First, some news …

**INTERTANKO may abandon fuel oil bunkers**
04 Oct 2006, 20:55 GMT

Tanker association INTERTANKO is considering stopping using fuel oil bunkers in favour of distillate fuels, the shipping weekly Fairplay reported today.

The possible move was understood to be in response to the accelerating adoption of low-sulphur restrictions under MARPOL Annex VI, such as the Sulphur Emissions Control Areas (SECAs) in the Baltic and North seas.

The additional cost to the industry would be $50 billion, the report said, and also suggested that the International Association of Dry Cargo Shipowners (Intercargo) would follow INTERTANKO's lead.

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<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Number of Ships</th>
<th>Percent of Fleet</th>
<th>Number of Main Engines</th>
<th>Percent of Main Engines</th>
<th>Installed Power (MW)</th>
<th>Percent of Total Power</th>
<th>Percent of Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cargo Fleet</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Container vessels</td>
<td>2,662</td>
<td>2%</td>
<td>2,755</td>
<td>2%</td>
<td>43,764</td>
<td>10%</td>
<td>13%</td>
</tr>
<tr>
<td>General cargo vessels</td>
<td>33,296</td>
<td>2%</td>
<td>31,347</td>
<td>31%</td>
<td>72,114</td>
<td>10%</td>
<td>72%</td>
</tr>
<tr>
<td>Tankers</td>
<td>90,968</td>
<td>8%</td>
<td>18,338</td>
<td>7%</td>
<td>44,906</td>
<td>11%</td>
<td>15%</td>
</tr>
<tr>
<td>Tanker combines carriers</td>
<td>10,339</td>
<td>8%</td>
<td>9,581</td>
<td>8%</td>
<td>34,285</td>
<td>11%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Non-Cargo Fleet</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger</td>
<td>4,370</td>
<td>8%</td>
<td>15,456</td>
<td>10%</td>
<td>19,522</td>
<td>0%</td>
<td>6%</td>
</tr>
<tr>
<td>Fishing vessels</td>
<td>23,571</td>
<td>23%</td>
<td>24,009</td>
<td>16%</td>
<td>18,474</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>Tugboats</td>
<td>5,548</td>
<td>9%</td>
<td>16,009</td>
<td>11%</td>
<td>16,116</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>Other (research, supply)</td>
<td>3,199</td>
<td>3%</td>
<td>7,500</td>
<td>5%</td>
<td>10,265</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Registered fleet total</td>
<td>88,640</td>
<td>82%</td>
<td>116,290</td>
<td>77%</td>
<td>289,083</td>
<td>62%</td>
<td>80%</td>
</tr>
<tr>
<td>Military vessels</td>
<td>19,460</td>
<td>18%</td>
<td>34,633</td>
<td>23%</td>
<td>172,478</td>
<td>38%</td>
<td>14%</td>
</tr>
<tr>
<td>World fleet total</td>
<td>108,106</td>
<td>100%</td>
<td>150,923</td>
<td>100%</td>
<td>461,557</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*The world fleet represents internationally registered vessels greater than 100 gross tons, the cargo fleet represents those vessels whose main purpose is transportation cargo. The table shows percent of energy demand. Energy demand includes the reduced activity (in hours and hours) by military vessels under typical operations.*
Outline for Discussion

- Fleet and Propulsion Overview
  - Environmental overview of ship emissions
    - Global shipping, North American inventory (3-5 slides)
    - Basics of pollutant formation, fate, transport (movie, slide)
    - Activity-based estimating methods (1-2 slides)
  - Interpretation of emissions estimates
    - Emission factor and fuel comparisons (steam v. diesel)
    - Example issues in reviewing operating emissions and offsets
      ...What might LNGs, other vessels and mobile sources really do?

Complex Maritime Transportation System

- Tug and towboats
  - 1-30 barges: 0.5 - 4 MW
- High speed ferries
  - 150-350 passengers: 2-4 MW
- Roll-on/Roll-off
  - 200-600 vehicles: 15-25 MW
- Tankers
  - 250,000 tons of oil: 25-35 MW
  - **LNG fleet: 20-30 MW**
- Container
  - 1750 TEU: 20-25 MW
  - 4300TEU: 35-45 MW
  - 6000 TEU: 55-65 MW
Overview of ship propulsion layouts

Steam Turbine Gear System

Med-speed Diesel Gear System

Slow-speed Diesel Gear System

Diesel Electric System

http://www.dieselduck.ca/machinery_page/diesel_engine/diesel_engine.01.htm
http://www.dieselduck.ca/machinery_page/propulsion_layout/propulsion_layout.htm
http://www.opet-chp.net/chpbackpressure.gif
http://www.steamsteem.com/pictures/fuelsyst.gif
Overview of LNG propulsion layout

Wartsila: efficient and environmentally friendly machinery systems for LNG carriers.pdf

Wartsila’s expected trends

California LNG projects

- Each facility similar in size and throughput
  - ~120 to ~130 ship calls per year … or less?

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    - …What might LNGs, other vessels and mobile sources really do?
Ship traffic differs by vessel type

- Containership
- Tanker
- Bulk Carrier
- General Cargo
- Refrigerated Cargo
- Ro-Ro
- Passenger

Trade driven by commodity demand & resource supply

Unadjusted Reefer traffic
Trade import patterns are clear ...

Spatial Distribution in Multimodal Context
Other GIS-based analyses of goods movement and environmental issues

- Application of Ship Speed and Mass to describe potential severity of risk-based ship collisions with whales
- Invasive species and ballast water treatment
- Port fees and transportation infrastructure
- Forecasting seaborne trade, energy, emissions
- Generating multimodal routing models with environmental, disaster, and sustainability indices

Best practices for CMV inventories

- Step 1: Identify the vessel(s) to be modeled, and engines in service
- Step 2: Estimate the engine service hours for the voyage or voyage segment
- Step 3: Determine the engine load profiles, including power and duty cycle
- Step 4: Apply emissions or fuel consumption rates for specific engine/fuel combinations
- Step 5: Estimate emissions or fuel consumption for the voyage or voyage segment

Steps 6+: Assign emissions spatially and temporally both in and out of port regions

Uncertainty remains, but bounding is improving
Atmospheric Dispersion and Removal Processes

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    - ...What might LNGs, other vessels and mobile sources really do?
Wartsila’s steam v. diesel comparison

AP-42 data, for Nat-Gas ICEs

- **NOx Value represents 2-stroke, lean-burn at 90-105% load.**
  - At <90% load, reported as 3.84 lb/MMBtu. 2-stroke, lean-burn engines at 90-105% load is 4.08 lb/MMBtu; at <90% load, reported as 0.847 lb/MMBtu. 4-stroke, rich-burn engines at 90-105% reported to be 2.21 lb/MMBtu; at <90% load, 2.27 lb/MMBtu.

- **Reported as SO2, using fuel sulfur content of 2,000g/10^6 scf.**

- **PM Value represents 2-stroke, lean-burn engines.**
  - PM for 4-stroke, lean-burn engines is 7.71 E-05; for rich-burn, 9.50 E-03.

- **Value represents 2-stroke, lean-burn at 90-105% load.**
  - At 90% load, reported as 0.353 lb/MMBtu. 4-stroke, lean-burn engines at 90-105% load is 0.317 lb/MMBtu; at <90% load, reported as 0.557 lb/MMBtu. 4-stroke, rich-burn engines at 90-105% reported to be 3.72 lb/MMBtu; at <90% load, 3.91 lb/MMBtu (Note higher CO for rich-burn engines).

<table>
<thead>
<tr>
<th>Internal Combustion Engines</th>
<th>lb/mm cu.ft. NG</th>
<th>lb/mmBTU NG</th>
<th>kg/mmBTU NG</th>
<th>g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>2840</td>
<td>2.65</td>
<td>1.20</td>
<td>4.10</td>
</tr>
<tr>
<td>SOx</td>
<td>0.6</td>
<td>0.00056</td>
<td>0.0025</td>
<td>0.00087</td>
</tr>
<tr>
<td>PM</td>
<td>10</td>
<td>0.0093</td>
<td>0.0042</td>
<td>0.0144</td>
</tr>
<tr>
<td>PM10</td>
<td>10</td>
<td>0.0093</td>
<td>0.0042</td>
<td>0.0144</td>
</tr>
<tr>
<td>VOC</td>
<td>116</td>
<td>0.11</td>
<td>0.05</td>
<td>0.17</td>
</tr>
<tr>
<td>CO</td>
<td>399</td>
<td>0.37</td>
<td>0.17</td>
<td>0.58</td>
</tr>
<tr>
<td>Lead NA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AP-42 data, for Dual-fuel ICEs

<table>
<thead>
<tr>
<th>Dual Fuel Engine</th>
<th>lb/hp-hr</th>
<th>lb/MMBtu</th>
<th>lb/hp-hr</th>
<th>lb/MMBtu</th>
<th>g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>0.024</td>
<td>3.2</td>
<td>0.018</td>
<td>2.7</td>
<td>10.92</td>
</tr>
<tr>
<td>PM</td>
<td>0.0007</td>
<td>0.1</td>
<td>0.0007</td>
<td>0.1</td>
<td>0.42</td>
</tr>
<tr>
<td>HC as CH4</td>
<td>0.000705</td>
<td>0.09</td>
<td>0.00529</td>
<td>0.8</td>
<td>23.99</td>
</tr>
<tr>
<td>CO</td>
<td>0.0055</td>
<td>0.85</td>
<td>0.0075</td>
<td>1.16</td>
<td>4.55</td>
</tr>
<tr>
<td>CO₂</td>
<td>1.16</td>
<td>165</td>
<td>0.772</td>
<td>110</td>
<td>468.38</td>
</tr>
</tbody>
</table>

- Assumes 5% Diesel and 95% Natural Gas.
- We could also compare with ARB values for onroad use of natural gas in ICEs with and without dual fuel. These values are lower than reported above – marine engine factors for dual fuel using LNG could merit updated review.

AP-42 data, for residual fired boilers

<table>
<thead>
<tr>
<th>Boiler and Diesel Emissions Compared</th>
<th>SFOC boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Boiler (average on No. 6 Fuel Oil)</td>
<td>290</td>
</tr>
<tr>
<td>NOx (NO₂)</td>
<td>lb/kgal</td>
</tr>
<tr>
<td>42.5</td>
<td>6.03</td>
</tr>
<tr>
<td>SO₂ (S)</td>
<td>423.9</td>
</tr>
<tr>
<td>SO₃ (S)</td>
<td>15.39</td>
</tr>
<tr>
<td>CO</td>
<td>5</td>
</tr>
<tr>
<td>PM</td>
<td>28.033</td>
</tr>
<tr>
<td>HC (total organic carbon)</td>
<td>1.04</td>
</tr>
</tbody>
</table>

- Lower NOx factors compared to ICEs
  - Much lower than ICEs with liquid petroleum fuel
- Higher SO₂ factors – due to residual oil
  - Would fall to similar level if gas-fired
- Higher PM is clearly a function of sulfur content
AP-42 data, for natural-gas fired boilers

<table>
<thead>
<tr>
<th>Boiler and Diesel Emissions Compared</th>
<th>SFOC boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Boiler (average on Natural Gas)</td>
<td>1020 Btu/scf</td>
</tr>
<tr>
<td>NOx (NO2)</td>
<td>lb/10^6 Btu</td>
</tr>
<tr>
<td>SO2 (S)</td>
<td></td>
</tr>
<tr>
<td>SO3 (S)</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td></td>
</tr>
<tr>
<td>PM (total)</td>
<td></td>
</tr>
<tr>
<td>HC (total organic carbon)</td>
<td></td>
</tr>
</tbody>
</table>

- Lower NOx factors compared to oil-fired boilers
- Low SO2 factors
- Lower PM

Wartsila’s steam v. diesel comparison matches well with published factors
How to combine different pollutants in terms of environmental impacts? Or not ...

- Criteria pollutants v. climate change
- Pollutants critical to attainment
- Health risk-based pollutants
- Some combination?

Total fuel cycle comparisons may be useful

TEAMS Model, in press JAWMA, www.rit.edu/~teams

![Graph showing total fuel cycle comparisons](image)
Identify possibly weak assumptions
Compare power trend with AP-42 emissions factors and with dual fuel factor

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Take-home Ideas

- LNG fleet may be cleaner than average
  - Growing, changing power technology, emissions
- Other shipping is significant, growing also
  - Emerging rules will likely improve fleet emissions
- Emissions from alternate propulsion may be cleaner but not negligible in terms of impacts
  - Comparison varies by pollutant, energy, CO2
- Inventory best practices are sensitive to inputs
  - Emissions factors, duty cycle, fuel type
- Offsets using older technology may be easy
  - … but these may only document planned modernization

A modern fleet of ships does not so much make use of the sea as exploit a highway. -- Joseph Conrad, The Mirror of the Sea, Ch. 22, 1906

Discussion welcome