LNG AS A MARINE FUEL

NORTHEAST DIESEL COLLABORATIVE
PORTS WORK GROUP

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CHOOSING A MARINE FUEL

OWNER

• 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?

SOCIETY

• 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

Time Frame for Imposition of EPA Emission Regulations for Mobile Sources

Cars & Light Trucks
- Tier 1/LEV I
- Tier 2/LEV II
- LEV III

Heavy Duty Trucks
- Unregulated
- EPA 1998
- EPA 2010

Construction Equipment
- Unregulated
- T1
- T2
- T3
- T4

Locomotives
- Unregulated
- T0
- T1
- T2
- T3
- T4

Category 1 & 2 Marine
- Unregulated
- T0
- T1
- T2
- T3
- T4

Category 3 Marine
- Unregulated
- T1
- T2
- T3

Aircraft
- Unregulated
- ICAO2005 (NOx only)

Model Year
- 1980
- 1990
- 2000
- 2010
- 2020

KEY:
- Unregulated
- Minimal Regulation
- Phase-In
- Most Stringent Regulation
EPA NEW MARINE ENGINE STANDARDS

• **Time Line – Tier 4**
  - After 2015, engine manufacturers 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**

<table>
<thead>
<tr>
<th>Type</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
</tr>
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<tbody>
<tr>
<td>On-road Diesel</td>
<td>500 ppm</td>
<td></td>
<td>15 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-road Diesel</td>
<td>3000 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locomotive Diesel</td>
<td>3000 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Distillate</td>
<td>3000 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Residual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45,000 ppm</td>
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</tbody>
</table>

**MARINE RESIDUAL**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EEZ</td>
<td>45,000 ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35,000 ppm</td>
<td>5,000 ppm</td>
<td></td>
</tr>
<tr>
<td>ECA</td>
<td>45,000 ppm</td>
<td>10,000 ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,000 ppm</td>
<td></td>
</tr>
</tbody>
</table>

EEZ = Exclusive Economic Zone (generally 200 miles from coast)
ECA = Emission Control Area (designated under IMO rules)
NORTH AMERICAN ECA IS **SO2 AND NOX**
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

VEHICLE ENERGY CONSUMPTION

consumes about as much energy as

two car ferries

two tugboats

110 semi trucks or

4,160 compact cars

NATURAL GAS FOR MARINE VESSELS
U.S. MARKET OPPORTUNITIES

APRIL 2012

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.

• 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
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

<table>
<thead>
<tr>
<th>Type</th>
<th>Size (tons)</th>
<th>Engines</th>
<th>Engine Cost</th>
<th>Fuel System Cost</th>
<th>Total Conversion Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tug</td>
<td>150</td>
<td>2 x 1500 HP</td>
<td>$1.2 million</td>
<td>$6.0 million</td>
<td>$7.2 million</td>
</tr>
<tr>
<td>Ferry</td>
<td>1000</td>
<td>2 x 3000 HP</td>
<td>$1.8 million</td>
<td>$9.0 million</td>
<td>$10.8 million</td>
</tr>
<tr>
<td>Great Lakes Bulk Carrier</td>
<td>19000</td>
<td>2 x 5000 HP</td>
<td>$4.0 million</td>
<td>$20 million</td>
<td>$24 million</td>
</tr>
</tbody>
</table>

## Fuel Usage of Model Vessels

<table>
<thead>
<tr>
<th>Type</th>
<th>Fuel</th>
<th>Annual Demand (gal)</th>
<th>Annual Equivalent LNG Demand (gal)</th>
<th>Annual Energy Demand (Therm)</th>
<th>Present Value 10-year Fuel Savings (7% Discount Rate)</th>
<th>Net Present Value of the Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tug</td>
<td>Distillate</td>
<td>424,000</td>
<td>768,221</td>
<td>583,848</td>
<td>$6.9 million</td>
<td>-$0.28 million</td>
</tr>
<tr>
<td>Ferry</td>
<td>Distillate</td>
<td>678,400</td>
<td>1,229,154</td>
<td>934,157</td>
<td>$11.1 million</td>
<td>$0.27 million</td>
</tr>
<tr>
<td>Great Lakes Bulk Carrier</td>
<td>Residual</td>
<td>2,080,064</td>
<td>4,097,179</td>
<td>3,113,856</td>
<td>$20.6 million</td>
<td>-$3.4 million</td>
</tr>
</tbody>
</table>
DO WE HAVE **LNG** MARINE ENGINES? **YES**

*Rolls Royce, Tier 3 certified: meets Tier 4, and is capable of 25% of Tier 4 NOx*
DO WE HAVE LNG? PIPELINE GAS 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.
LNG MARINE BUNKERING

LNG MARINE VESSEL BUNKERING PATHWAYS

<table>
<thead>
<tr>
<th>LNG Source</th>
<th>LNG Source</th>
<th>Bunkering Location &amp; Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPORTED</td>
<td>Large Scale (centralized)</td>
<td>At import site</td>
</tr>
<tr>
<td></td>
<td>Distributed with storage</td>
<td>Distributed without storage</td>
</tr>
<tr>
<td></td>
<td>Distributed without storage</td>
<td></td>
</tr>
<tr>
<td>US PRODUCED</td>
<td>Existing liquefaction or satellite storage facility</td>
<td>At production site</td>
</tr>
<tr>
<td></td>
<td>Distributed with storage</td>
<td>Distributed without storage</td>
</tr>
<tr>
<td></td>
<td>Distributed without storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New marine LNG liquefaction facility</td>
<td>At production site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At remote site</td>
</tr>
</tbody>
</table>

Truck-to-ship fueling
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

3. Release to the atmosphere

4. Flaring

5. L/CNG (for vehicles)

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

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

Potential options at remote marine bunker sites to reduce GHGs
POTENTIAL METHANE LEAKAGE FROM LNG BUNKERING

Preliminary analysis

<table>
<thead>
<tr>
<th>METHANE EMISSIONS</th>
<th>MARINE BUNKERING PATHWAY</th>
<th>g CH₄/mmBtu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Upstream</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>Bunkering</td>
<td>2</td>
<td>189</td>
</tr>
<tr>
<td>Vessel Operation</td>
<td>207</td>
<td>207</td>
</tr>
<tr>
<td>TOTAL</td>
<td>277</td>
<td>464</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Process</th>
<th>CH₄ Leakage [g/mmBtu]</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Truck Loading</td>
<td>6.9</td>
<td>4%</td>
</tr>
<tr>
<td>LNG Truck Transport</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td>LNG Truck Off-Loading</td>
<td>5.6</td>
<td>3%</td>
</tr>
<tr>
<td>LNG Tank Filling at Bunker Site</td>
<td>24.1</td>
<td>13%</td>
</tr>
<tr>
<td>LNG Storage at Bunker Site</td>
<td>111.4</td>
<td>59%</td>
</tr>
<tr>
<td>LNG Vessel Fueling</td>
<td>40.8</td>
<td>22%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>188.8</td>
<td>100%</td>
</tr>
</tbody>
</table>
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