LNG AS A MARINE FUEL

NORTHEAST DIESEL COLLABORATIVE

PORTS WORK GROUP

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CHOOSING A MARINE FUEL

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- 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?

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- Criteria Pollutants – Clean? Tier 4?
- EPACT – Domestic Fuel?
- LCFS/RFS – Low Carbon Intensity? Renewable?
- Energy Efficiency – Improved Fuel Economy?

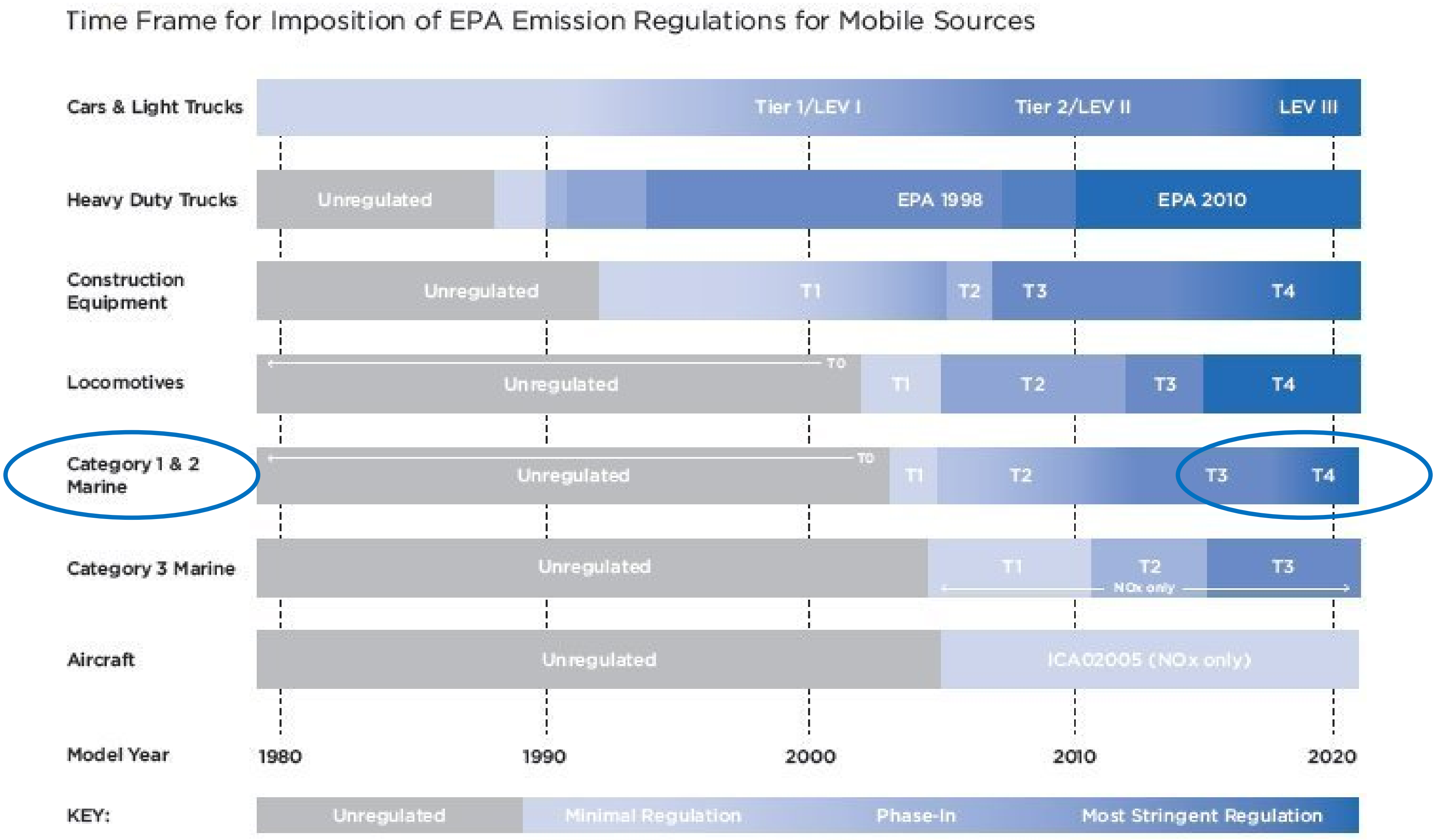
WHY LNG & WHY NOW?

- **EPA Regulatory Drivers**
  - Marine >600 kW, Tier 4 from 2015 onward (new builds now)
  - Natural Gas Engines able to meet Tier 4 more easily than diesel
  - EPA fuel sulfur limits driving up cost of residual & distillate fuel
- **Cost Drivers**
  - Fuel up to 50% of annual budget for marine operators
  - NG fuel can be half the price of diesel per unit of energy
  - High CAPEX for vessel conversion to LNG – *ROI and pay-back*
  - Lack of price transparency for LNG fuel – *uncertainty*
  - Long take-off requirements for LNG contracts – *more uncertainty*
- **Operability Drivers**
  - Marine needs long range capability
  - Only a liquid (LNG) can meet range demands (CNG not practical)

MAJOR OBSTACLES

- **High CAPEX** for vessel conversion to LNG – *ROI and pay-back*
- Lack of **Price Transparency** for LNG fuel – *uncertainty in benefits of conversion*
- Long take-off requirements for **LNG Contracts**– *more uncertainty*
- Limited **LNG Fueling Infrastructure**
- Potential for **Methane Leakage** from bunkering operations – *erodes GHG benefit of NG compared to diesel*

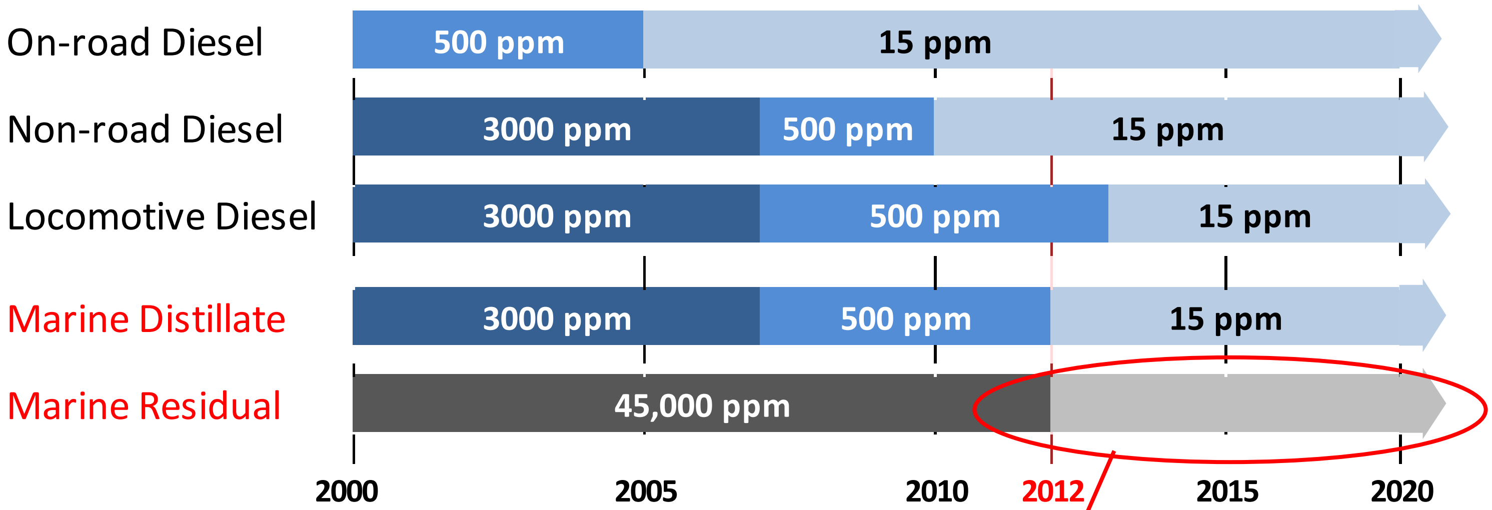
CLEAN CRITERIA POLLUTANT STANDARDS

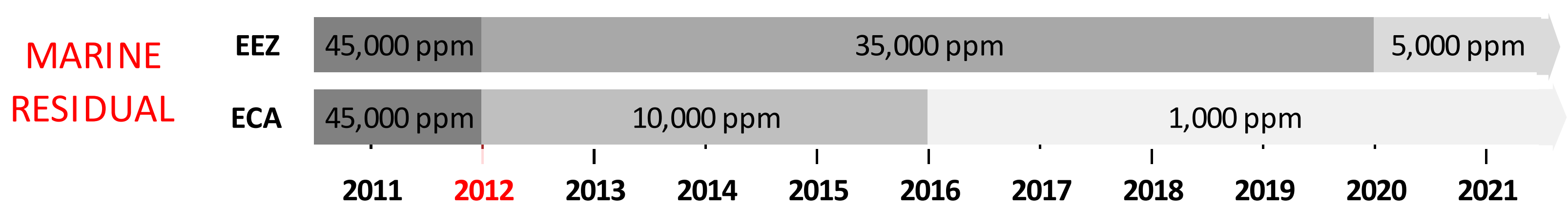


EPA NEW MARINE ENGINE STANDARDS

- **Time Line – Tier 4**
  - ✓After 2015, engine manufactures will have limited ability to produce non-Tier 4 engines and only for repowers
  - ✓After 2016 all new vessels will have to have Tier 4 compliant engines
- **Technology**
  - ✓For diesel engines, Tier 4 will require SCR and DOC, perhaps DPF
  - ✓LNG engines can meet Tier 4 with Oxidation Catalyst only
- **Future Requirements**
  - ✓Tier 5 might be expected in the 2025 timeframe – to include GHG limits, Tighter NOx and PM limits
  - ✓LNG may be able to meet future Tier 5 limits without major technology changes

THE WAR ON FUEL SULFUR





EEZ = Exclusive Economic Zone (generally 200 miles from coast)
ECA = Emission Control Area (designated under IMO rules)

NORTH AMERICAN ECA IS SO2 AND NOX

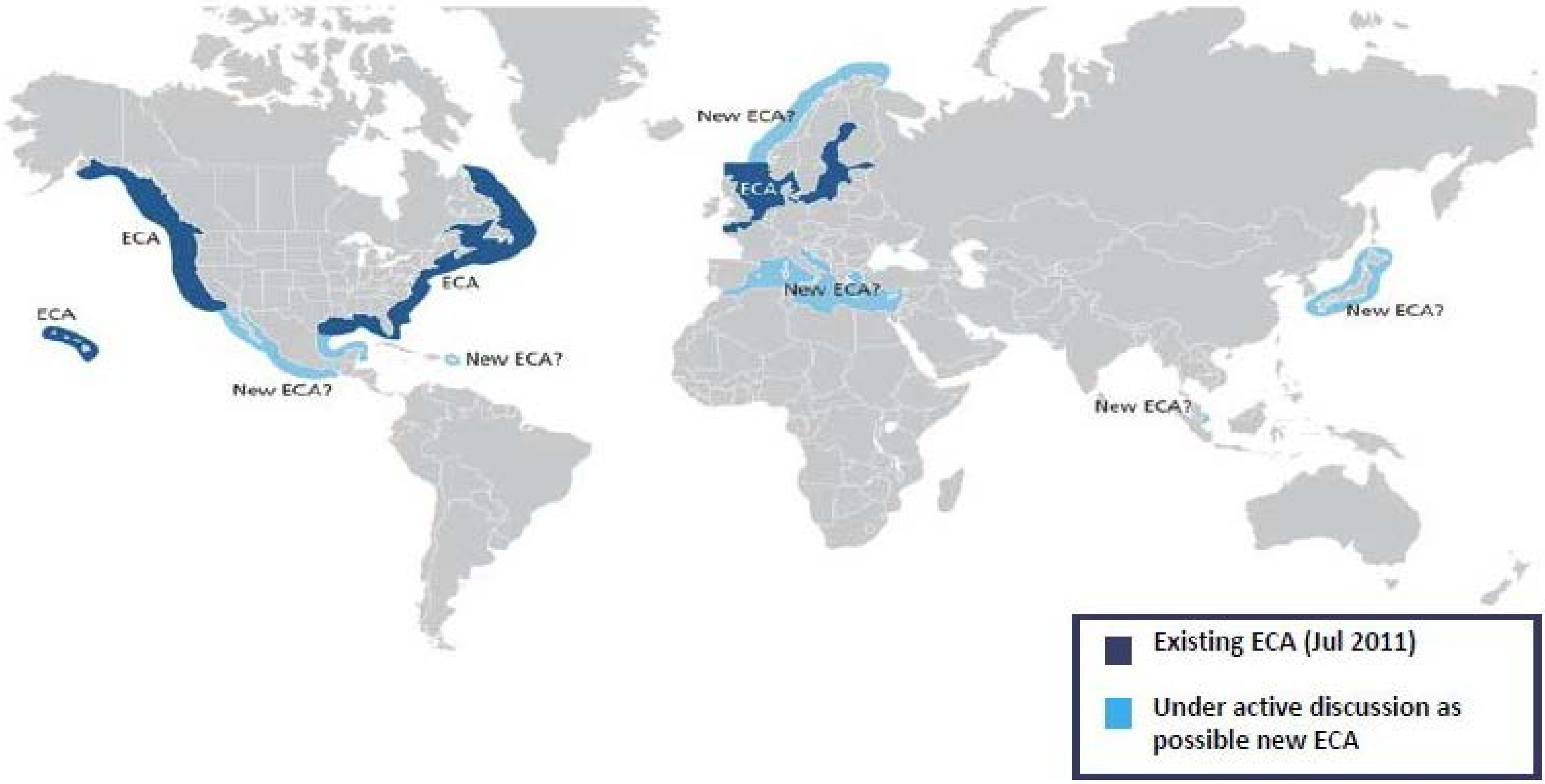
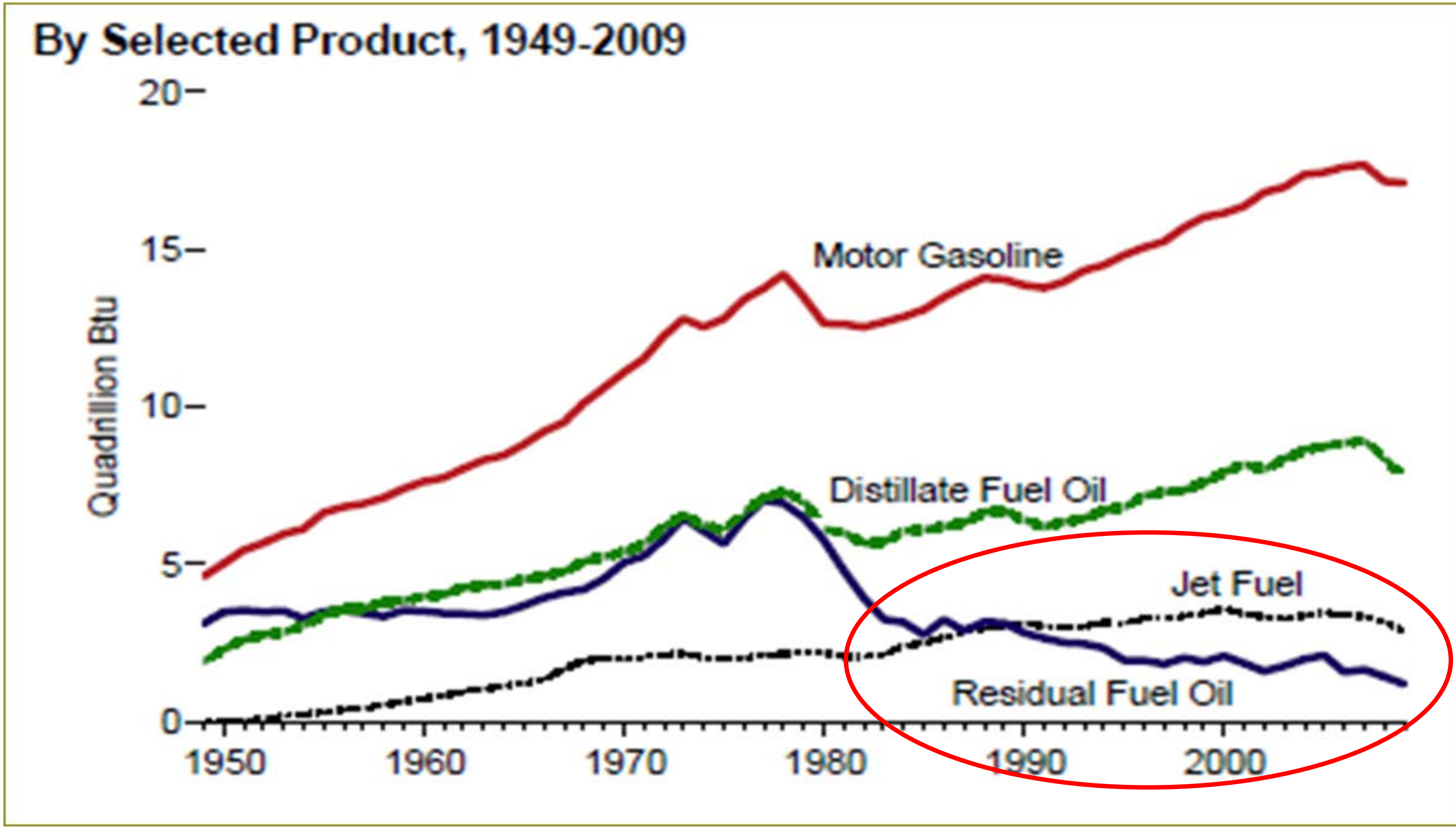


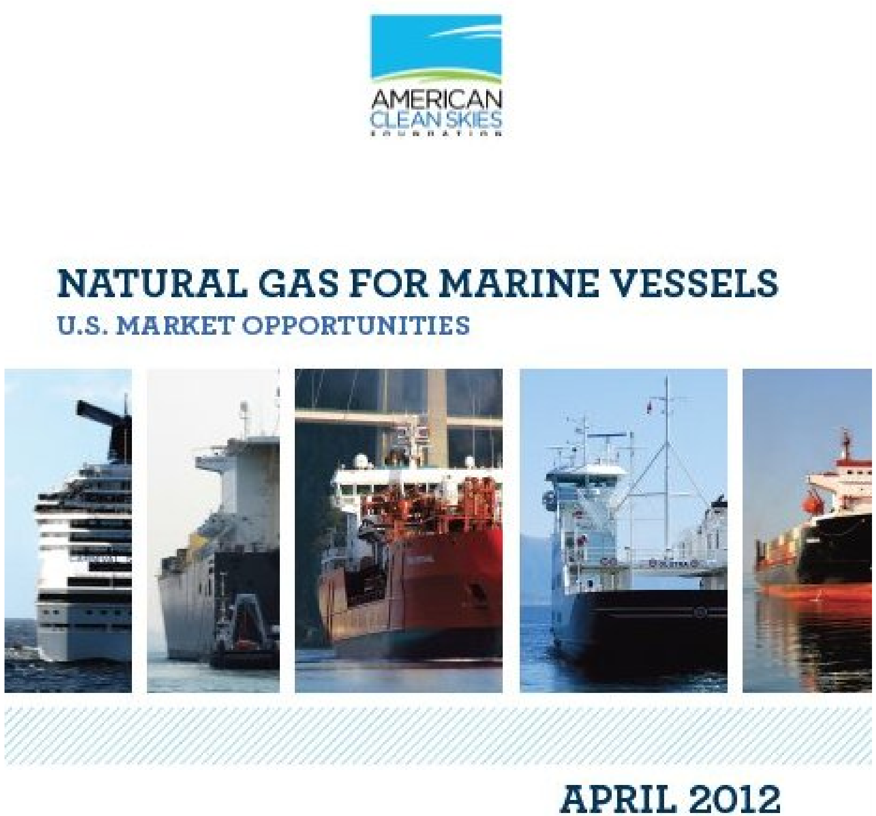
Image Provided by DNV

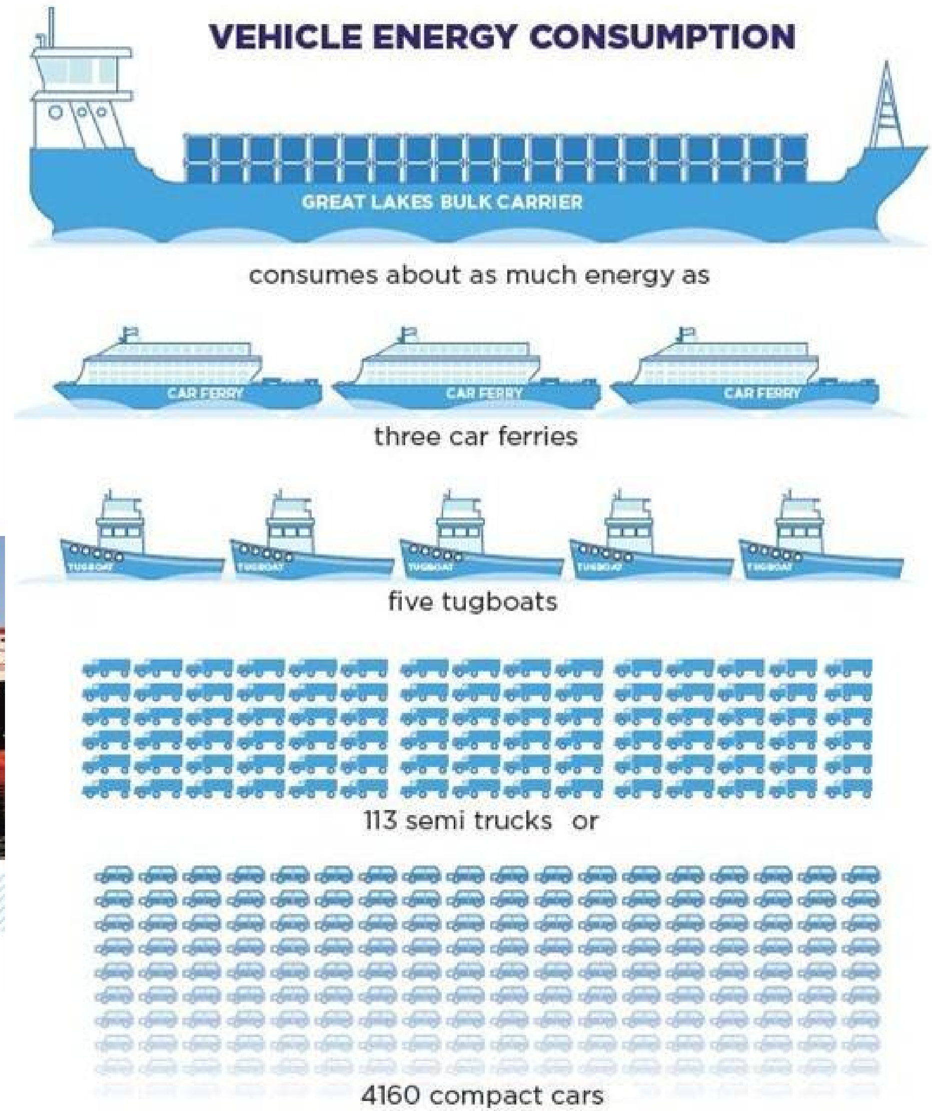
DECLINING USE OF RESIDUAL FUEL SINCE 1980s



In the US marine vessels are last major user of residual fuel

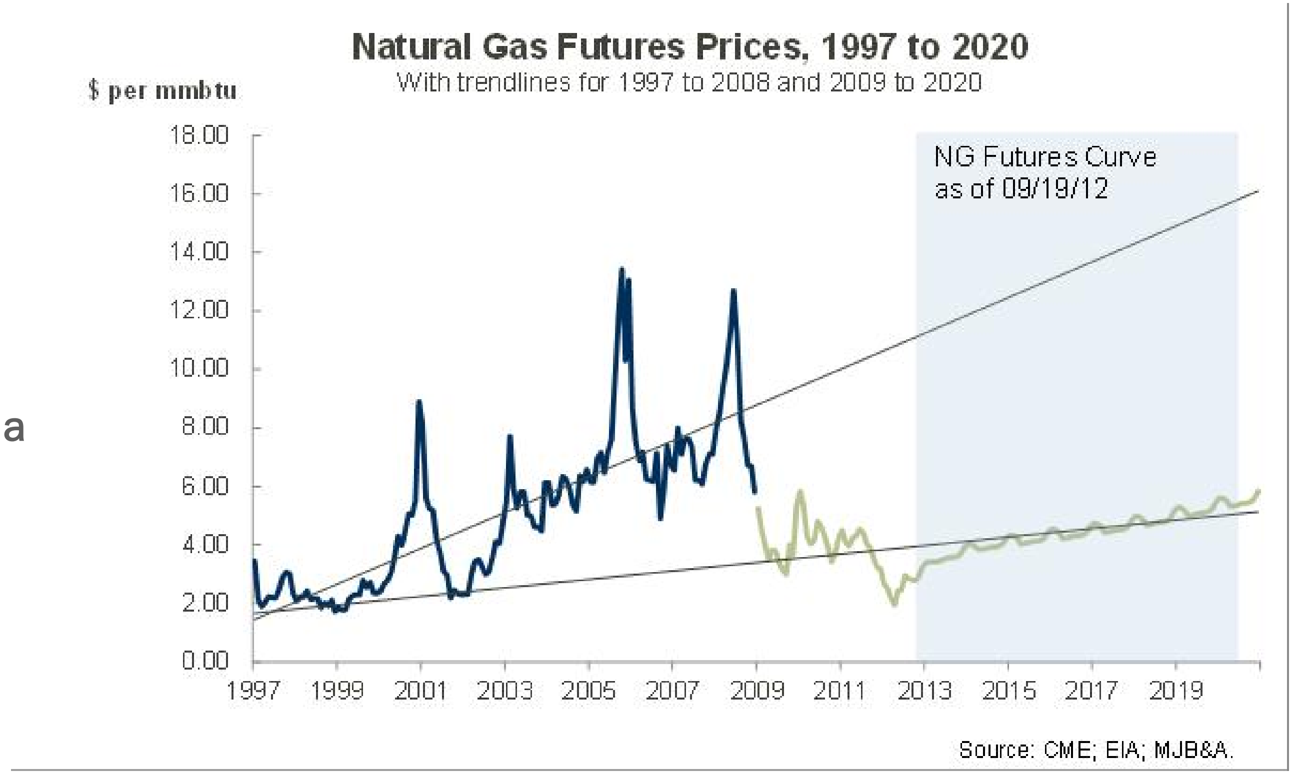
FUEL COST MATTERS TO HIGH CONSUMPTION USERS

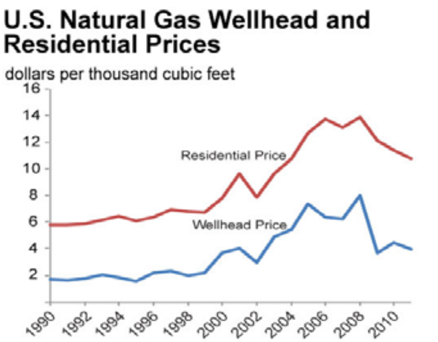




NATURAL GAS COMMODITY VS DELIVERED PRODUCT

- 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





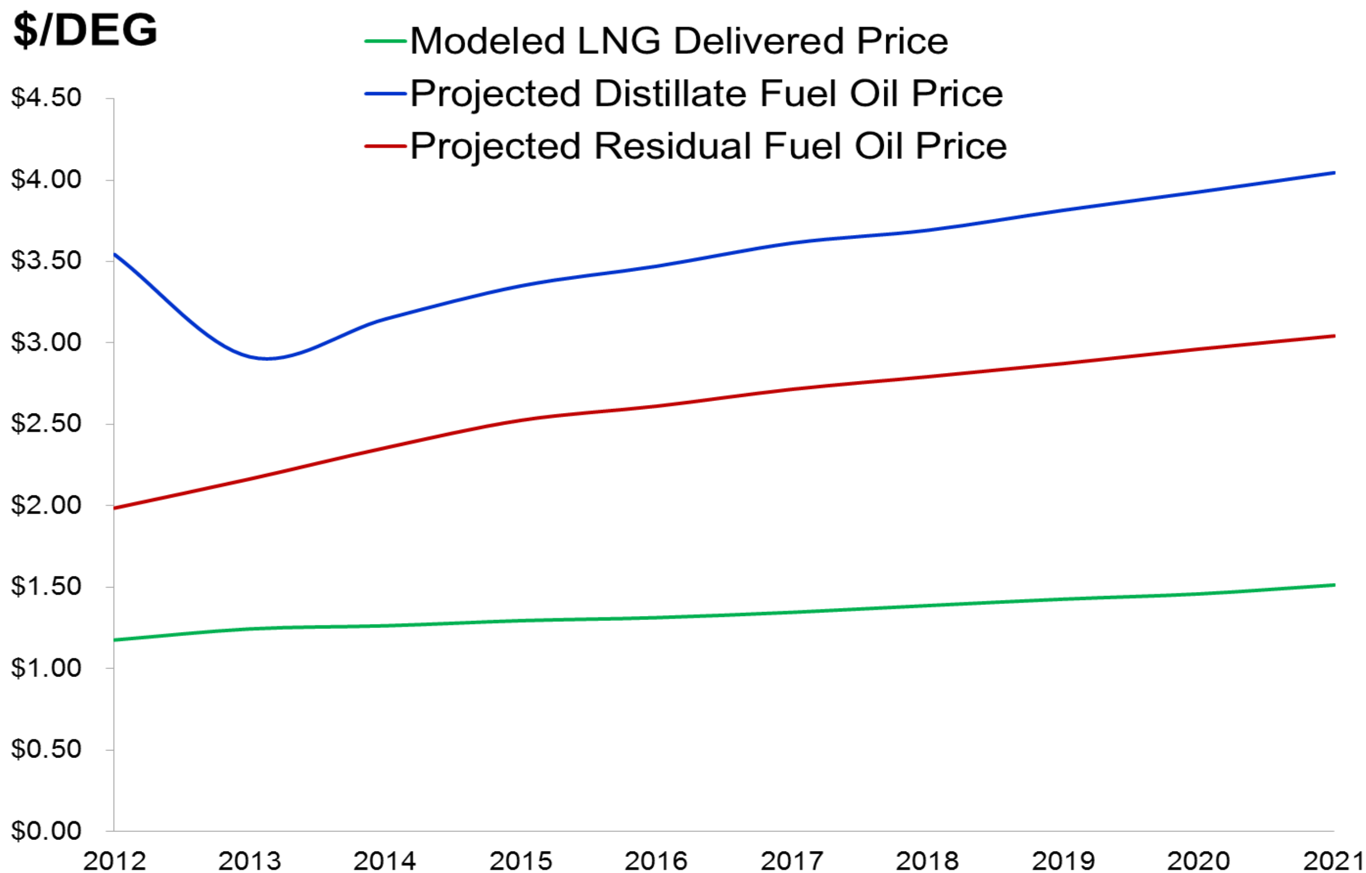
Source: U.S. Energy Information Administration, Forms EIA-857 and EIA-895 (June 2012), preliminary 2011 data.

- 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

To be conservative ~$1.51/therm x 1.29 DGE + $0.55 tax = $2.50 DGe

PROJECTED MARINE FUEL COSTS

Based on EIA AEO April 2012 early release, and production model for new LNG liquefaction facility (taxes not included)



Retail LNG in CA (Clean Energy fuels, 1/13): $2.92/DEG (incl. $0.55/gal taxes)

DEG = Diesel Equivalent gallon = 129,000 Btu = 1.29 therms

~$1.00/therm x 1.29 DGE + $0.55 tax = $1.84 DGe + Delivery

LNG CONVERSION COST & PAY BACK PERIOD

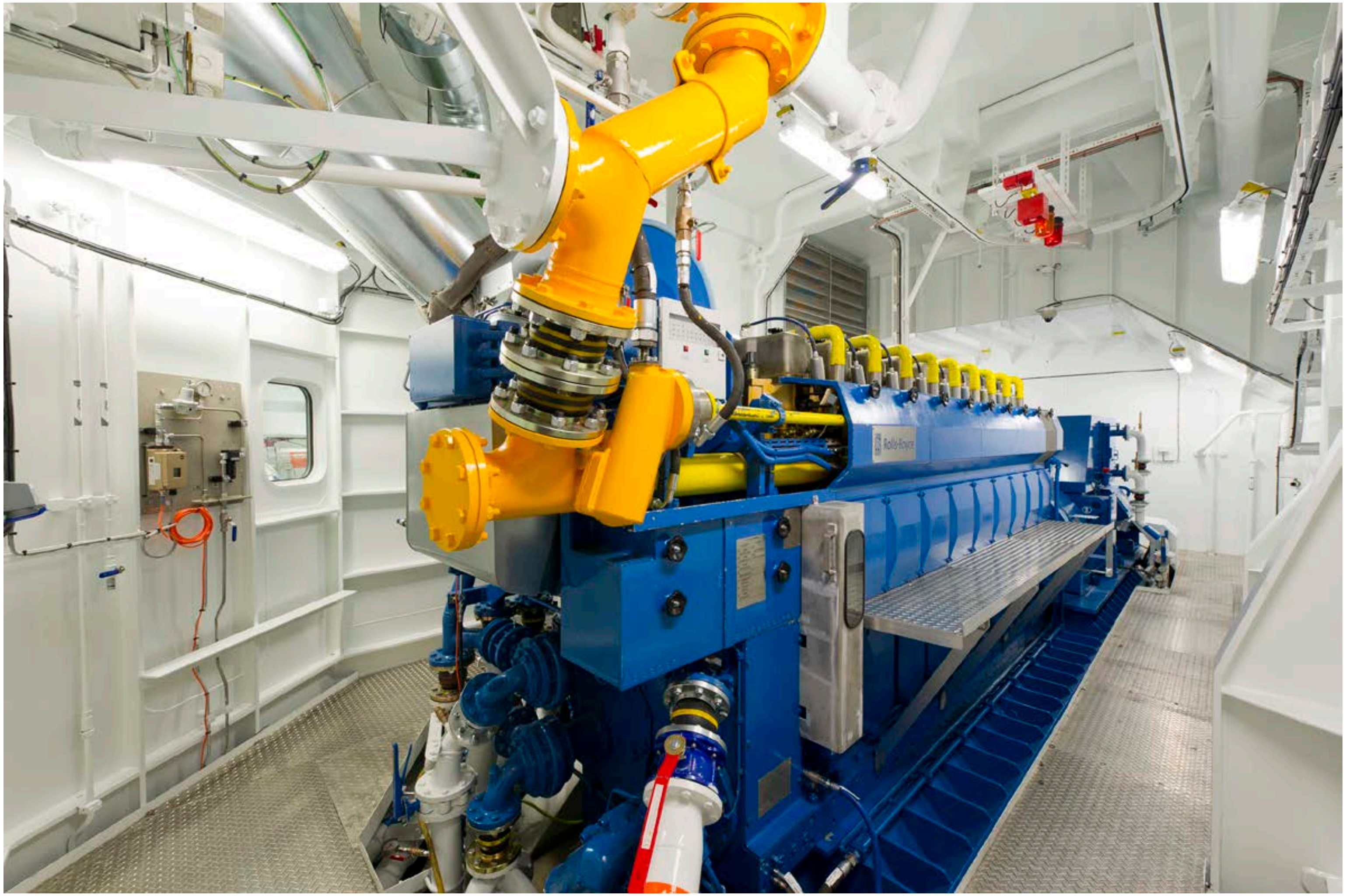
Order of Magnitude Costs to Convert Typical Marine Vessels to LNG Operation

Type	Size (tons)	Engines	Engine Cost	Fuel System Cost	TOTAL CONVERSION COST
Tug	150	2 x 1500 HP	$1.2 million	$6.0 million	$7.2 million
Ferry	1000	2 x 3000 HP	$1.8 million	$9.0 million	$10.8 million
Great Lakes Bulk Carrier	19000	2 x 5000 HP	$4.0 million	$20 million	$24 million

Fuel Usage of Model Vessels

Type	Fuel	Annual Demand (gal)	Annual Equivalent LNG Demand (gal)	Annual Energy Demand (Therm)	Present Value 10-year Fuel Savings (7% Discount Rate)	Net Present Value of the Project
Tug	Distillate	424,000	768,221	583,848	$6.9 million	-$0.28 million
Ferry	Distillate	678,400	1,229,154	934,157	$11.1 million	$0.27 million
Great Lakes Bulk Carrier	Residual	2,080,064	4,097,179	3,113,856	$20.6 million	-$3.4 million

DO WE HAVE LNG MARINE ENGINES? YES

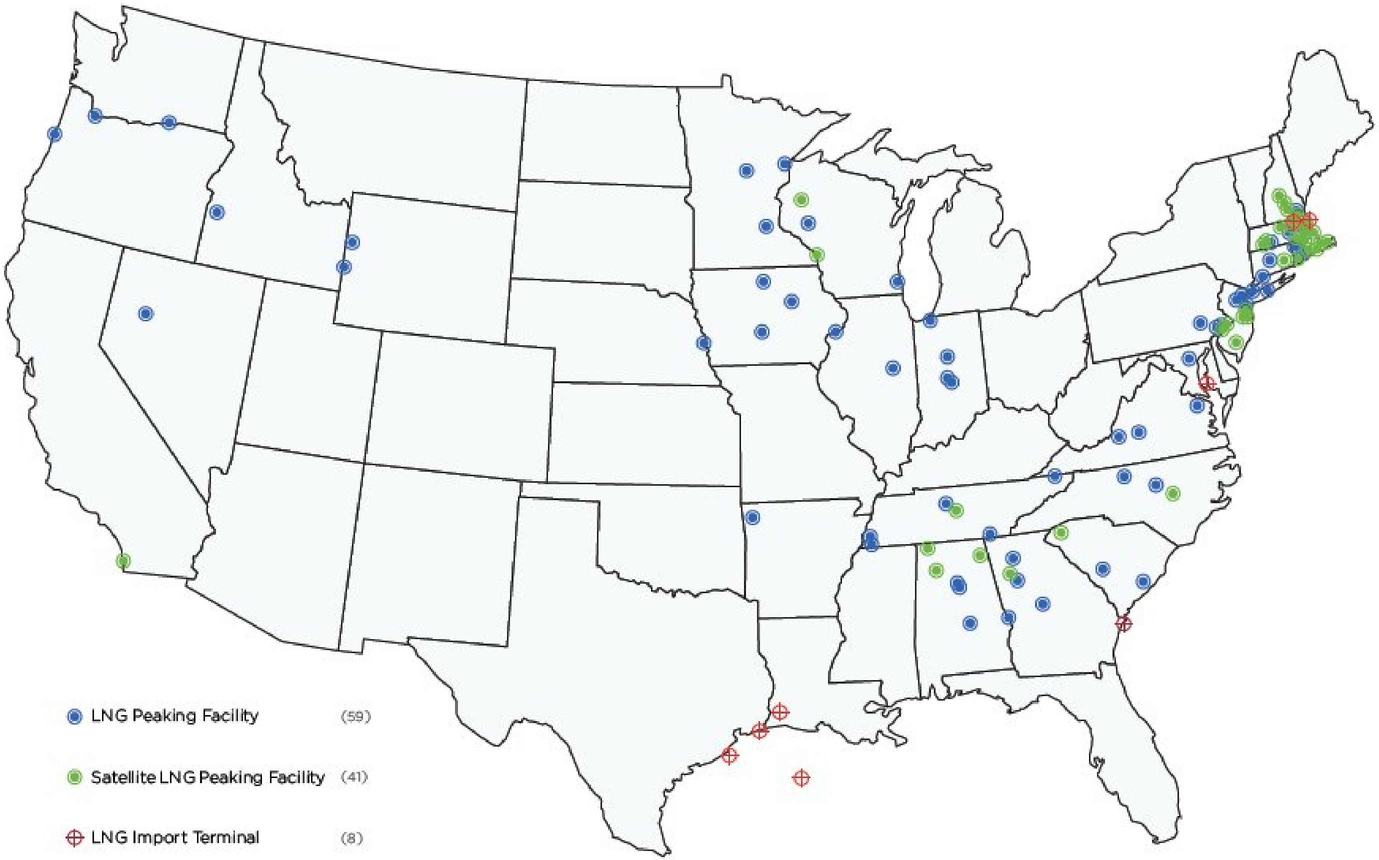


Rolls Royce, Tier 3 certified: meets Tier 4, and is capable of 25% of Tier 4 NOx

CRRMN158.CPG, 2012 Tier 3 CoC issued 8/14/12
http://www.rolls-royce.com/marine/news/2012/120904_epa_approval.jsp

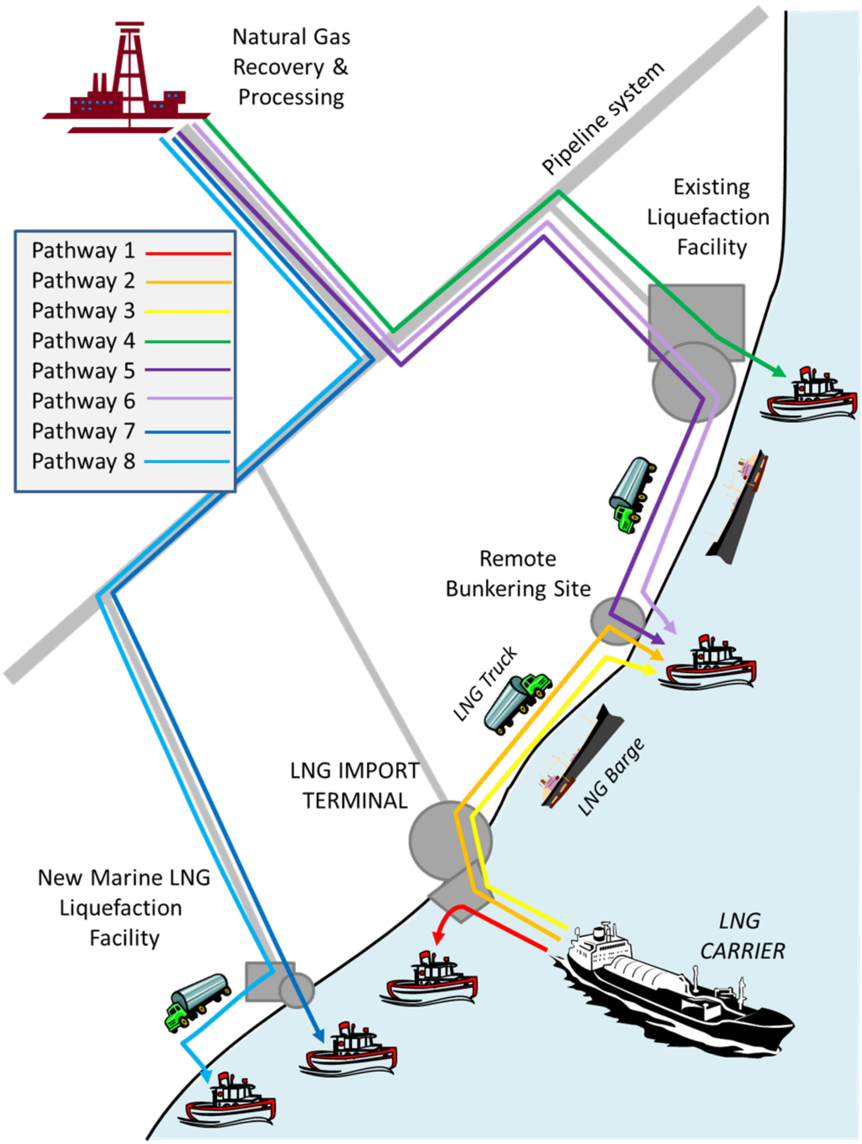
DO WE HAVE LNG? PIPELINE GAS CONNECTED

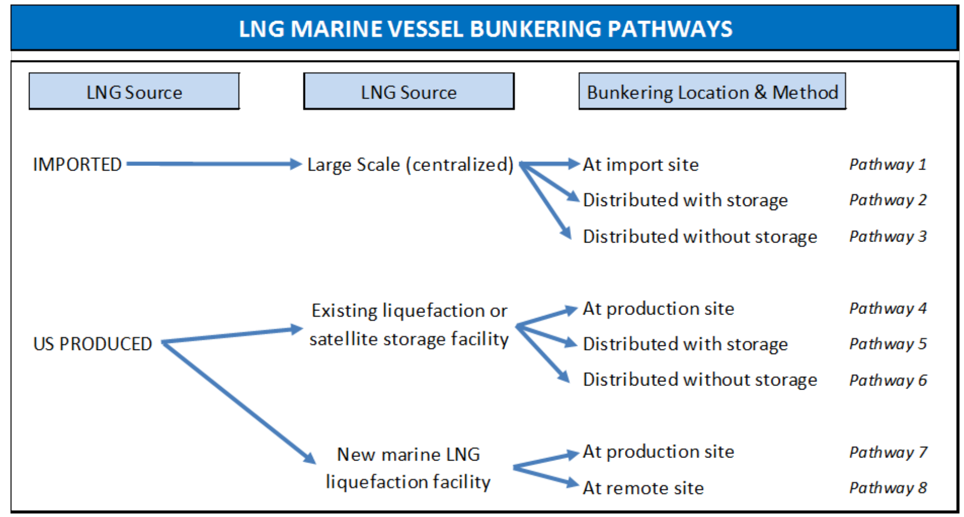
U.S. LNG Peaking Shaving and Import Facilities, 2008 [R5]



Note: Satelite 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 MARINE BUNKERING





MARINE LNG METHANE LEAKAGE SOURCES

- Boil-off-Gas vented during long-term storage of LNG in land-side storage tanks (heat absorption)
- Vapor displaced when filling near empty LNG storage tanks
- Liquid and vapor purged from filling lines/hoses after filling an LNG storage tank
- Flash losses created from pre-cooling tanks/equipment
- Flash losses created when transferring LNG from a high-pressure to a low-pressure tank

The longer LNG is held in the supply chain, and the more times it is handled, the greater potential for methane leakage

LNG BOIL-OFF-GAS (BOG) HANDLING

1. Capture vapors , compress them and inject them into pipeline grid
2. Capture vapors, re-liquefy them, and put LNG into storage tank

Used at LNG import terminals and liquefaction plants – “BOG handling systems”

3. Release to the atmosphere

Least cost option – likely at remote marine bunker sites absent regulation. Increases GHGs from use of LNG as marine fuel

4. Flaring
5. L/CNG (for vehicles)

Potential options at remote marine bunker sites to reduce GHGs

POTENTIAL METHANE LEAKAGE FROM LNG BUNKERING

Preliminary analysis

	g CH_4/mmBtu							
METHANE EMISSIONS	**MARINE BUNKERING PATHWAY**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Upsteam	68	68	68	400	400	400	400	400
Bunkering	2	189	46	0	182	46	0	46
Vessel Operation	207	207	207	207	207	207	207	207
TOTAL	**277**	**464**	**322**	**607**	**789**	**654**	**607**	**654**

Lowest potential leakage is from direct ship fueling at import terminal or liquefaction plant with a BOG handling system

Highest potential leakage is from land-side tank to ship fueling at a remote site with no BOG handling system

Process	**CH_4 Leakage [g/mmBtu]**	**CH_4 Leakage % of Total**
LNG Truck Loading	6.9	4%
LNG Truck Transport	0.0	0%
LNG Truck Off-Loading	5.6	3%
LNG Tank Filling at Bunker Site	24.1	13%
LNG Storage at Bunker Site	111.4	59%
LNG Vessel Fueling	40.8	22%
TOTAL	**188.8**	**100%**

SUMMARY

- **LNG is a good fuel for marine vessels**
  - ✓Reasonable range
  - ✓Pure hydrocarbon
- **LNG will not be cost-effective for all vessels despite low fuel costs**
  - ✓High CAPEX for vessel conversion
- **LNG price is low relative to distillate fuel, but the market will benefit from more transparency**
- **Efficient LNG infrastructure for marine bunkering is a "chicken and egg' situation**
- **BOG handling is important at remote marine bunker sites**
  - ✓Methane leakage erodes GHG benefit of NG

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