



NATURAL GAS - TRANSPORTATION FUEL OF THE FUTURE?

NACAA FALL MEMBERSHIP MEETING
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KEY MESSAGES

- **Clean Opportunities** exist for Marine, Rail, Heavy Duty Long Haul Trucks and Light Duty NGVs
- Natural Gas **Delivered Cost** will determine the extent of transportation market opportunities
- A major selling point is that the cost of **LNG** can be **<\$2.50/DGe*** including taxes
- Natural gas has less carbon, so less CO₂, but Methane (CH₄) does have a significant GWP (**so leaks do matter**)
- Natural Gas can be **CNG, LNG, ... Or?**

FUEL COST MATTERS TO HIGH CONSUMPTION USERS



NATURAL GAS FOR MARINE VESSELS U.S. MARKET OPPORTUNITIES



APRIL 2012



consumes about as much energy as



three car ferries



five tugboats



113 semi trucks or

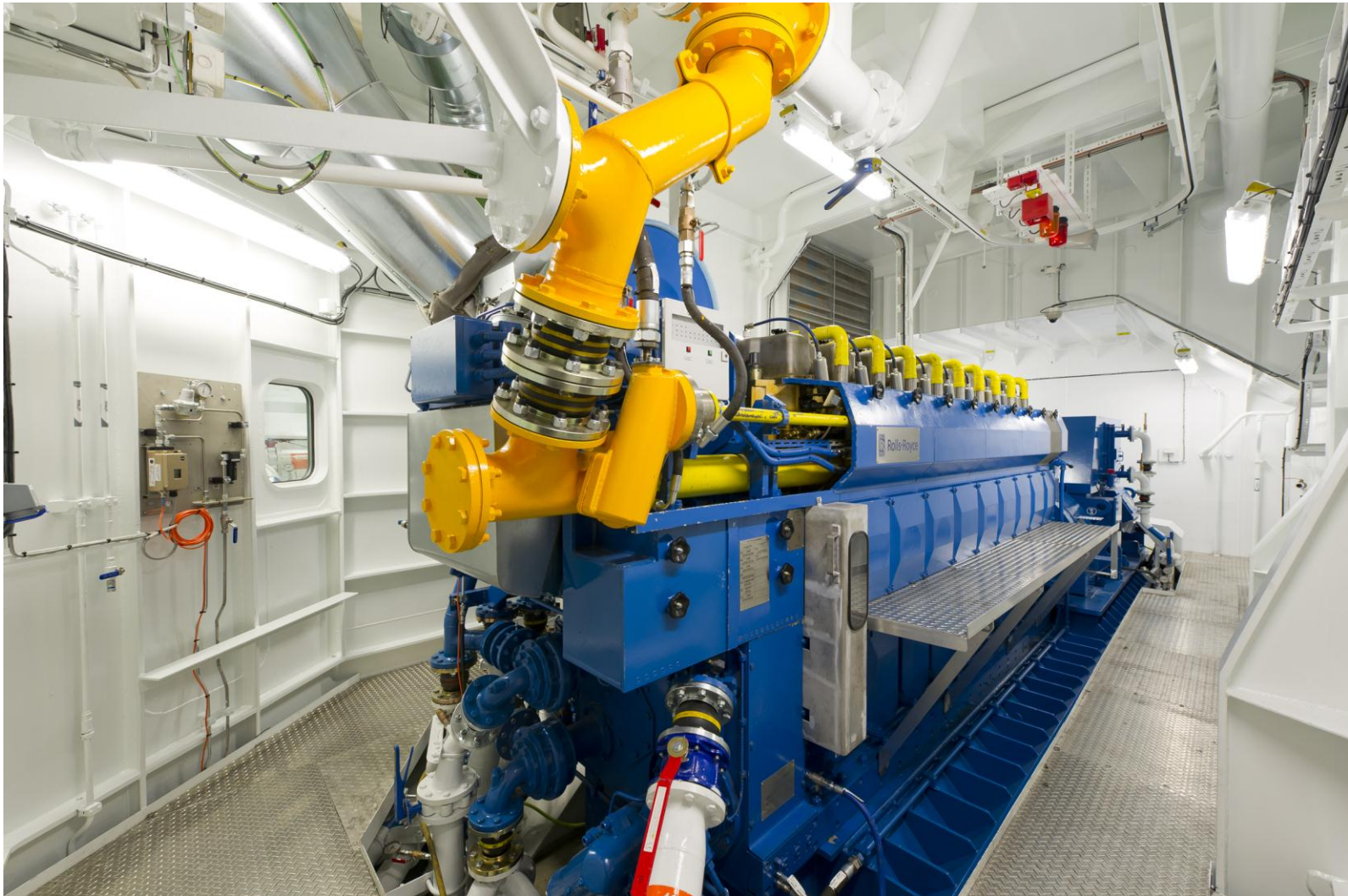


4160 compact cars

OWNER/OPERATOR/REGULATOR METRICS

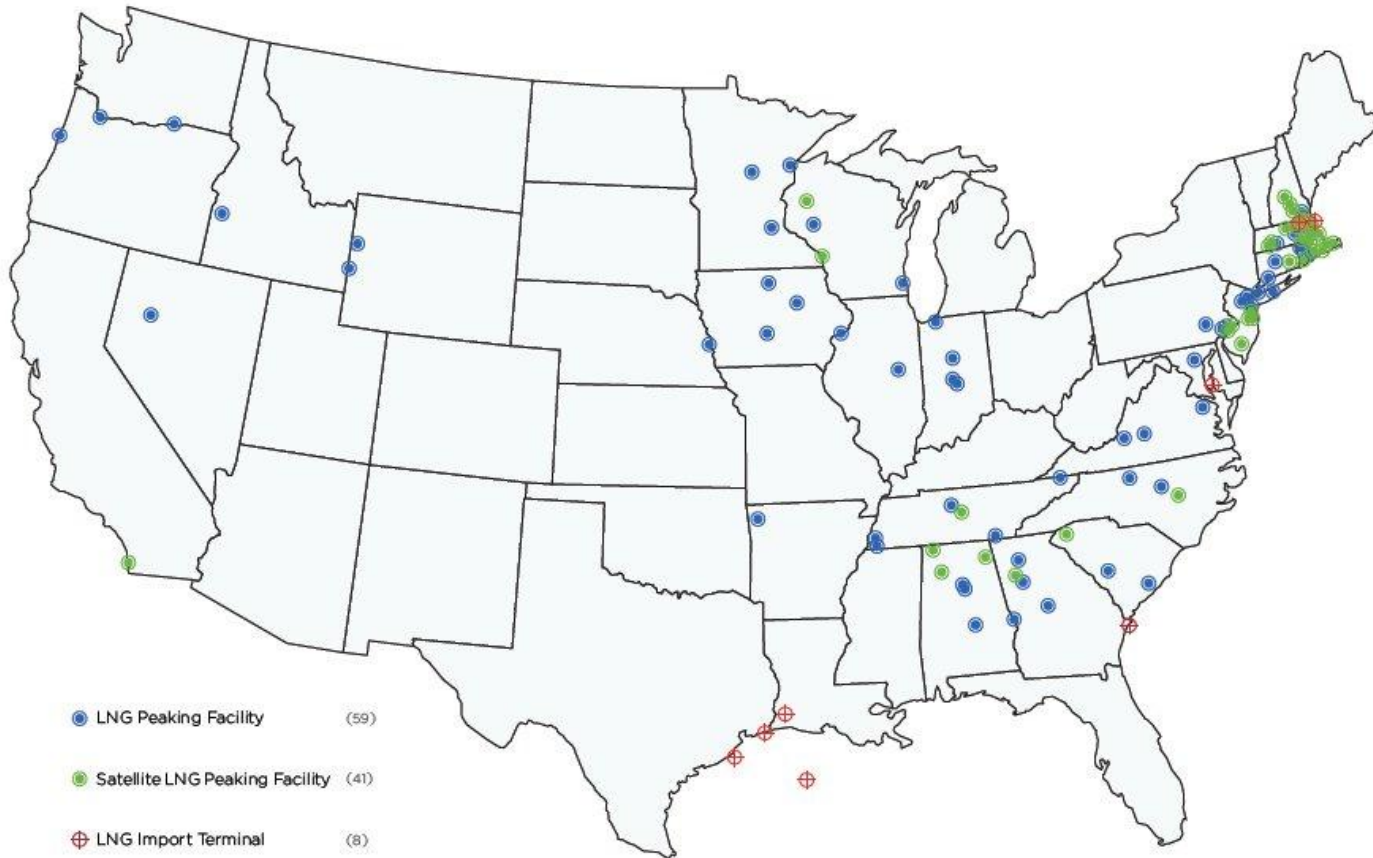
- **Fuel Suitability** – Support operational mission?
- **Range** – Fuel space and weight considerations
- **Infrastructure** – Is fuel widely available?
- **Safety** – Any significant new safety issues?
- **Capital Cost** – Can higher Capex be recovered?
- **Fuel Cost** – Will Opex savings support ROI?
- **Criteria Pollutants** – Clean? Tier 4?
- **EPACT** – Domestic Fuel?
- **LCFS/RFS** – Low Carbon Intensity? Renewable?
- **Energy Efficiency** – Improved Fuel Economy?

DO WE HAVE LNG MARINE ENGINES? YES



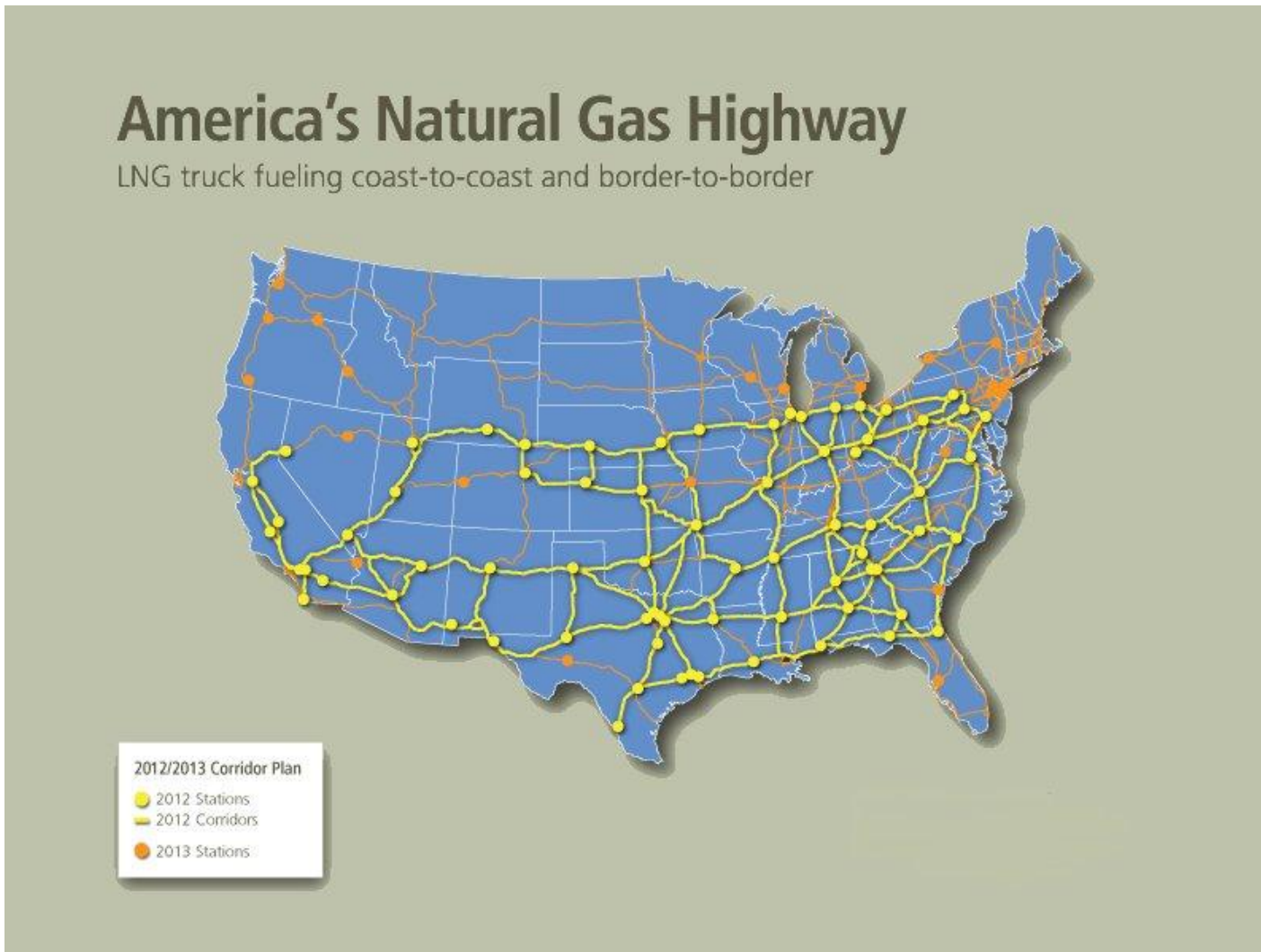
LIQUEFIED NATURAL GAS (PIPELINE CONNECTED)

U.S. LNG Peaking Shaving and Import Facilities, 2008 [R5]



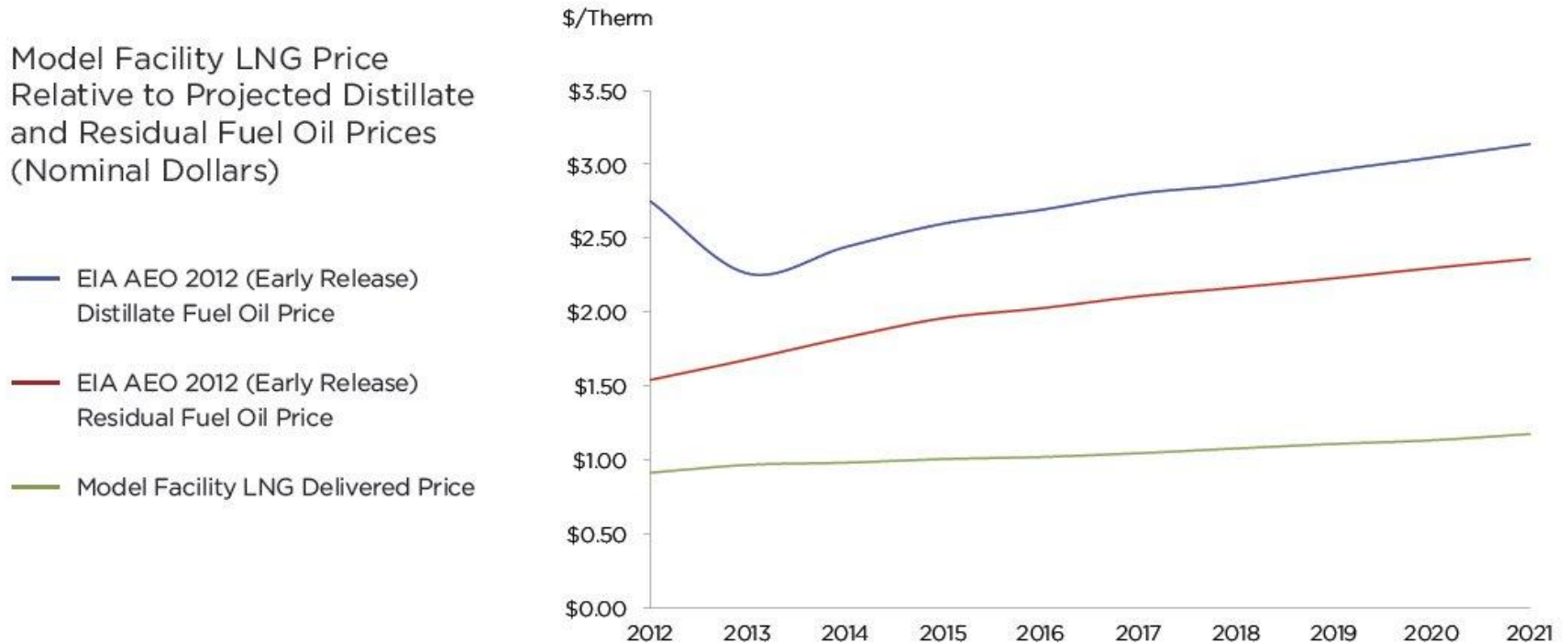
Note: Satellite LNG facilities have no liquefaction facilities. All supplies are transported to the site via tanker truck.
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.

LNG TRUCK NATURAL GAS (TRUCK CONNECTED)



LNG COST EIA AEO APRIL 2012 EARLY RELEASE

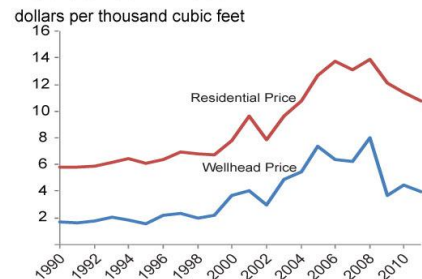
Model Facility LNG Price
Relative to Projected Distillate
and Residual Fuel Oil Prices
(Nominal Dollars)



NATURAL GAS COMMODITY VS DELIVERED PRODUCT

- Limited market data exists for LNG because consumption is low and there is no spot market
- Low U.S. LNG export capacity means world prices are not currently a US price driver

U.S. Natural Gas Wellhead and Residential Prices



Source: U.S. Energy Information Administration, Forms EIA-857 and EIA-895 (June 2012), preliminary 2011 data.

Natural Gas Futures Prices, 1997 to 2020

With trendlines for 1997 to 2008 and 2009 to 2020



Source: CME; EIA; MJB&A.

- Shale gas extraction has dramatically reduced natural gas price volatility and shifted the long-term price trend
- LNG prices are however driven by commodity price plus potentially significant processing and transport costs for new infrastructure

LNG, GOOD ROI = HIGH CONSUMPTION

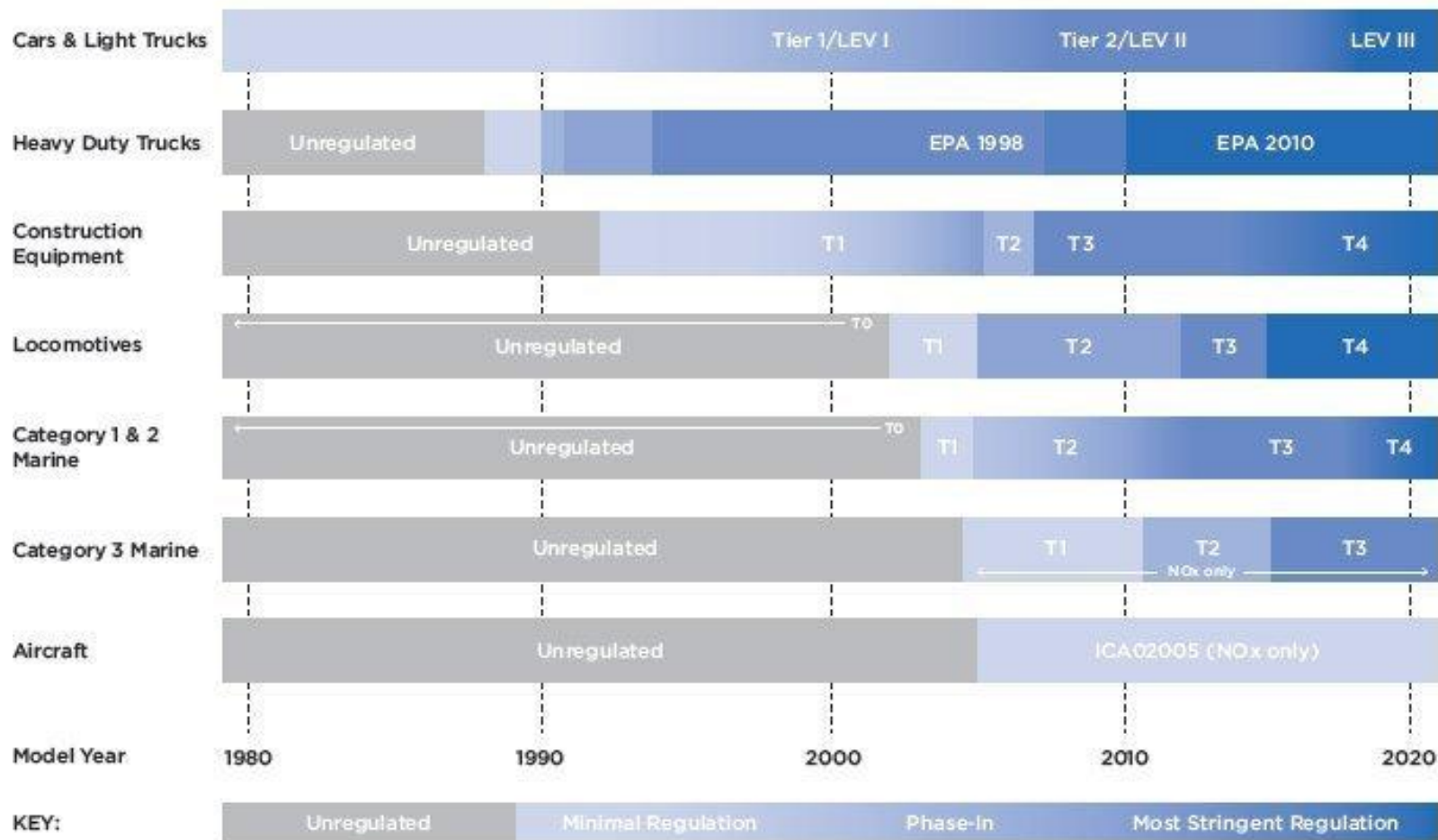
TRUCK (Class 8 Tractor)



| | <i>unit</i> | DIESEL | LNG |
|------------------------|-------------|----------|------------|
| Annual Miles | | 80,000 | 80,000 |
| Fuel Use | MPG | 6.0 | |
| | MPG | | 5.3 |
| Annual Fuel | gal | 13,333 | |
| | gal | | 15,094 |
| Fuel Cost | \$/gal | \$3.94 | |
| | \$/gal | | \$2.50 |
| ANNUAL FUEL COST | \$ | \$52,533 | \$37,736 |
| ANNUAL SAVINGS | \$ | | \$14,797 |
| INCR PURCHASE COST | \$ | | \$50,000 |
| PAY-BACK PERIOD | YR | | 3.4 |

CLEAN CRITERIA POLLUTANT STANDARDS

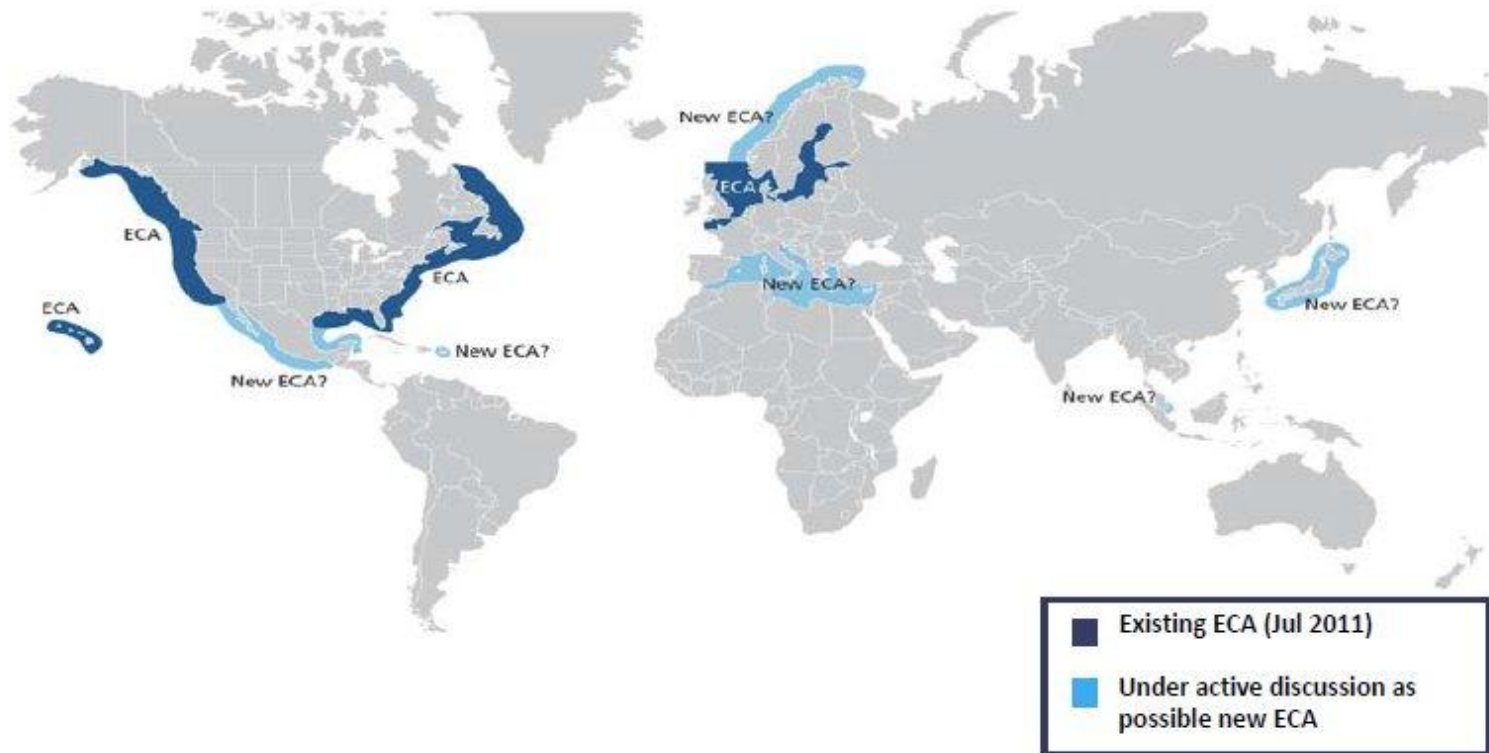
Time Frame for Imposition of EPA Emission Regulations for Mobile Sources



NORTH AMERICAN ECA IS SO₂ AND NO_x

Legislations and Regulations

- emission control areas (ECA)



LEAKS MATTER, BUT MOSTLY UPSTREAM, WILL IMPROVE

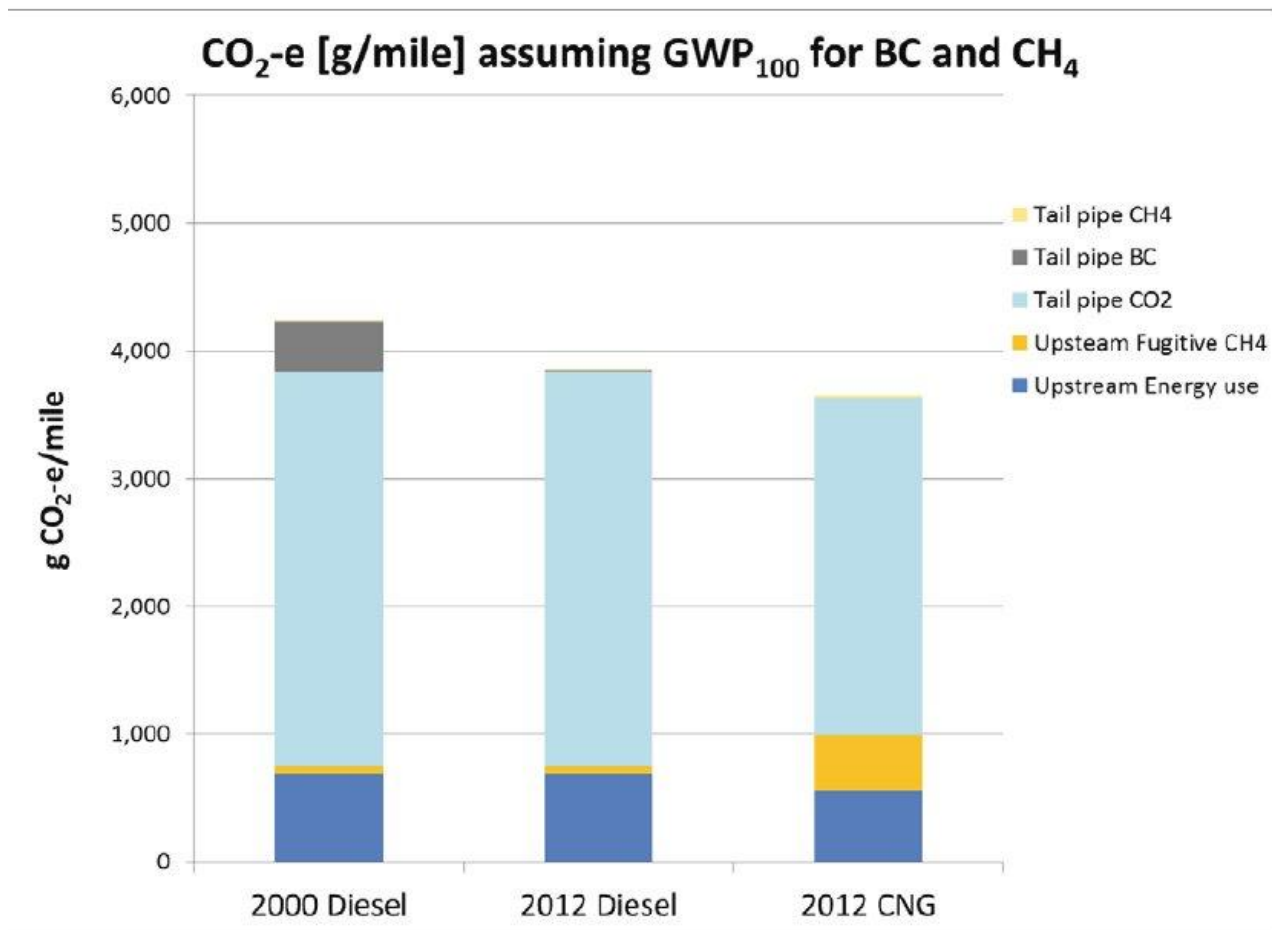


Figure 3 Wells-to-wheels GHG emissions (g/mile CO₂-e) from old diesel, new diesel and new CNG buses (assuming GWP₁₀₀ for methane and black carbon)

COMPRESSED NATURAL GAS (CNG)

- **Gas** at ambient temperature and pressure
- Similar: Compressed Hydrogen
- Stored as compressed **Gas** @ 3,000/3,600 psi
- ~\$2.28/DGe
- ~5% energy loss for compression
- Sold as **Therm** (100,000 btu), DGe (129,000 btu)
- Need **6x as much space** as distillate (**range issues**)
- **Low Capex** Vehicle, **Medium Capex** Infrastructure
- Must refuel more often (**high** leakage)
- Vehicle leaks are **low** (sealed pressure cylinders)
- Vehicle exhaust leaks **low** (catalyst)

LIQUEFIED NATURAL GAS (LNG)

- **Gas** at ambient temperature and pressure
- Similar: Liquefied Hydrogen, Alt: LPG, DME (low P)
- Stored as cryogenic **Liquid** @ -160C
- ~\$2.50/DGe (current estimate)
- ~20% energy loss for liquefaction
- Sold as **Gallon** (75,000 btu)
- Need **2x as much space** as distillate (**same weight**)
- **Medium Capex** Vehicle, **Medium Capex** Infrastructure
- Refuel less often (**low** leakage)
- Vehicle leaks are **medium** (**only modest pressure**)
- Vehicle exhaust leaks **low** (catalyst)

NATURAL GAS DERIVED LIQUID (NOT NGLS)

- **Liquid** at ambient temperature and pressure
- Methanol, Ethanol (OHs), FT Diesel, MTG (drop in)
- Stored as a **Liquid**
- ~\$2.50/DGe* (for Methanol), Others More \$
- ~30% energy loss for syngas conversion
- Sold as **Gallon** (55,000 btu for Methanol)
- Need **2.2x as much space** as distillate (**2x weight**)
- **Low Capex** Vehicle, **Low Capex** Infrastructure
- Refuel leaks are **low** (vapor recovery)
- Vehicle leaks are **low**(vapor recovery)
- Vehicle exhaust leaks **low** (catalyst)

NATURAL GAS AND BIOMASS CAN BE ANYTHING...

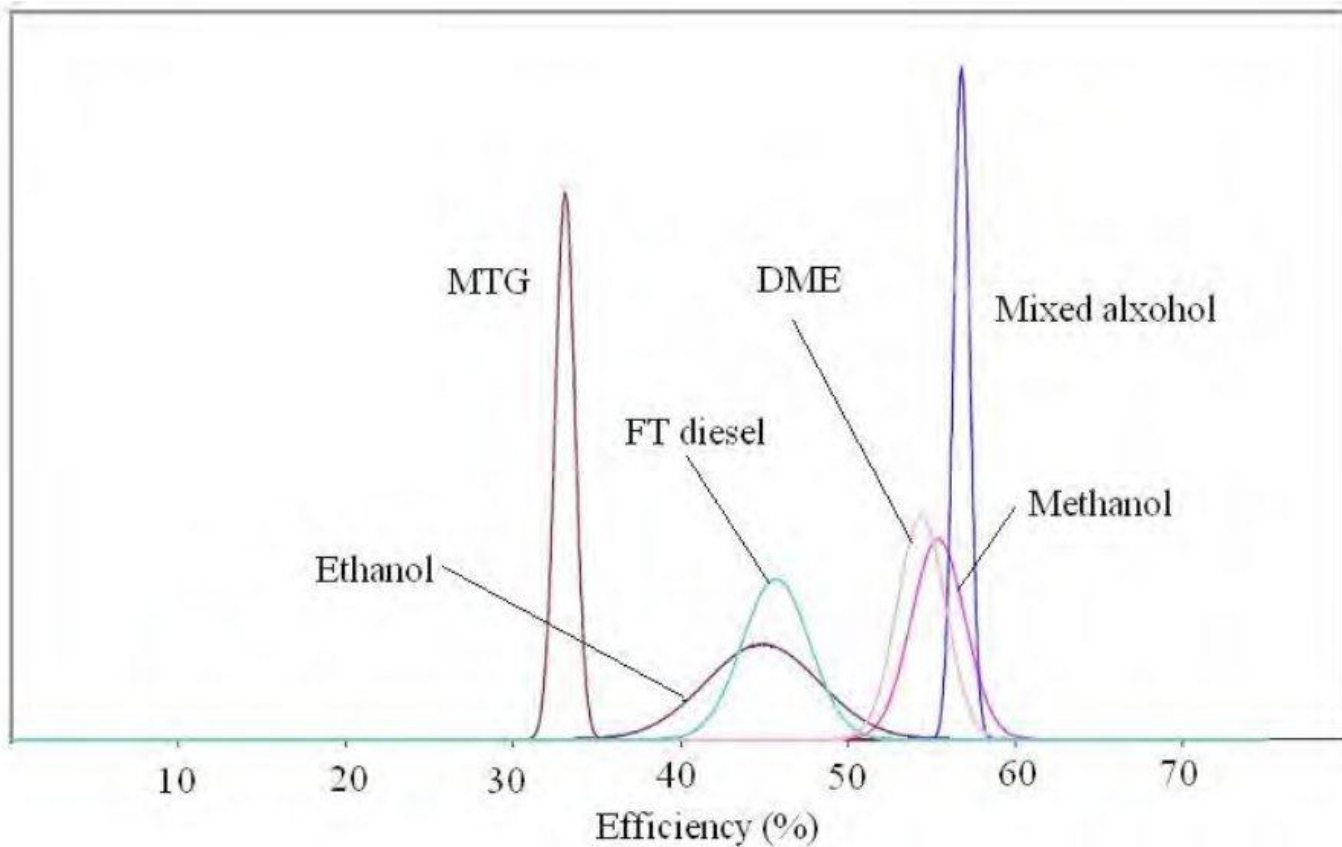


Figure 8. Probability distribution function of biomass to tank utilization efficiency from the MonteCarlo analysis [Stark]

Less Efficient, Lower Yields ← ————— → More Efficient, Higher Yields

ANALYSIS MATRIX, 2012, 2025, 2050

| Technology | Mission | Range | Infrastructure | Vehicle Capex | Fuel Opex | Emissions (NOx, HC, CO, PM) | EPACT | GHG/LCFS | Energy Efficiency (mpg) | Major Barrier |
|--|---------|-------|----------------|---------------|-----------|-----------------------------|-------|----------|-------------------------|----------------------|
| Gasoline/Diesel Conventional | ● | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | EPACT/GHG |
| Gas to Liquid (GTL) | ● | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | GHG |
| Liquid Petroleum Gas (LPG) | ● | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | Fuel Opex |
| Renewable Content Gasoline/Diesel | ● | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | EPACT/GHG |
| Biodiesel | ● | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | Fuel Opex |
| Ethanol (E85) | ● | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | Fuel Opex |
| Methanol (M85) | ● | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | Safety |
| Compressed Natural Gas (CNG) | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | Infrastructure |
| Liquefied Natural Gas (LNG) | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | Infrastructure |
| Hythane (CNG/Hydrogen) | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | Infrastructure |
| Hybrid Electric Vehicles (HEV) all fuels | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | EPACT |
| Plug-in Hybrid Electric Vehicle (PHEV) | ● | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | Capex |
| Extended Range Electric Vehicle (EREV) | ● | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | Capex |
| Battery Electric Vehicle (BEV) | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | Range/Capex |
| Methanol (M100 Fuel Cell) | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | Infrastructure/Capex |
| Hydrogen Fuel Cell | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | Infrastructure/Capex |

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