate vs. within-CA leakage rate

CH_4 Emissions and Leakage Rate from CA NG System – Throughput based

Source , California 2007	CH4 Emissions (BCF)	Leakage based on NG throughput (%)
Production and Processing	2.7	0.12
Transmission and storage	1.1	0.05
Distribution	7	0.33
		0.5

- Leakage rate for CA system ONLY (emissions occurring within CA)
- NG Throughput = 2200 BCF of methane moved through CA pipelines
- NG Production = 323 BCF of methane
- Production rate may be underestimated when divided by all NG through-put
- WTW would include production outside CA

CH_4 Emissions and Leakage Rate from CA NG System – Production-Based for Production Stage only

Source , California 2007	CH4 Emissions (BCF)	Leakage % (All emissions to NG)	Leakage % (Dry gas emissions only)
	2.5		
– Associated Gas			

Assumptions: NG Production = 323 BCF of methane, Dry Gas Production = 94 BCF of methane, Associated Gas Production= 229 BCF of methane. Production includes on-site use (ARB, 2013)

- In-between method to allocate based on equipment and energy content under consideration (CEC, 2014)
- WTW leakage rate would incorporate production outside CA

CA Emissions from Ambient Measurements

- Convert ambient measurements of total methane concentration to emissions
- Determine source attribution
- Can be achieved using multiple methods and data
  - Inverse modeling, correlations, use of co-pollutant ratios (ethane/propane/methane)
- Conversion of ambient concentrations of total methane to oil and gas emissions have inherent uncertainties
  - Correlations
  - Inventory inputs
  - Model uncertainties
  - Inability to distinguish between natural seeps, abandoned wells, venting, fugitives, and uncombusted methane

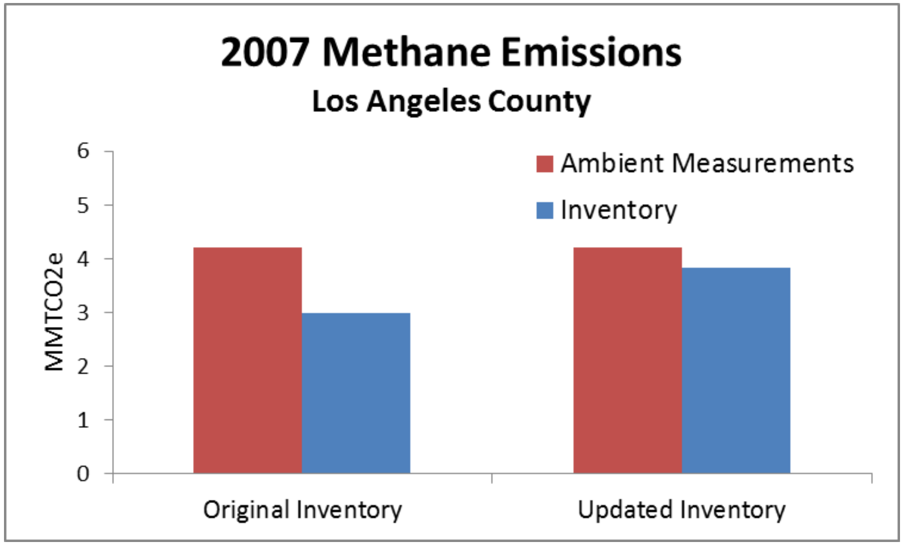
Academic Studies

Study	Source	Leak Rate
Jeong et al (2014)	Associated production, all processing, storage	5.3+/−1.1% of gas produced
	Associated production only	4.7% of gas produced
	Dry gas production only	1.8% of gas produced
Peischl et al (2013)	SoCAB production fields	17% of unprocessed NG/ local production
	Pipeline quality gas, SoCAB	0.7% of gas flowing into basin
Wennberg et al (2012)	SoCAB, distribution	2% of gas flowing into basin

Notes: Jeong relies on Peischl leak rate,
ARB has updated regional inventory and production in Peischl and Wennberg

Uncertainties of CA Atmospheric Studies

- Limited number of studies
- Studies generally focused on Southern California or rely on Southern California measurements
- Source Apportionment
  - Particularly natural seeps in LA area
- Updated Inventory Comparison for Regional Estimates
- Updated Regional Production



Summary of U.S. and State Leakage Rates

- Range of national leakage rates based on multi-study analysis
  - 0.7 to 2.5% (excluding Howarth), Howarth: 2.6-4.5%

- Range of California (including regional) leakage rates
  - State-wide: 0.5 to 5.3% (two emissions estimates)
  - Regional: varies and includes a rate of 17% for production in LA
  - California studies difficult to compare
    - Few estimates, varying boundaries, and generally Southern CA based
    - Updated knowledge on regional inventories and production
  - Analysis focused on statewide estimates, using updated knowledge and detailed activity data point to a estimate at or below 1%
    - Oil district VOC rules and limited cast iron pipelines
  - Emissions still important and can be reduced cost-effectively

- LCFS proposing GREET 2013 with associated leakage rates

Ongoing Studies

Ongoing Studies

- CEC has 4 studies to look at leakage from the infrastructure and from the home
- EDF has 16 studies related to CH_4 leakage across the supply chain with results by the end of 2014
- GTI national study to measure leaks from distribution pipelines
  - ARB is supplementing the study with CA specific measurements

Ongoing Studies

- ARB:
  - Tower measurements throughout the state
  - Mobile measurements and flux chambers to study source specific emissions
- UC Irvine: studying leaks from pipelines, power plants, and CNG stations in Southern CA
- LBNL: ARB-funded studies for atmospheric measurements and inverse modeling to study and evaluate inventory sources
- JPL: Flight measurements and remote sensing techniques to study regional emissions and quantify specific significant sources of methane
- Megacities project will monitor GHG emissions from cities
  - ARB participation including measurement support
- Picarro surveyor increased use including by gas companies

Summary of Leakage Estimates

- Inventory estimate of methane emissions from fugitives and venting is improving annually
- Current multi-study national analysis indicate most studies within a range of 1-3% nationally
- CA estimates more limited and regional
- Analysis focused on statewide estimates and using updated knowledge on production and detailed activity data point to a estimate at or below 1%
- Significant number of ongoing studies will improve estimates even more including ARB study on pipelines
- Next steps will include in-depth analysis of studies and incorporating ongoing work

Mitigation Ongoing and Potential

Existing Federal and State Efforts on Fugitives, Venting, and Flaring

- Federal:
  - New Source Performance Standards and National Emissions Standards for Hazardous Air Pollutants
  - Voluntary Programs (Natural Gas STAR)
- California:
  - District air quality rules
  - PUC and Utility Safety Plans
- Other state rules: Colorado, North Dakota, Ohio, Pennsylvania, Texas, and Wyoming

Planned and Potential Additional Efforts: National Rulemakings

- National Climate Action Plan directed the Administration to develop a comprehensive, interagency strategy to cut methane emissions
  - Six white papers on different oil and gas emission sources
  - Reduce venting and flaring on public lands

- Executive Actions on Methane from Natural Gas Systems

Planned and Potential Additional Efforts: California – ARB

- Short Lived Climate Pollutant Strategy

- Regulation on Oil & Gas Production, Processing, and Storage (State-wide) considering:
  - Control technologies
  - Leak Detection and Repair

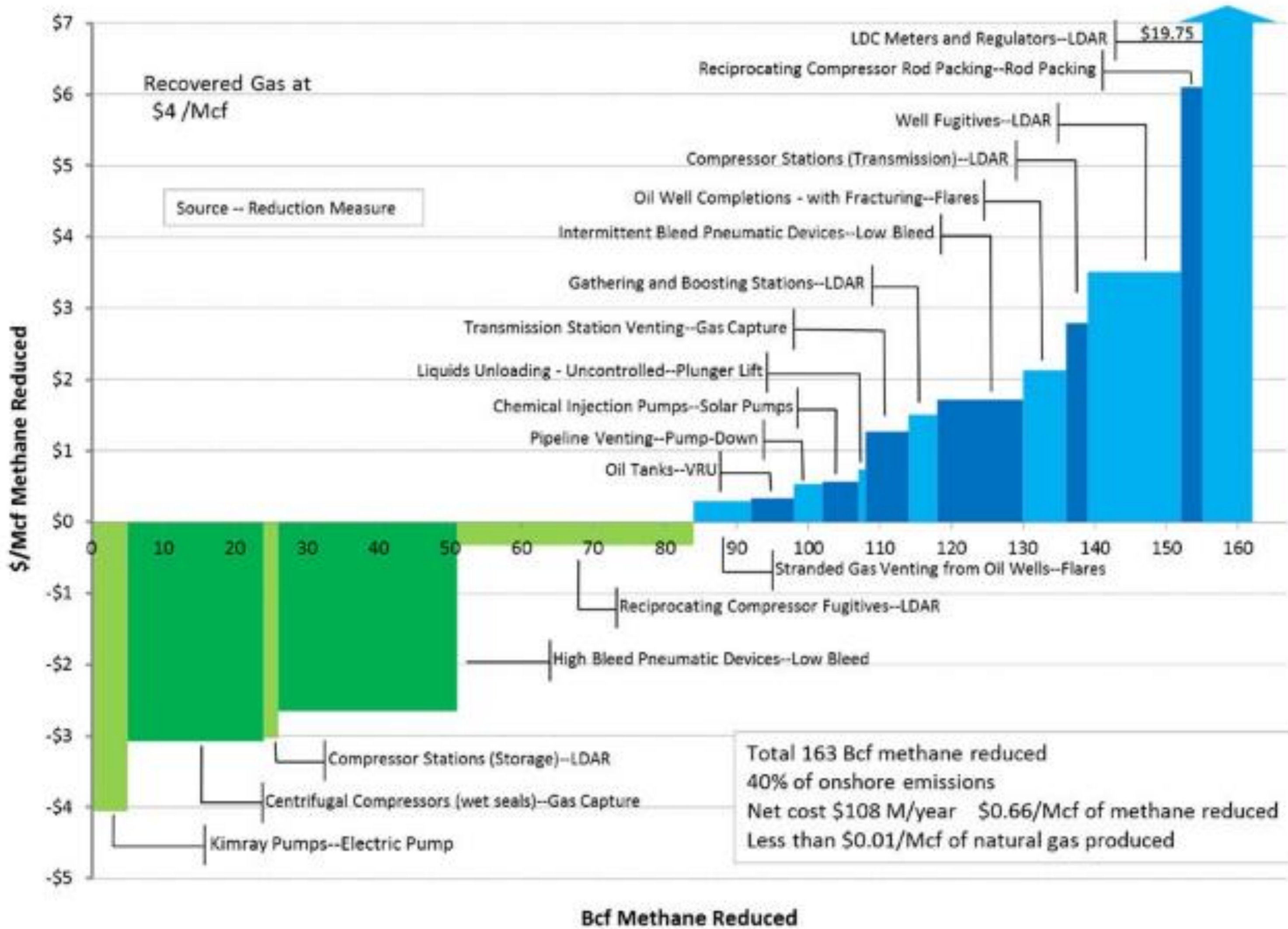
- Consideration of a measure for pipelines and associated facilities

Planned and Potential Additional Efforts: California

- California Public Utilities Commission (CPUC)
- California Energy Commission – AB 1257
- New Legislation SB 1371 – GHG and safety in pipeline repairs

Mitigation Strategies and Costs

Mitigation Cost Analysis: National Aggregate MAC Curve for Baseline Technology Assumptions (ICF, 2014)



Source: Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries

California Mitigation

- In key oil production regions, VOC rules have had the co-benefit of reducing methane emissions
  - e.g. many storage tanks have VRUs
- Pipelines
  - not much cast iron in state, some being replaced
- Additional cost-effective mitigation options still available
- Current rule making aimed at state-wide standards that will reduce the leakage rate

Summary

- Uncertainties in leakage rates
- Leakage rates estimates cluster around 1-3% nationally with some larger estimates
- Understanding is improving and will improve even more in the next few years
- Cost-effective ways to reduce emissions
- California:
  - In key oil production regions, VOC rules have reduced methane emissions as a co-benefit
  - ARB is undertaking a regulation for state-wide reductions
- National, regional, and state efforts to understand and reduce leakage underway

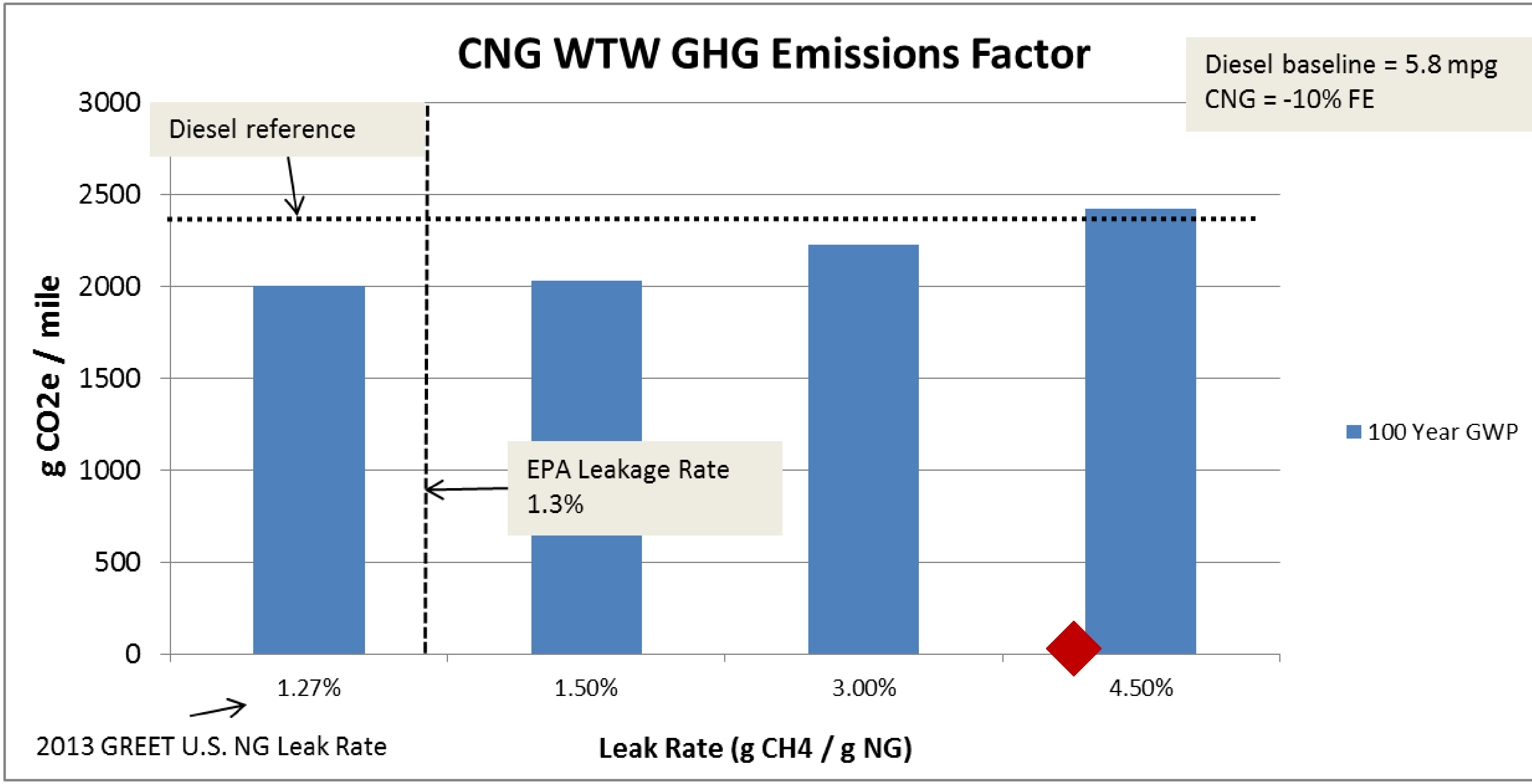
Impact on Emission Rates

Methane Leakage WTW Sensitivity

- Using LCFS NG pathway analysis
  - Default leak rate = 1.27% (Argonne GREET 2013)
  - Draft LCFS CA GREET 2 (8-22-2014 workshop)
- Scale up leak rate within LCFS methodology
- Translate LCFS gCO2e/MJ into gCO2e/mile
  - Uses vehicle fuel efficiency (e.g. MPG or MJ/mi)
  - NG truck 10% lower efficiency than diesel (LCFS)
- Utilizing IPCC AR4 100-year GWP of 25

Break-even Point: CNG in HHD

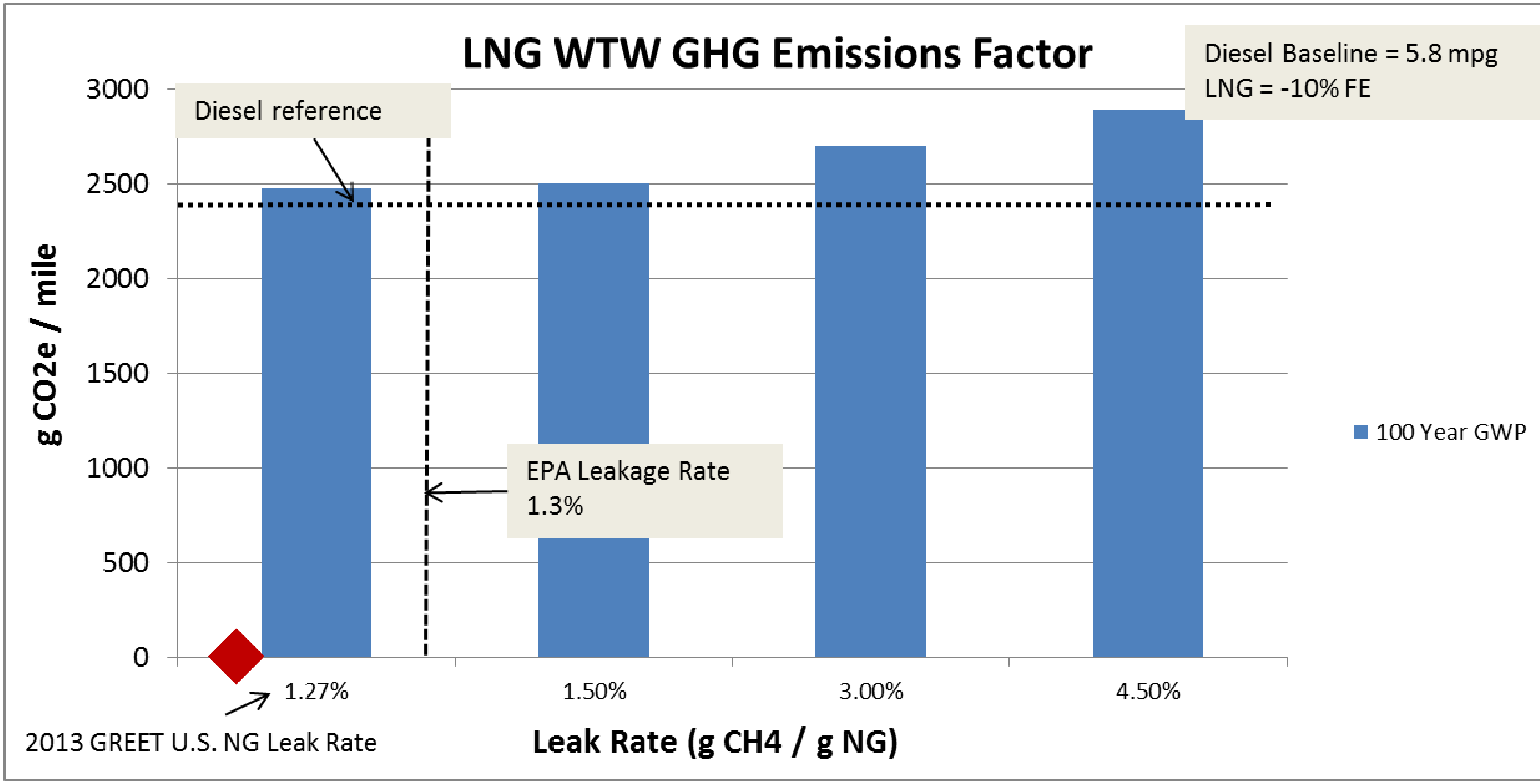
◆ *= Break-even leak rate at 100 year GWP*



Notes: a) CNG fuel efficiency penalty based on LCFS EER for HDVs
a) Using fossil NG and Diesel LCFS values (not including renewables)

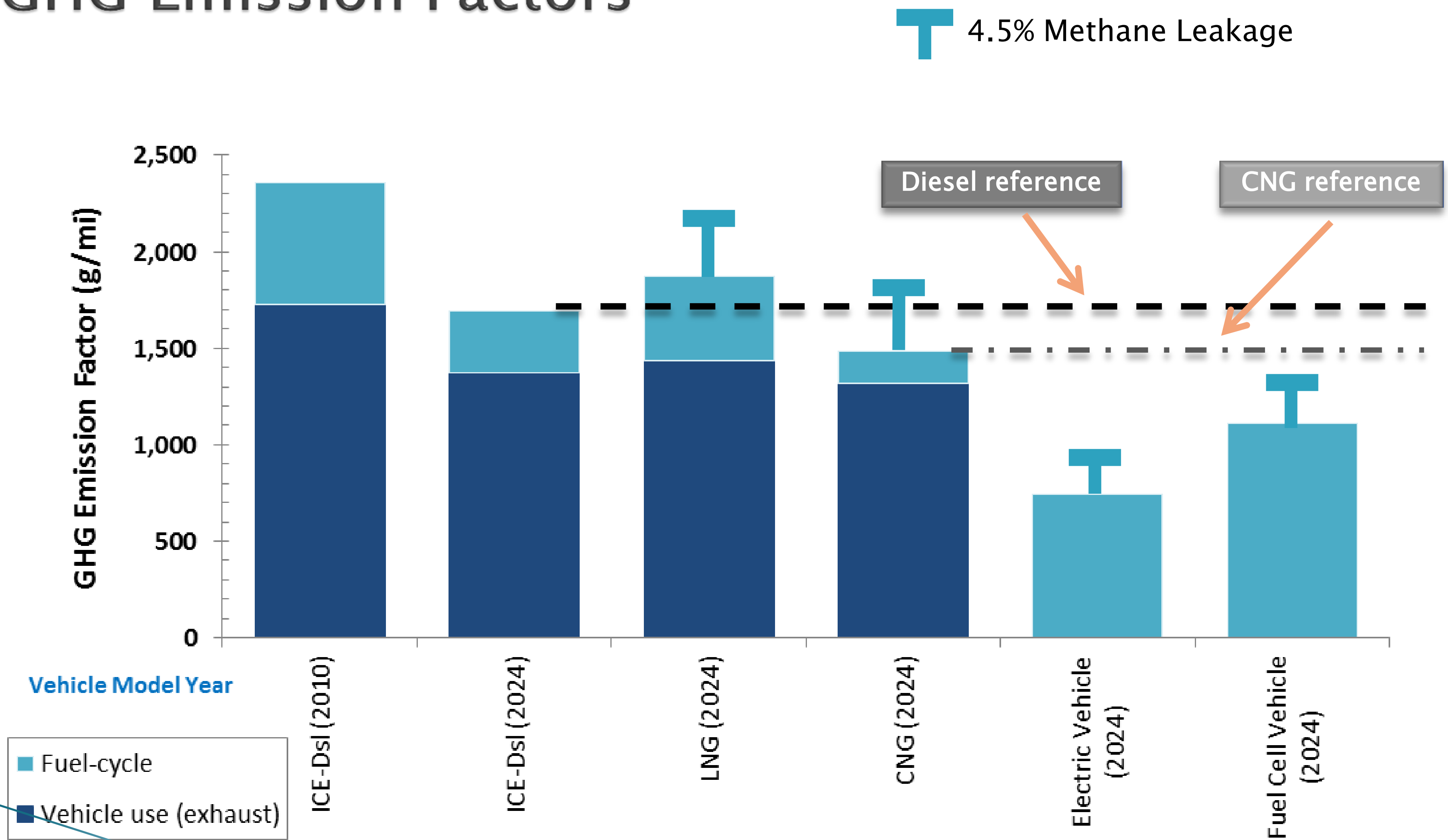
Break-even Point: LNG in HHD

= Break-even leak rate at 100 year GWP



Notes: a) CNG fuel efficiency penalty based on LCFS EER for HDVs
a) Using fossil NG and Diesel LCFS values (not including renewables)

Well to Wheel: HHD Truck
GHG Emission Factors



* Analysis uses draft LCFS CA GREET 2.0 carbon intensities and assumptions as presented during the August 22, 2014 workshop. Updates to LCFS pathways are ongoing.

Summary: Methane Sensitivity

- At 100 year GWP, and -10% NG MPG
  - Break-even at ~4.0% for CNG HHD truck
  - Break-even at <1.27% for LNG HHD truck
- Sensitive input assumptions for analysis:
  - Vehicle fuel efficiency difference between diesel baseline and NG truck
  - GWP value
    - 100 year vs. 20 year
    - IPCC AR4 vs AR5
- External research conducted by EDF, UC Davis, NRDC on methane leakage sensitivity
  - Refer to CEC IEPR Workshop, June 23, 2014

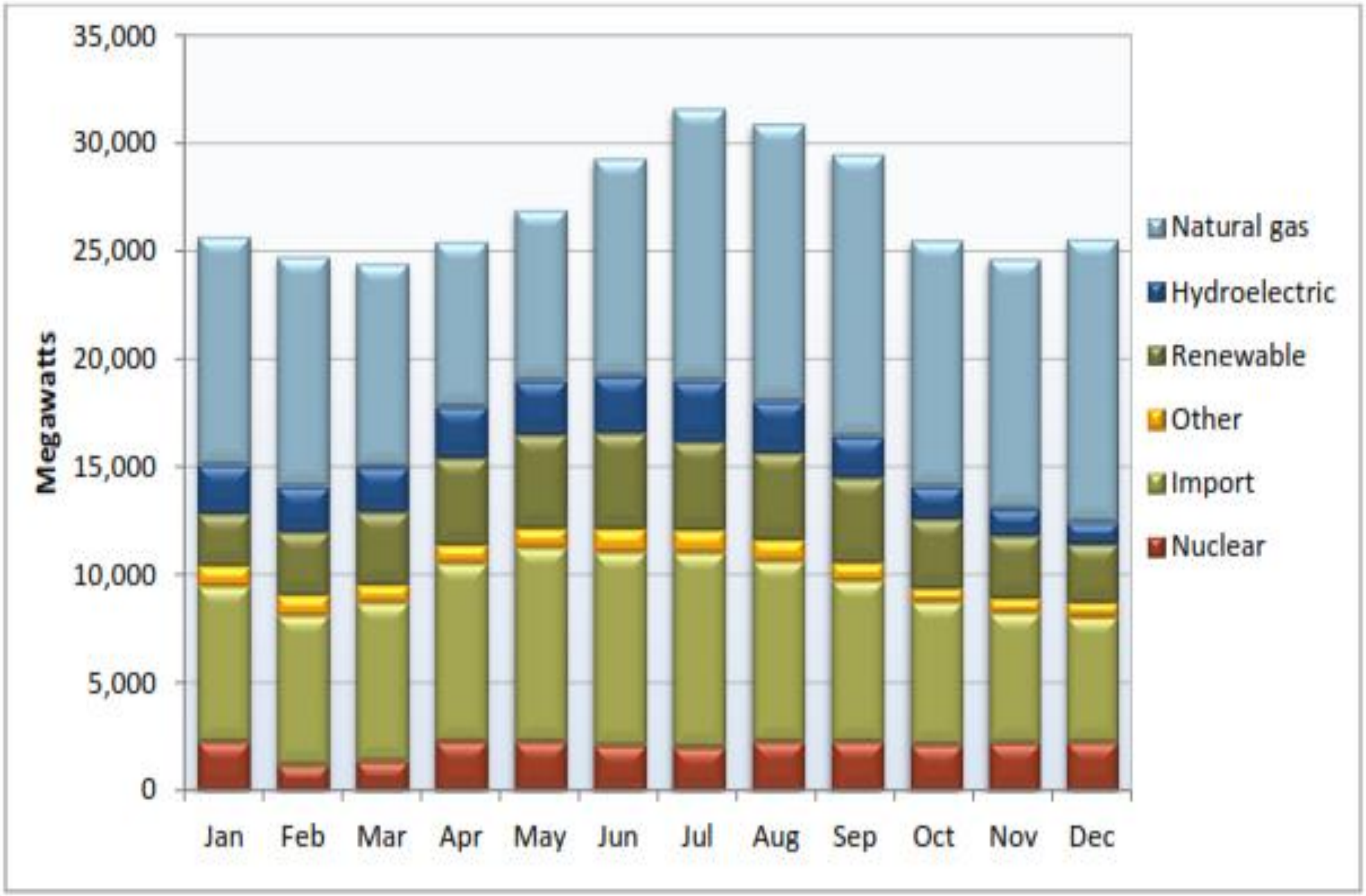
4. What infrastructure improvements are needed to facilitate the use of emerging fuels?

Outline

- Transport and Distribution:
  - Electricity
  - Hydrogen
  - Natural Gas
  - Biofuels

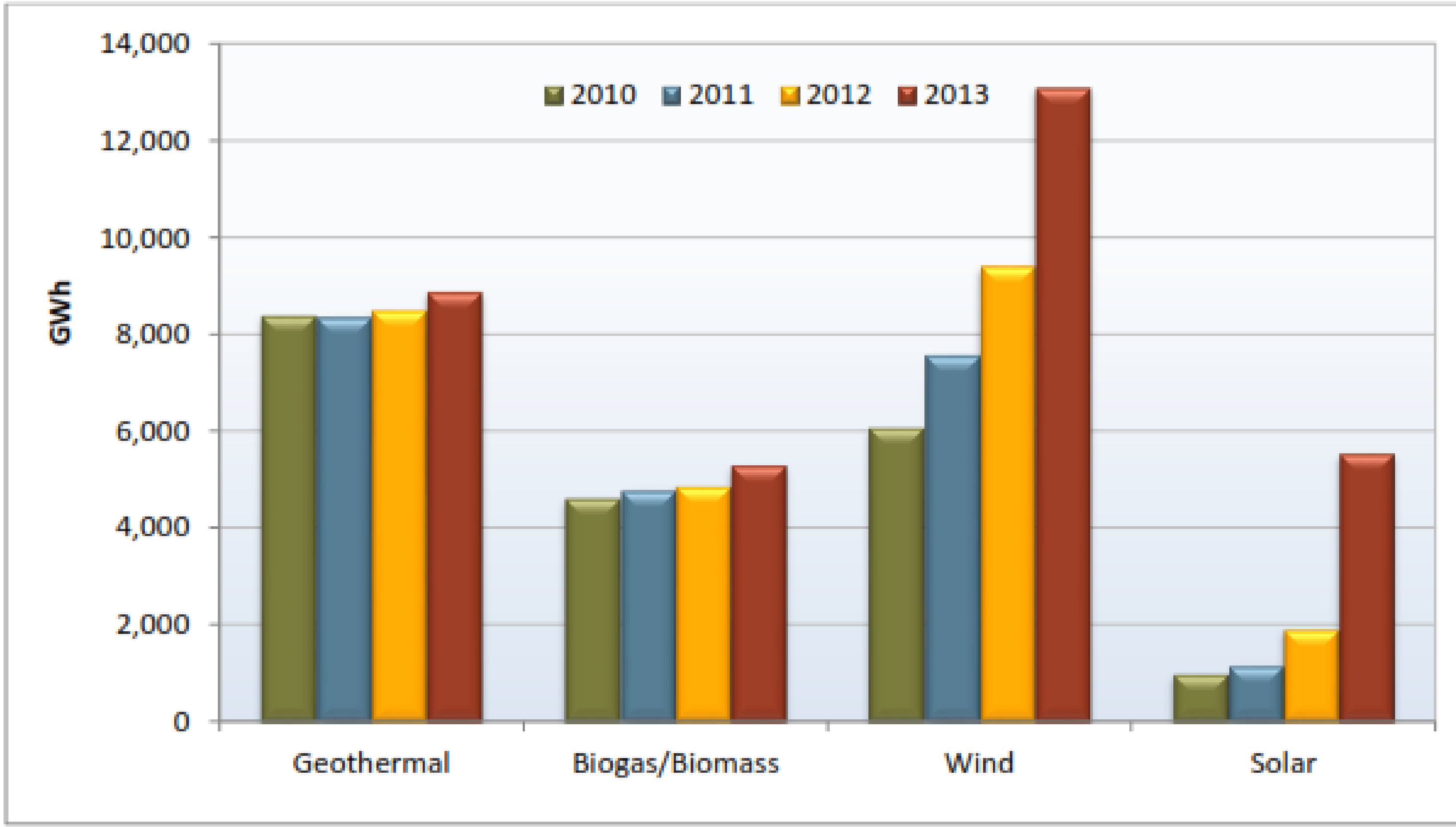
Electricity

Average Cal-ISO Hourly Generation by Month for 2013



Source: 2013 Annual Report on Market Issues and Performance by Cal-ISO

Renewable Electricity Generation in Cal-ISO Grid in 2013



Source: 2013 Annual Report on Market Issues and Performance by Cal-ISO

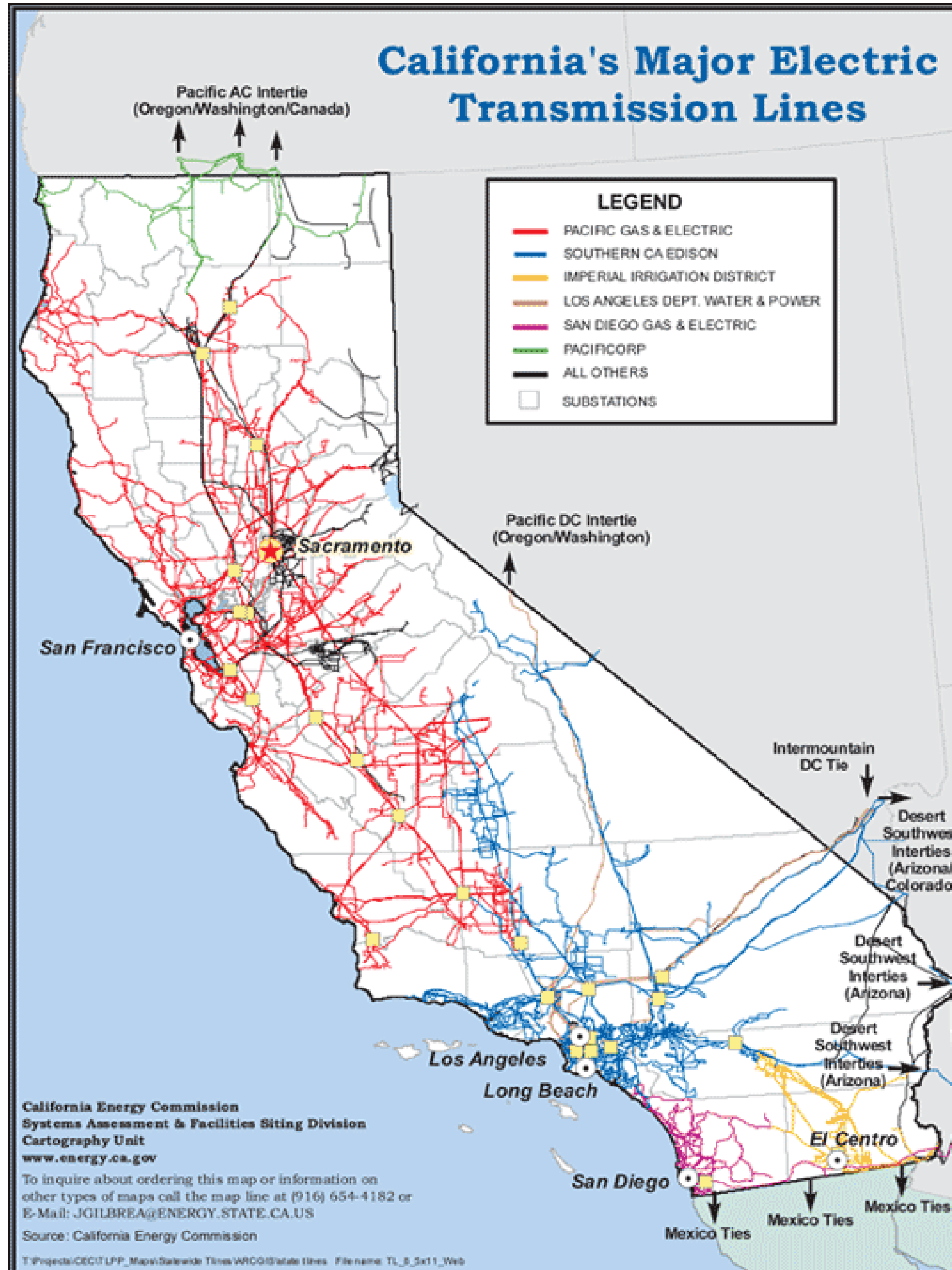
Demand Created by Energy Users

- Categories of Energy Users
  - Residential
  - Commercial
  - Industrial
  - Transportation
- Most Patterns Are Cyclic and Predictable
  - Daily patterns
  - Weekly patterns
  - Monthly Patterns

Generation vs. Demand

- Base Load
  - Usually corresponds closely to minimum daily morning load
  - Generator types: nuclear, coal, hydroelectric, and geothermal
  - Generators operate continuously near capacity and produces reliable and efficient electricity at low cost
- Intermediate Load
  - Covers predictable ramping of load with additional capacity beyond base load to cover expected max load
  - Solar, wind, and combined cycle gas turbines can be used for intermediate loads
- Peaking:
  - Need smaller generator that starts and ramps quickly, and is usually expensive to operate but moderately priced
  - Usually kept on warm standby, and runs about 10 to 15% of the time
  - Generator Types: simple-cycle gas turbines

California Electrical Transmission Grid

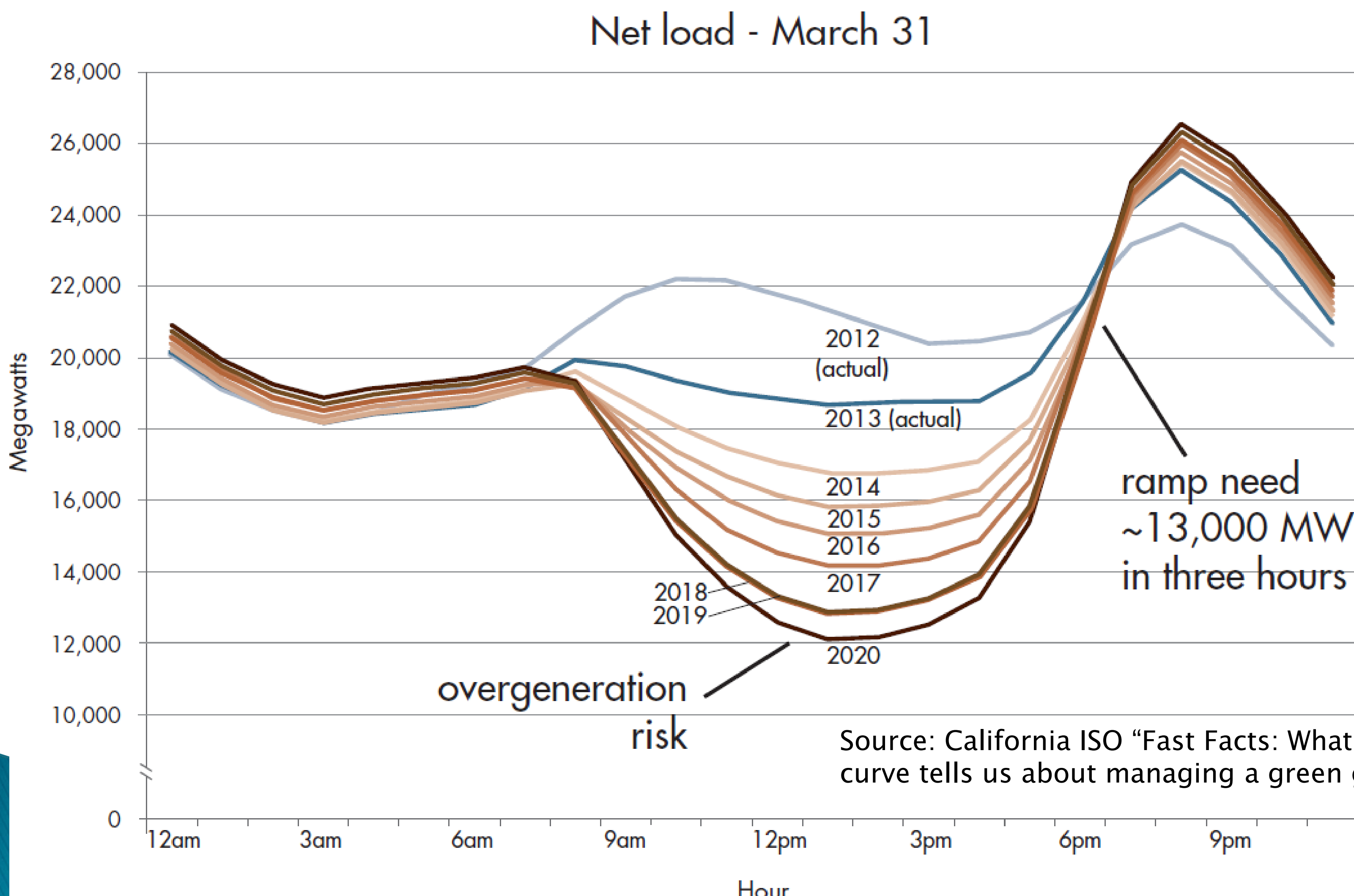


Source: http://www.wrsc.org/attach_image/californias-major-electric-transmission-lines

California Renewable Energy Transmission Initiative (RETI)

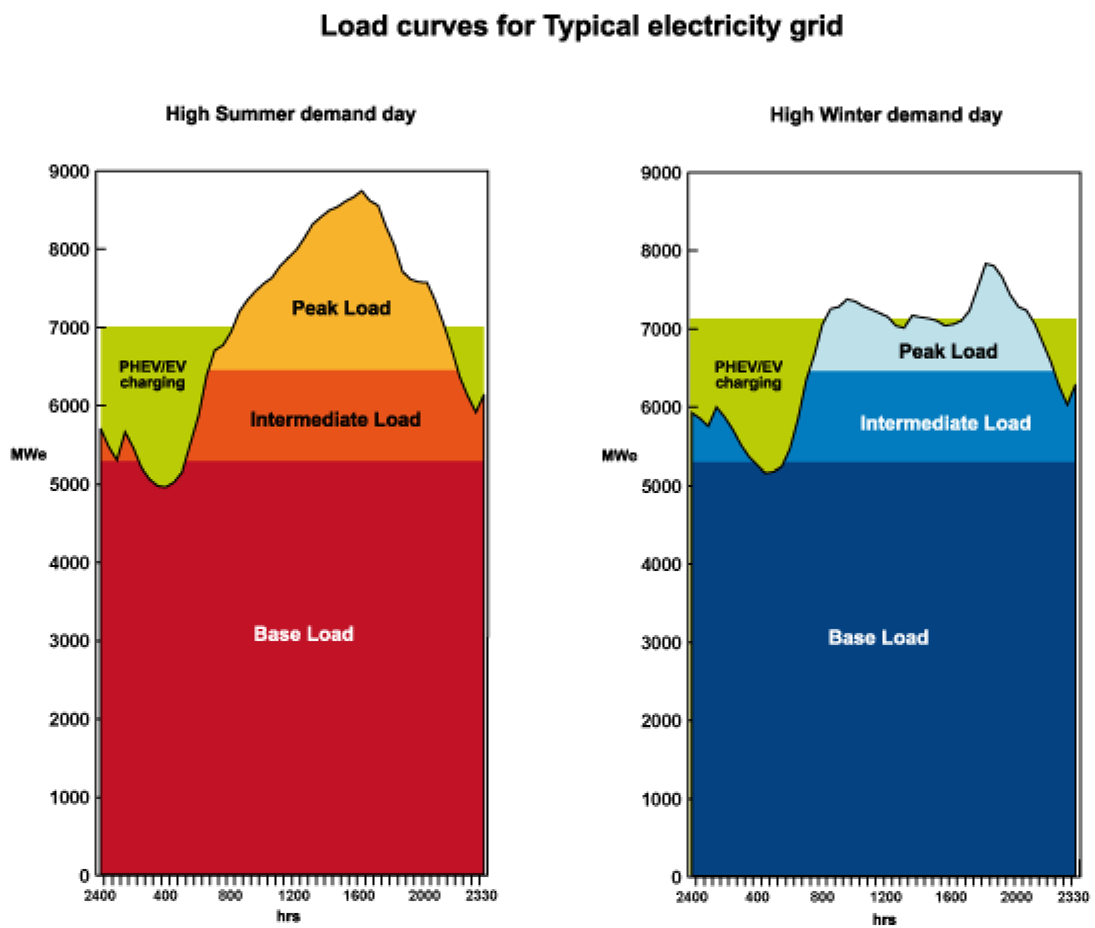
- Extensive improvements in transmission grid are needed to accommodate new renewable-energy power facilities
- RETI is a statewide initiative to:
  - Help identify transmission projects needed to accommodate renewable energy goals
  - Facilitate transmission corridor designation
  - Facilitate transmission and generation siting and permitting
  - Support future energy policy
- Joint effort by CPUC, CEC, Cal-ISO, IOUs, POUs
- Three-Phase process
  - Phase 1: Identify and rank competitive renewable energy zones (CREZs)
  - Phase 2: Prioritize CREZs and develop statewide conceptual transmission plan
  - Phase 3: Detailed transmission planning for priority CREZs

The Duck Curve: Effect of Solar Energy on Future Net Demand



Source: California ISO "Fast Facts: What the duck curve tells us about managing a green grid" 2013

Changing Net Demand Patterns due to PHEV/EV Charging in Typical Low Demand Times



Reference: http://www.world-nuclear.org/info/Current-and-Future-Generation/World-Energy-Needs-and-Nuclear-Power/

Effects of MD/HD Vehicle Charging on Grid

- Uncertain of charging for MD/HD electric vehicles occurring during the day or evening
- It is anticipated that MD/HD vehicle charging will have similar effect on grid as LD does
- On-road charging during the day may help flatten the duck curve
- Evening charging may contribute to a second peak in the evening

California Efforts

- There is a multi-agency effort underway to evaluate potential pathways for achieving deep reductions in GHG emissions
- Led by Energy Principals and includes close coordination among ARB, CA ISO, CPUC, DWR, CDFA, and OPR.
- Modeling will include characterization of:
  - Electricity supply
  - Passenger vehicles, goods movement, transportation planning, and transportation Infrastructure
  - Water supply and demand as it affects energy use and emissions (including desalination plants)

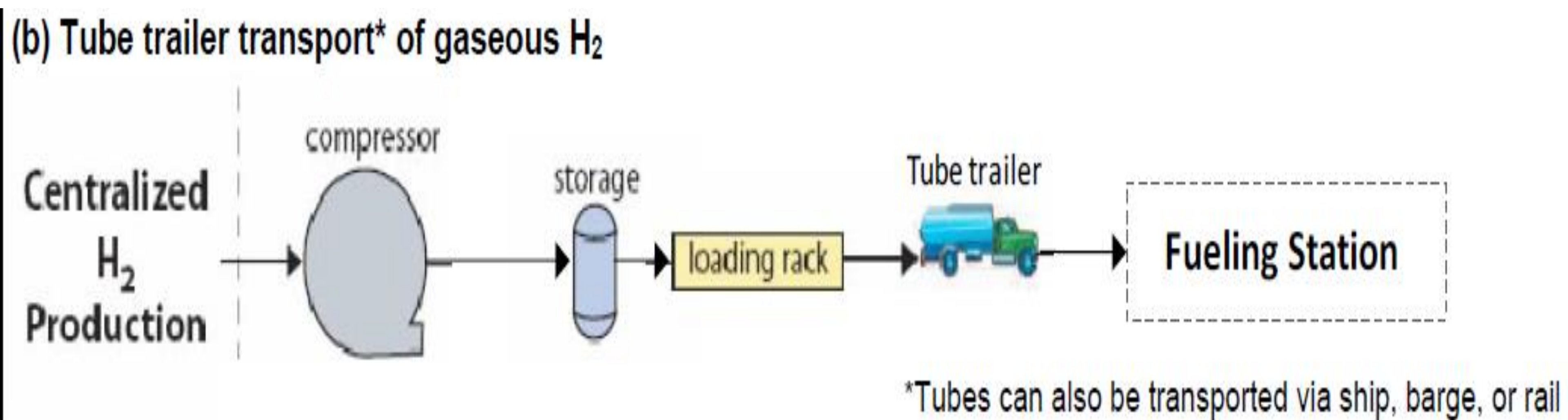
Hydrogen

Hydrogen Transport & Distribution

- Hydrogen is currently distributed by:
  - Over-road vehicles via:
    - Gaseous tube trailer
    - Liquid tanker
  - Pipeline in gaseous form
- Hydrogen could be delivered via solid or liquid carrier
- Renewable H_2 may also be distributed via over-road vehicles or pipeline, although it is typically produced at point-of-use

Gaseous Hydrogen Delivery

- Steel tube trailer delivers compressed H_2
  - Economically constrained to a radius of ~186 mi from the point of production
  - Current carrying capacity for steel tube trailers is 250–500 kg
  - Composite vessels being developed for tube trailer
  - Pressure currently limited to 250 bar by DOT



(b) Tube trailer transport* of gaseous H_2

*Tubes can also be transported via ship, barge, or rail

Hydrogen Compression

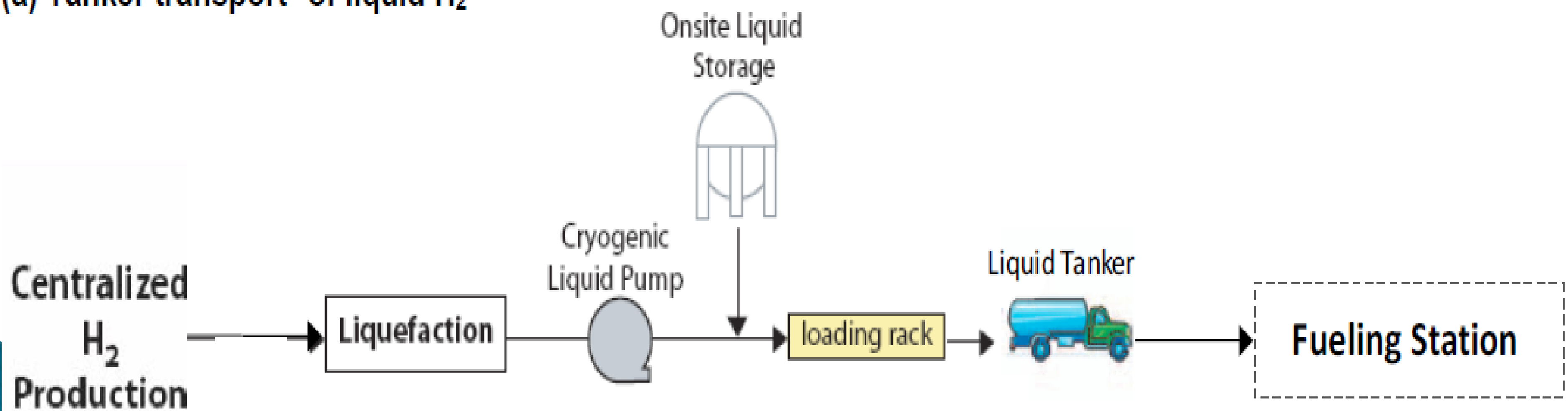
- Sizable energy penalties for compression:
  - 4–8 % of energy content to compress hydrogen to 35 MPa
  - 30–40% of energy content to liquefy hydrogen

	Advantages	Disadvantages
Liquid Hydrogen	• Cost-effective at higher volumes	• Requires additional equipment (e.g., electric chillers, vaporizers, etc.) • Liquefaction is energy intensive
Gaseous Hydrogen	• Cost-effective at lower volumes	

Liquid Hydrogen Delivery

- Cryogenic tank truck delivers liquid H2
  - 90% of merchant hydrogen transported in liquid form
  - Most economical means of transport >100 kg/day and for distances greater than ~185 mi
  - Carrying capacity up to 4,000 kg at atmospheric pressure

(a) Tanker transport* of liquid H_2

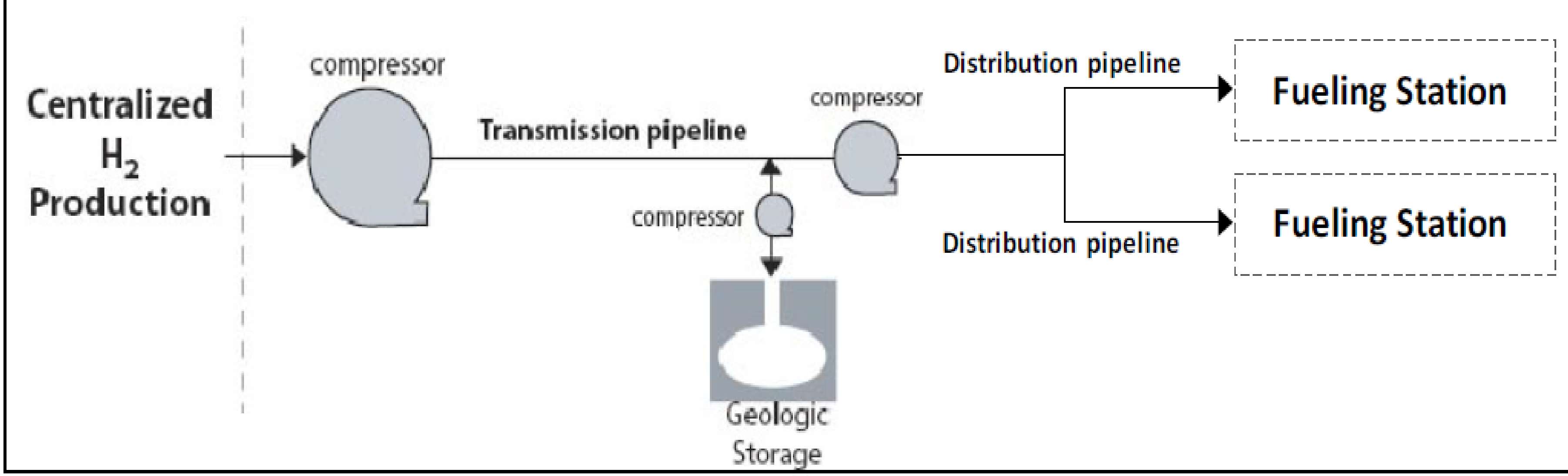


*Tanks can also be transported via ship, barge, or rail

Transport via Hydrogen Pipeline

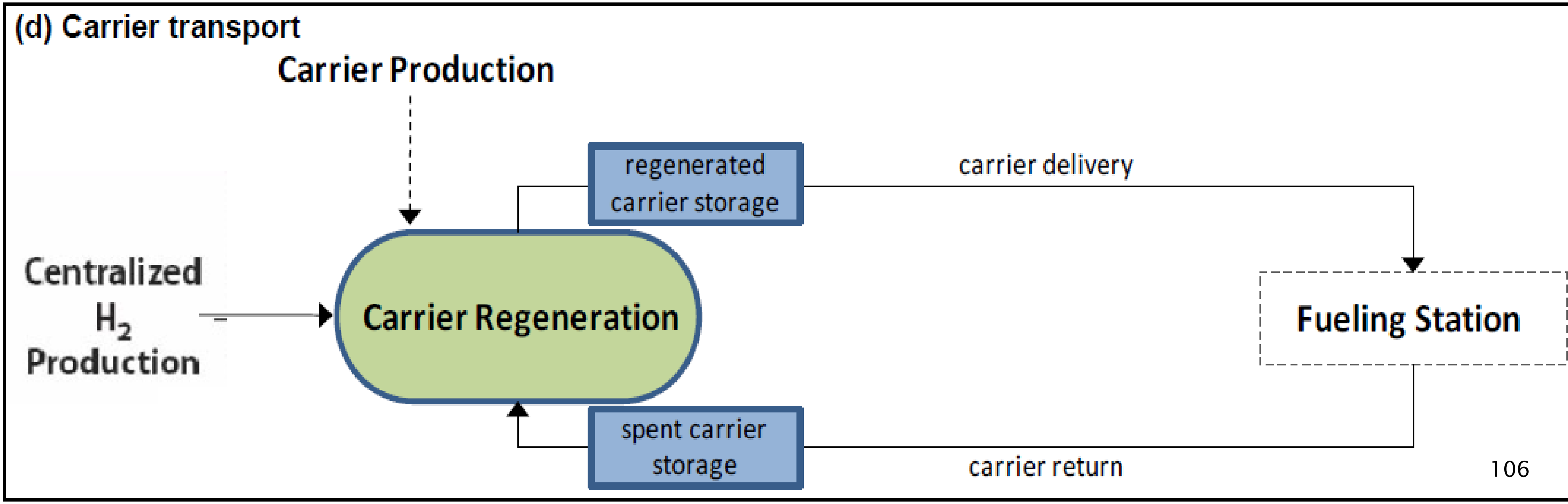
- More than 1,200 miles of existing H_2 pipelines serve regions with high concentrations of industrial H_2 users
- Transmission line pressures 30–150 bar
- Capital intensive, however long-term lowest cost option for large volume H_2 transport

(c) Pipeline transport of gaseous H_2

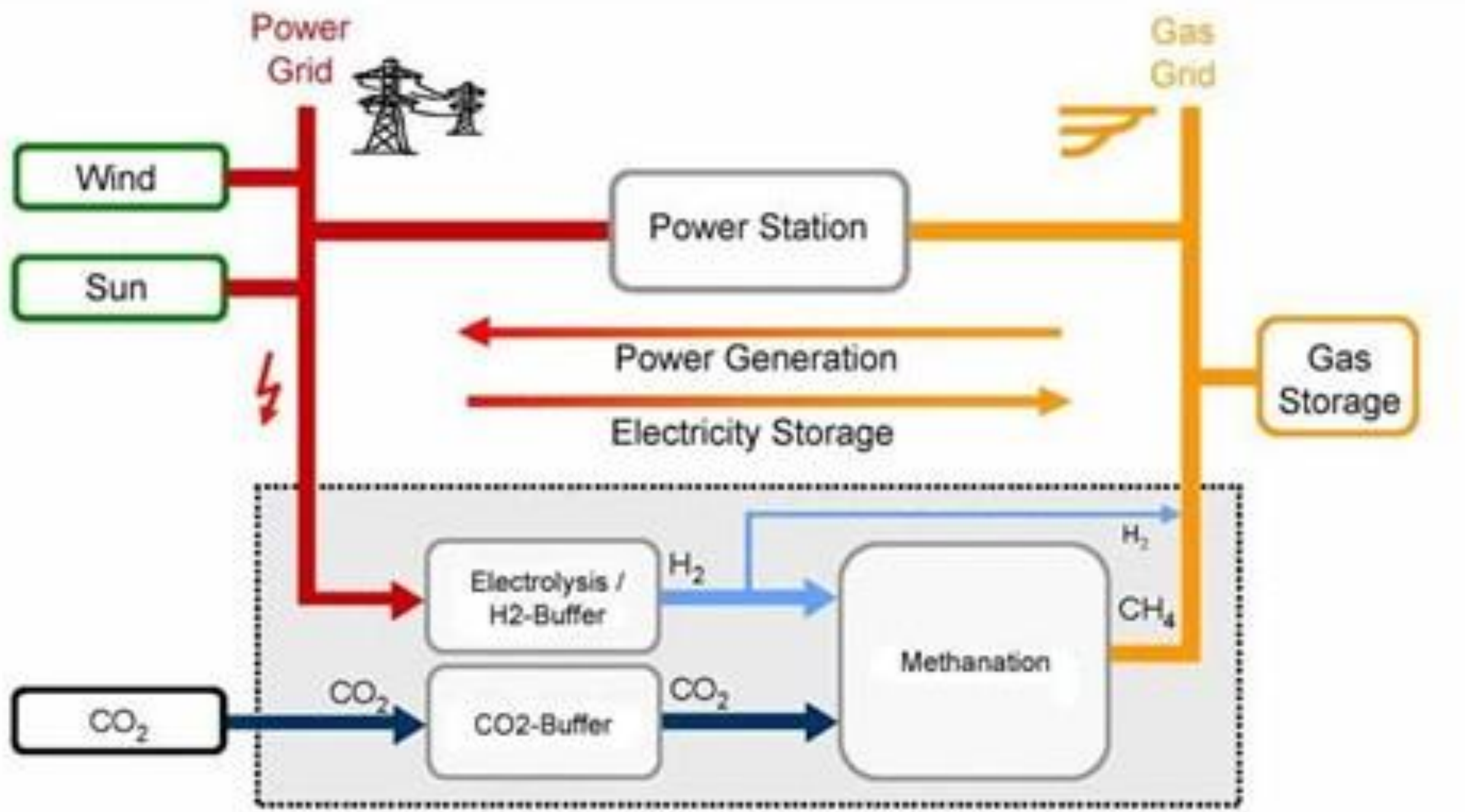


Hydrogen Carrier Transport

- Transport in solid or liquid carrier form
  - Employs a material that chemically binds or physisorbs hydrogen
  - Still in R&D phase, not currently used



Power to Gas (P2G) Concept



H_2 Transport via NG Pipeline

- Hydrogen Enriched Natural Gas (max 10% H_2 by vol) compatible with current NG pipeline
- 305,000 miles of NG transmission pipelines versus 1,200 miles for H_2
- Avoids capital cost of building H_2 pipeline network
- Robust grid and operation management for NG pipeline well-established
- H_2 enriched NG could reduce criteria pollutants in gas-fired combustion systems
- Hydrogen separation at point-of-use enables transportation fueling opportunity
- Currently demonstrated in Falkenhagen, Germany

Hydrogen Fueling Network

- California is dedicated to building a robust network of hydrogen stations across the state
- California Fuel Cell Partnership published *A California Road Map*
  - Found that 68 hydrogen stations are necessary for the initial rollout of light-duty fuel cell electric vehicles
- Governor Brown's ZEV Action Plan calls the state to "actively consider heavy-duty ZEVs when planning infrastructure for light-duty vehicles"
- Assembly Bill 8 dedicated up to $20M/year to support continued construction of at least 100 hydrogen fuel stations

H₂ Stations in Northern CA

May 2014

Northern CA Hydrogen Stations

Open

Emeryville - AC Transit

In Development

Cupertino
Foster City
Mountain View
*West Sacramento

Campbell
Hayward
Mill Valley
Oakland
Palo Alto
Redwood City
*Rohnert Park
San Jose
San Ramon
Saratoga
South San Francisco
*Truckee
Woodside

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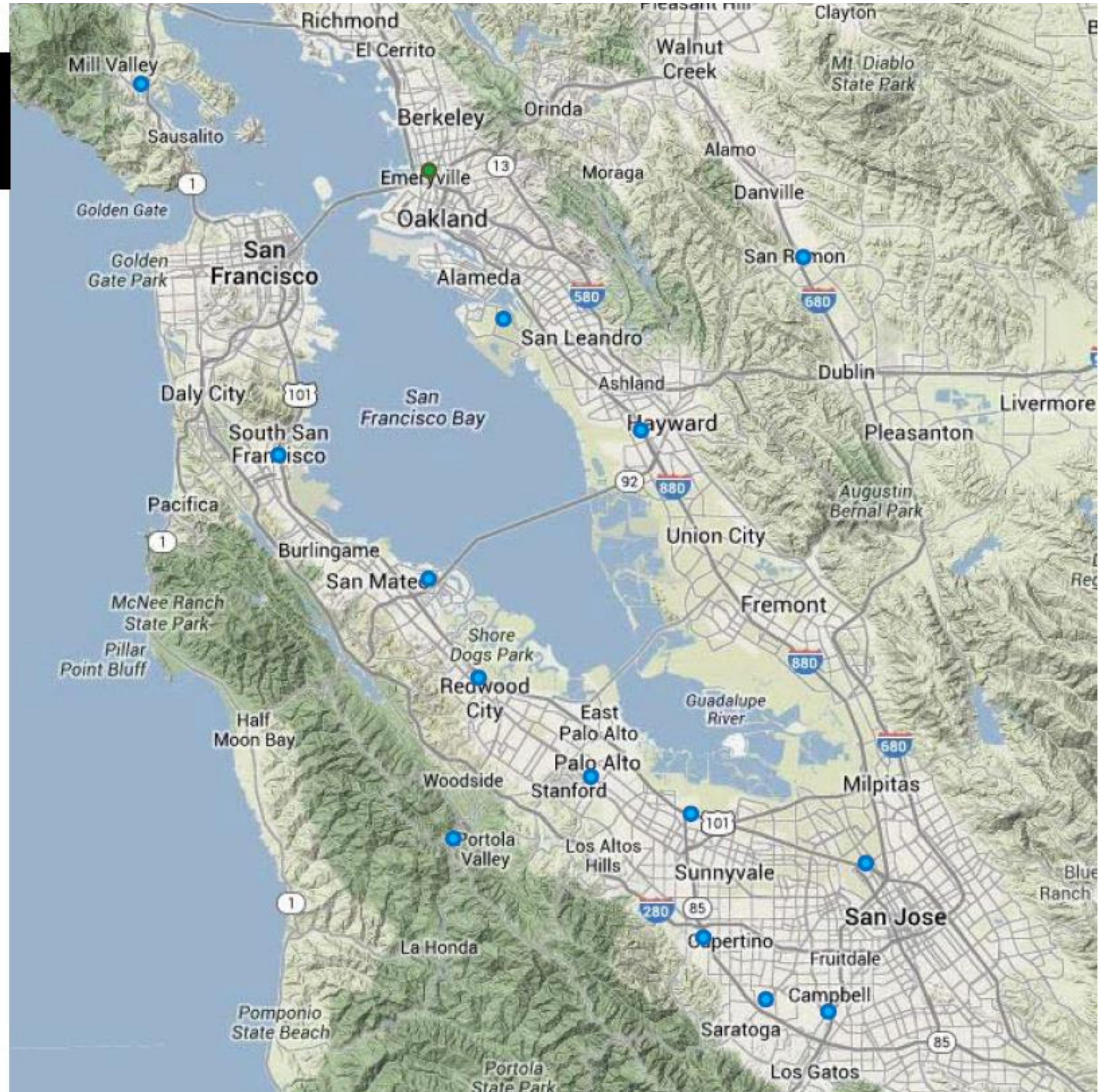

California Fuel Cell Partnership
DRIVING FOR THE FUTURE
Managed by BKi

H_2 Stations in Southern CA

Southern CA Hydrogen Stations

Open

- Burbank
- Fountain Valley - OCSD
- Irvine - UC Irvine
- Los Angeles - Harbor City
- Los Angeles - West LA 1
- Newport Beach - Shell
- *Thousand Palms - SunLine Transit
- Torrance - Shell

In Development

- Anaheim
- Chino (upgrade)
- Diamond Bar (upgrade)
- Irvine - UC Irvine (upgrade)
- Irvine - Walnut Ave.
- Lawndale
- Los Angeles - Cal State LA
- Los Angeles - West LA 2
- Los Angeles - Westwood
- Los Angeles - Woodland Hills
- Los Angeles - Beverly Blvd.
- Mission Viejo
- Redondo Beach
- San Juan Capistrano
- Santa Monica 1

- *Coalinga
- Costa Mesa
- La Canada Flintridge
- Laguna Niguel
- Lake Forest
- Long Beach
- Los Angeles - LAX
- Los Angeles - 9
- Los Angeles -10
- Ontario
- Orange
- Pacific Palisades
- *Riverside
- *San Diego
- *Santa Barbara
- South Pasadena

**Not shown on map*

California Fuel Cell Partnership
www.cafcp.org/stationmap

Using LDV H_2 Fueling Network

- Most retail hydrogen stations built for light-duty vehicles in CA will not be available to medium-/heavy-duty fuel cell vehicles:
  - Differing fueling protocol for vehicles with more than 10 kg of storage capacity onboard
  - Physical constraints (e.g., height clearance, etc.)
  - Limited fuel capacity
  - Longer fill time for larger vehicles
  - May impact light-duty vehicle fueling experience
- Some medium-/heavy-duty vehicles may be able to use LDV H_2 stations without complications

Leveraging LDV H2 Stations for MD/HD Applications

- One solution:
  - Co-locate station equipment (dispensers, storage, compressors, etc.)
- Advantages:
  - Capital cost, operating costs, real estate optimized
  - Opportunity to demonstrate advanced hydrogen pipeline materials and network concepts
- Disadvantages:
  - Co-locating can be challenging physically and operationally
  - May not always be cost-effective

H_2 Refueling Network for Fuel Cell Medium-/Heavy-Duty Vehicles

- Parallel efforts supporting LDV commercialization is needed for MD/HD:
  - H_2 station network plan similar to California Fuel Cell Partnership's publication
    - Location
    - Timeline
  - Establish dedicated public funds for MD/HD designated hydrogen infrastructure
- Identify and build upon synergies between LDV and MD/HD vehicle fueling stations

Natural Gas

Natural Gas

- Pipeline Natural Gas
  - Pipeline delivery pressures from 0.25 to 60 psi
- Compressed Natural Gas
  - Stored in a high-pressure container at 3000-3600 psi, occupying about 1% of its original volume
- Liquefied Natural Gas
  - Natural gas condensed to liquid after cooling to −259° F
  - Liquid form allows large volumes of natural gas to be transported to locations unreached by gas pipelines

Distribution of Natural Gas Fueling Stations

Publically Accessible Natural Gas Stations (Heavy Duty)

- CNG (490)
- LNG (57)

Renewable Natural Gas (RNG)

- Dewatered, purified biogas that is pipeline-quality
- Considered "drop-in" fuel for NG vehicles
- Potential to use existing NG infrastructure
  - Landfill methane must meet pipeline specifications before injection
- In areas without ready access to piped natural gas, natural gas dispensing stations would require trucked distribution

Potential Substitutes for Diesel

- Natural Gas as a Substitute for Diesel
  - CNG has 25% of the energy density of diesel
  - LNG has 60% of the energy density of diesel
  - Refueling slower for CNG, but can be fueled locally
  - LNG is cryogenically chilled and then transported to the dispensing site
  - LNG offers higher volumetric energy density than CNG, but has higher WTT emissions due to liquefaction
- Current sales of trucks using CNG are higher than those for LNG

Biofuels

- Biodiesel is distributed by truck, train, or barge.
  - Prohibited from petroleum pipelines
- Renewable gasoline, diesel, jet fuel can utilize existing infrastructure since it is molecularly identical
- Ethanol is transported by:
  - Train or truck—90%
  - Barge or dedicated pipeline—10%

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