The Potential Conversion of the U.S. Great Lakes Steam Bulk Carriers to LNG Propulsion

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Goals of Project

• Conceptual designs of LNG conversion for 10 remaining steam powered bulk carriers


• Evaluate fuel cost and air emissions
• Prepare shipyard conversion plan
• Estimate overall economics and payback periods
• Organize and lead trip to observe Norwegian LNG use
Outline

• Vessels under consideration
• Emission Control Area (ECA) emissions
• Advantage of conversion to LNG fuel
• Challenges in using LNG fuel
• Conceptual design for AAA LNG conversions
  – Fuel use comparison and tank sizing
  – Air emissions comparison
  – Arrangement feasibility
• Conclusions
### U.S. Flag Great Lakes Steam Bulk Carriers

<table>
<thead>
<tr>
<th>Name</th>
<th>Length</th>
<th>Year Built</th>
<th>normal SHIP</th>
<th>Capacity (net tons)</th>
<th>Typical Cargoes</th>
<th>Fleet</th>
<th>Building Yard</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edward L. Ryerson</td>
<td>730'</td>
<td>1960</td>
<td>9,000</td>
<td>30,800</td>
<td>Iron ore</td>
<td>Central Marine Logistics</td>
<td>Manitowoc</td>
<td>straight decker</td>
</tr>
<tr>
<td>American Victory</td>
<td>730'</td>
<td>1943</td>
<td>7,000</td>
<td>29,120</td>
<td>Iron ore, coal, limestone</td>
<td>American</td>
<td>Bethlehem</td>
<td>AO71 Neshamie</td>
</tr>
<tr>
<td>American Valor</td>
<td>767'</td>
<td>1953</td>
<td>7,000</td>
<td>28,560</td>
<td>Iron ore, coal, limestone</td>
<td>American</td>
<td>AMSHIP Lorain</td>
<td></td>
</tr>
<tr>
<td>John G. Munson</td>
<td>768'</td>
<td>1952</td>
<td>7,000</td>
<td>28,560</td>
<td>Iron ore, coal, limestone</td>
<td>Keylakes</td>
<td>Manitowoc</td>
<td></td>
</tr>
<tr>
<td>Arthur M. Anderson *</td>
<td>767'</td>
<td>1952</td>
<td>7,000</td>
<td>28,336</td>
<td>Iron ore, coal, limestone</td>
<td>Keylakes</td>
<td>AMSHIP Lorain</td>
<td>boom forward, bunker aft</td>
</tr>
<tr>
<td>Cason J. Callaway  *</td>
<td>767'</td>
<td>1952</td>
<td>7,000</td>
<td>28,336</td>
<td>Iron ore, coal, limestone</td>
<td>Keylakes</td>
<td>GLEW Detroit</td>
<td></td>
</tr>
<tr>
<td>Philip R. Clarke  *</td>
<td>767'</td>
<td>1952</td>
<td>7,000</td>
<td>28,336</td>
<td>Iron ore, coal, limestone</td>
<td>Keylakes</td>
<td>AMSHIP Lorain</td>
<td></td>
</tr>
<tr>
<td>Herbert C. Jackson</td>
<td>690'</td>
<td>1959</td>
<td>6,000</td>
<td>27,776</td>
<td>Iron ore, coal, limestone, Interlake Steamship</td>
<td>GLEW Detroit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Fortitude</td>
<td>690'</td>
<td>1953</td>
<td>7,000</td>
<td>24,976</td>
<td>Iron ore, coal, limestone</td>
<td>American</td>
<td>AMSHIP Lorain</td>
<td></td>
</tr>
<tr>
<td>Wilfred Sykes</td>
<td>671'</td>
<td>1949</td>
<td>7,000</td>
<td>24,080</td>
<td>Iron ore, coal, limestone</td>
<td>Central Marine Logistics</td>
<td>AMSHIP Lorain</td>
<td>parent hull for later ships</td>
</tr>
<tr>
<td>Kaye E. Barker</td>
<td>767'</td>
<td>1952</td>
<td>7,000</td>
<td>29,008</td>
<td>Iron ore, coal, limestone</td>
<td>Interlake Steamship</td>
<td>AMSHIP Lorain</td>
<td>to be converted to diesel</td>
</tr>
<tr>
<td>Alpena</td>
<td>519'</td>
<td>1942</td>
<td>4,000</td>
<td>15,568</td>
<td>Cement</td>
<td>Inland Lakes Management</td>
<td></td>
<td>layup- storage</td>
</tr>
<tr>
<td>St. Marys Challenger</td>
<td>552'</td>
<td>1906</td>
<td>3,000</td>
<td>12,656</td>
<td>Cement</td>
<td>Port City Steamship Services</td>
<td></td>
<td>layup- storage</td>
</tr>
</tbody>
</table>

* AAA class

Ten remaining U.S. Flag steam bulk carriers

Three, the AAA Class, are to the same design – initial and primary focus
Emission Control Area (ECA)

- In place for the Baltic Sea and North Sea
- North American ECA became enforceable in August 2012
- ECA includes non-Arctic coastal and inland waters of the U.S., Canada and Saint Pierre & Miquelon
- Lower marine fuel sulfur and NOx requirements
MARPOL (EPA) Marine Fuel Sulfur Limits

Alternative: use exhaust gas scrubbers (NaOH, weight, space, labor, cost, discharge)

1% S differential for IF running $50-90/t in Rotterdam
Diesels will require Selective Catalytic Reduction (SCR) for Tier III (aqueous urea, weight, space, labor, cost)
Status of Emission Control Area (ECA) Air Emissions Requirements

Status

- Fuels must be available
- Congressionally mandated GL steamship exemption
- EPA offer for streamlined conversion to diesel, with S waiver to permit burning IFO to 2026 without scrubber

Premise for study:

Not coming up to EPA ECA emissions standards is not sustainable in the long run
Reasons to Consider LNG Conversions

• LNG cargo carriers use cargo burn-off for fuel (steam, then diesel) approaching 240 vessels; over 40 years experience (classification by ABS, DNV, others)

• Beginning in 2000 with the ferry Glutra, first non-LNG cargo vessel these LNG vessels, mostly in Norway (DNV), now approaching 30

• Recent conversion of a 5 year old 25,000 DWT product tanker Bit Viking from HFO to LNG in a two month conversion (DNV)

• Harvey Gulf International contracted for 4 LNG powered offshore supply vessels (first US flag, ABS, U.S. Coast Guard)
Advantages of using LNG Fuel

• Greater propulsion efficiency – almost 85% better

• Potential reduced fuel cost (on an energy equiv. basis)
  IFO 180 $2.30/gallon LNG equiv. $2.50/gallon (WSF 2014 pred.)
  MDO $2.90/gallon LNG equiv. $2.18/gallon
  LNG predicted to be more stable and flatter into the future

• Reduced air emissions - without the need for scrubber/NaOH
  or Selective Catalytic Reduction (SCR)/aqueous urea to meet
  ECA requirements

• Potential reduced manning – up to 1 officer and 3 crew

• Cleaner, quieter, lower maintenance
Challenges in using LNG Fuel

- Fuel availability – can be trucked initially
- Volume for fuel storage – 3 to 4 times more ship volume
- Protecting hull structure from spills
- Increased capital cost – ship cost up 15-20%
- Training and increased safety culture
- Methane slip – Green House Gas (21 x CO₂)
AAA Conceptual Design

- Same delivered power
- Acceptable range
- All LNG, if feasible (not yet)
- ABS/DNV prefer LNG tanks near centerline
  \(\text{min}(B/5 \text{ or } 11.5 \text{ m})\) from side
  \(\text{min}(B/15 \text{ or } 2 \text{ m})\) abv bottom
- Room for two 17.5 ft OD x 43 ft tall tanks P/S in place of boilers, DFT, and upper bunkers
Plant Configuration

- Two P/S 159 cubic m useable volume LNG tanks separate & duplicate LNG tanks, cold boxes, and Gas Valve Units
- Single fuel or dual fuel gas main engine
  Rolls-Royce Bergen B35:4012VG engine (5400 kW)
  or Wärtsilä 12V34DF engine (5400 kW)
- CRP propeller driven through single reduction gear
- Two Cat diesel generators to replace steam turbogenerators
  Cat C18 ACERT 60 Hz 550 kWe @ 1800 rpm
- Two new gas or dual fuel auxiliary boilers
- No change to vessels forward of FR 183
Assumed Round Trip Voyage Duluth to Gary

<table>
<thead>
<tr>
<th>mode of operation</th>
<th>percent propulsion power</th>
<th>auxiliaries in use</th>
<th>hours per voyage</th>
<th>percent of voyage</th>
</tr>
</thead>
<tbody>
<tr>
<td>loading</td>
<td>0.00%</td>
<td>ship service, ballast pumps</td>
<td>6</td>
<td>4.40%</td>
</tr>
<tr>
<td>maneuvering</td>
<td>30.00%</td>
<td>ship service</td>
<td>6</td>
<td>4.40%</td>
</tr>
<tr>
<td>reduced speed</td>
<td>50.00%</td>
<td>ship service</td>
<td>8</td>
<td>5.90%</td>
</tr>
<tr>
<td>open lake</td>
<td>85.00%</td>
<td>ship service</td>
<td>103</td>
<td>76.30%</td>
</tr>
<tr>
<td>locking/docking</td>
<td>10.00%</td>
<td>ship service, thrusters</td>
<td>2</td>
<td>1.50%</td>
</tr>
<tr>
<td>unloading</td>
<td>0.00%</td>
<td>ship service, ballast pumps, conveyors</td>
<td>10</td>
<td>7.40%</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td></td>
<td>135</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

### Annual Fuel Cost Comparison

<table>
<thead>
<tr>
<th></th>
<th>Rolls-Royce B35:40V12PG</th>
<th>Wärtsilä 12V34DF</th>
<th>MaK 6M43C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Engine Fuel</strong></td>
<td>Bunker C</td>
<td>LNG</td>
<td>LNG &amp; MDO</td>
</tr>
<tr>
<td><strong>Generator Set Fuel</strong></td>
<td>Bunker C, MDO</td>
<td>MDO</td>
<td>MDO</td>
</tr>
<tr>
<td><strong>Main Engine Fuel Price</strong></td>
<td>$675/t</td>
<td>$690/t</td>
<td>$690/t, $1025/t</td>
</tr>
<tr>
<td><strong>Generator Fuel Price</strong></td>
<td>$675/t, $1025/t</td>
<td>$1025/t</td>
<td>$1025/t</td>
</tr>
<tr>
<td><strong>Fuel Cost per Voyage</strong></td>
<td>$123,038</td>
<td>$83,261</td>
<td>$86,535</td>
</tr>
<tr>
<td><strong>Voyages in 300 Day Season</strong></td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td><strong>Annual Fuel Cost</strong></td>
<td>$6,521,014</td>
<td>$4,412,833</td>
<td>$4,586,355</td>
</tr>
<tr>
<td><strong>Annual Fuel Savings rel. to current steam plant</strong></td>
<td>$2,108,181</td>
<td>$1,934,659</td>
<td>$689,159</td>
</tr>
<tr>
<td></td>
<td>32.3%</td>
<td>29.7%</td>
<td>10.6%</td>
</tr>
</tbody>
</table>

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EPA waiver
Tank Sizing and Endurance

- Chart Ferox, a.s., Decin, Czech Republic
- Vertical tank designs with cold box below within skirt
  - VTS 261/8 261 cubic m; 8 bar
  - VTS 199/8 199 cubic m; 8 bar tank 17.5’ OD; 43’ tall
- Using two shorter tanks
  - with a 15% head space when filling; 5% cooling margin
  - net useable tank volume = 159.2 cubic m each
- Endurance
  - single fuel: bunkering once per round trip with 61% margin
  - dual fuel: bunkering once per round trip with 56% margin
  - ~9 days of operations; ~6 on diesel only
# Annual Air Emissions Comparison

[metric tonnes/year - after January 1, 2015]

<table>
<thead>
<tr>
<th></th>
<th>Rolls-Royce B35:40V12PG</th>
<th>Wärtsilä 12V34DF</th>
<th>MaK 6M43C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing Steam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>main engine fuel</td>
<td>2% S Bunker C</td>
<td>LNG</td>
<td>LNG/0.1% S MDO</td>
</tr>
<tr>
<td>generator fuel</td>
<td>0.45% S MDO</td>
<td>0.1% S MDO</td>
<td>0.1% S MDO</td>
</tr>
<tr>
<td>notes</td>
<td></td>
<td></td>
<td>no SCR</td>
</tr>
<tr>
<td><strong>HC w/o CH4</strong></td>
<td>4.26</td>
<td>64.52</td>
<td>91.05</td>
</tr>
<tr>
<td><strong>CH4</strong></td>
<td>n.a.</td>
<td>93.59</td>
<td>152.15</td>
</tr>
<tr>
<td><strong>NOx</strong></td>
<td>76.71</td>
<td>70.19</td>
<td>73.44</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>8.38</td>
<td>36.67</td>
<td>64.44</td>
</tr>
<tr>
<td><strong>PM</strong></td>
<td>36.28</td>
<td>0.64</td>
<td>2.54</td>
</tr>
<tr>
<td><strong>PM-10</strong></td>
<td>36.28</td>
<td>0.64</td>
<td>2.54</td>
</tr>
<tr>
<td><strong>PM-25</strong></td>
<td>35.19</td>
<td>0.62</td>
<td>2.46</td>
</tr>
<tr>
<td><strong>SOx</strong></td>
<td>371.05</td>
<td>1.60</td>
<td>1.65</td>
</tr>
<tr>
<td><strong>CO2</strong></td>
<td>30722.7</td>
<td>15091.0</td>
<td>15540.1</td>
</tr>
<tr>
<td><strong>CO2 equivalent GHGs</strong></td>
<td>30722.7</td>
<td>17056.3</td>
<td>18735.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18156.6</td>
</tr>
</tbody>
</table>
AAA Single Fuel Conversion Inboard Profile
AAA Single Fuel Conversion Poop Deck
AAA Single Fuel Conversion Spar Deck

Spar Deck
AAA Single Fuel Conversion Main Deck
AAA Single Fuel Conversion Operating Deck
AAA Single Fuel Conversion Tank Top
AAA Dual Fuel Conversion Inboard Profile

engine 0.6 m longer, moved aft

MaK 6M46C DF 1.64 m longer, not feasible
AAA Dual Fuel Conversion Operating Deck
Conclusions and Plans

Conclusions

• The availability of LNG at an appropriate price will be critical to the economic viability of conversion to LNG fuel rather than conversion to diesel.

• The other challenges appear to be workable.

• The arrangement of the AAA LNG conversions to ABS/DNV requirements appears feasible.

Next tasks for AAA class

• Weight/stability study
• Shipyard planning/cost
• Life-cycle cost/payback

Transferability to other vessels
Acknowledgements

GLMRI study funded through a grant funded by the U. S. Department of Transportation Office of the Secretary and the Maritime Administration (Grant #DTMA1H11002).
Special Thanks to

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- Oystein Djupvik & Peter Husoy, Kleven Verft, Ulsteinvik, NO
- Jan Fredrick Meling, Helge Vespestad & other officers and crew of Viking Princess, Eidesvik, Bomlo, NO
- Michael Aasland, Marius Leisner & Lars Blikom, Det Norske Veritas, Hovik, NO
- Lasse Karlsen & Oyvind Vormedal, Norwegian Maritime Authority, Haugesund, NO
Thank you.

Questions?
Lean Burn Gas Engine Operation

courtesy of Wärtsilä
Two Gas Engine Concepts in Use Today

**Single-fuel installations**
Single-fuel spark ignited Otto cycle
e.g. Rolls-Royce Bergen engines

**Dual-fuel installations**
Dual-fuel diesel pilot ignited Otto cycle
e.g. Wärtsilä and MaK engines

~1% power from Diesel cycle micro pilot
can also run on just diesel as a back-up

exhaust stroke not shown
courtesy Wärtsilä