Emissions From Maritime Shipping Sector In A Freight Context

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21-22 May 2007
Freight is an important multimodal transport function.

Shipping is an integral part of global trade.
Freight is an increasing contributor to the economy
Air pollution and Climate Impacts from Ships

- Two reasons to reduce ship emissions:
  - Ships contribute to problems TODAY
  - Growth in shipping makes problems worse TOMORROW

- Other reasons (depending on perspective)
  - Controls more cost-effective than other modes
  - Impacts mitigation may be asymmetric
Mode share comparison

![Graph showing mode share comparison for different types of cargo volume (Gtkm). The graph compares Road, Shipping, Aviation, and Rail with data for U.S. Freight, EU25 Freight, and Seaborne Trade.](image-url)
Sips are more heterogeneous than onroad transport

- 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
  - 4300 TEU: 35-45 MW
  - 6000 TEU: 55-65 MW
Ship emissions estimates bounded

Whiskers: 5th and 95th bounds
Boxes: 25th and 75th bounds
Points: Best estimates of various studies

Best Estimate: ~15.4% of anthropogenic CO₂
Best Estimate: ~7.8% of anthropogenic SO₂
Best Estimate: ~2.7% of anthropogenic NOₓ
Ship traffic differs by vessel type

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

Trade driven by commodity demand & resource supply
Trade import patterns are clear … … connected to domestic freight system
Different top-down proxies provide different regional pictures

And these differences may produce different impacts assessments
Forecasting Summary

- Power-based trends used for forecasting
  - First-order indicator of proportional change in emissions, adjusted for control measures
- Forecasts are primarily extrapolations of BAU that can be bounded and/or adjusted
  - North American trends validated by comparison with other modal trends and ship trade-energy models, at multiple scales

- Ship emissions growth rates are faster than GDP

- Future emissions with IMO-compliant SECA will be greater than base year emissions in 2002.
Fast-growing sectors can dominate forecast
U.S. Containership energy use driven by strong growth in “heavy-leg” activity

Note the significant activity to move empty containers. Trade-based models can account for this through utilization factors, etc.

Linkage: Containership cargoes generate truck, rail activity

~6.5% ~7% ~10%
Shipboard power trends indicate strong growth in energy demand
Building a valid range of world forecasts ... starting with trade and energy

Implication: World (ocean) freight emissions on track to double before 2050 (pre-2030?)

North America doubles between 2015-2020
China supplies NA and EU – faster growth?

Extrapolating trends since ~1980-85 depending on data source

Concept illustration credited to discussions with M. Granger Morgan, Carnegie Mellon University

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Next Steps

- Recognize different growth rates and re-forecast spatially
- Consider policy and technology interventions
- Couple better with economics trends
- Go multimodal
- Expand globally
Approaches to setting ship targets

1. Reduce emissions to improve performance, irrespective of growth.  *DO SOMETHING SOON*

2. Reduce emissions to hold current exposure (impacts?) constant at some base year, offsetting trade-driven growth in emissions.  *HOLD THE LINE*

3. Reduce emissions by X amount, maintaining emissions reductions (impacts?) from some base year, despite trade growth.  *MITIGATE IMPACTS*
Menu of options to be matched with strategies and fleet

- Environmental control technologies
  - Pre-combustion: e.g., water emulsions
  - In-engine: e.g., humidification
  - Post-combustion: e.g., SCR, scrubbers, PM controls

  *Only technology (and cost) combos get multiple pollutants*
  *Nearly all carry CO2 penalties of 1-3% for retrofits*

- Alternative marine fuels and energy systems

  *Could double fuel price (freight rate ↑), and may require phase in*

- Operational (behavior) changes

  *Possible in short term, possible multimodal logistics effects*
  *Achieves reductions in CO2 and all pollutants (win-win)*
(Marine) Freight Transport insights

- Technology will involve **fleet retrofits** and new-builds
- Economics determines role of **alternative fuels**
- 0.5% SECA *or lower* may be justified in large regions
  - Health effects work ongoing, but SOx control benefits appear greater than control costs
  - Reducing SOx and NOx will modify climate assessments
    - Most abatements increases CO2; reduced emissions change ozone and indirect aerosol forcing
- **Market incentives** promising at several scales
- **Operational logistics** changes may involve all modes
- **Decades required** to completely achieve change
GIFT Network Model
(under development)

**Figure 1. Intermodal Freight Transport Model**

<table>
<thead>
<tr>
<th>Case I (Least Cost) (Ship predominates)</th>
<th>Case II (Least Time) (Truck predominates)</th>
<th>Case III (Least CO₂) (Rail predominates)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance (miles)</strong></td>
<td><strong>Time (hours)</strong></td>
<td><strong>Energy (MBtu)</strong></td>
</tr>
<tr>
<td>950</td>
<td>54</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Cost ($)</strong></td>
<td><strong>Energy (MBtu)</strong></td>
<td><strong>Cost ($)</strong></td>
</tr>
<tr>
<td>$1,480</td>
<td>12.0</td>
<td>$1,690</td>
</tr>
<tr>
<td><strong>CO₂ (kg)</strong></td>
<td><strong>CO₂ (kg)</strong></td>
<td><strong>CO₂ (kg)</strong></td>
</tr>
<tr>
<td>340</td>
<td>990</td>
<td>220</td>
</tr>
<tr>
<td><strong>SOₓ (kg)</strong></td>
<td><strong>SOₓ (kg)</strong></td>
<td><strong>SOₓ (kg)</strong></td>
</tr>
<tr>
<td>4.5</td>
<td>1.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Total fuel cycle comparisons

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

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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

Corbett and Koehler, 2003; Corbett and Koehler, 2004
Fuel consumption over past 50 years

Containerized shipping and globalization explains diversion between usage and IEA energy allocation inventories

From Eyring et al., Part 1, JGR, 2005
Looking for preferred technology frontiers among uncertain, variable alternatives.

Benefit-cost ratio of fuel switching … and scrubbing


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Summary of IPCC forecast trends

ExoJoules (EJ) for Power; Trillion US$ for GNP/GDP

Petroleum use represents all sectors (dominated by passenger vehicles).

Not a good trend line for marine cargo transportation sector in isolation

Cargo growth should follow GNP if US consumption is trade dominated
Bounding insights to transform policy debate, focus dialogue

Is further debate on forecast rates more useful than consideration of reduction targets that offset growth in trade under range of trends?
North American Results: Hypothetical IMO-compliant SECA (1.5% S) reduces future emissions from BAU … but not compared to base year

- Reduces 700,000 metric tons from 2020 no-SECA
- Increases by ~2 million Mtons over 2002 base-year
Freight transport and environment: multi-scale, multimodal challenge bigger than ships

More sustainable freight logistics, inventory, production, and consumption

Evaluation of economic drivers/barriers to innovation and diffusion of sustainable concepts, regulatory jurisdiction and standards

Design of transportation strategies to achieve economic, energy, and environmental goals that improve stewardship faster than growth

Forecasting trends and alternative mitigation pathways
Integrated measures of sustainable transportation beyond air pollution

Impacts analysis: Environmental and health effects
Multi-scale characterization: Emissions inventories, fate-transport modeling

Emissions and discharges: Air pollution formation and control technologies

System attributes: Vessel or vehicle, engine, and propulsion design
Jurisdictional constraints

Can treaty consensus achieve these target ranges at all?

Economic instruments can work at these levels faster than treaty or multinational or federal action - if compatible at larger scales

Treaties often are weaker than national laws

Some nations don't participate, even though their ships sail globally

Ports try to address policy problems AND attract cargoes for regional economy

Jurisdictional conflict occurs when national policy doesn't address local or regional problems

International Treaty

Only Enforceable by Treaty Nations

Enforced by Port State

National Sovereignty

Enforced by Flag State

National Sovereignty

Only Enforceable by Treaty Nations

Federal Laws

State/Province Authority

State Laws

Port Authority

Regional Concerns:
Security
Pollution
Safe Navigation

Enforced by Flag State

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### Intermodal Comparisons: Infrastructure Factors

<table>
<thead>
<tr>
<th>Mode</th>
<th>NO\textsubscript{x}</th>
<th>CO</th>
<th>Carbon Intensity(^3) ($/tC)</th>
<th>Fraction of CO\textsubscript{2} (%)</th>
<th>Size of Fueling Stations (power)</th>
<th>No. of Fueling Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine</td>
<td>71</td>
<td>16</td>
<td>950</td>
<td>6</td>
<td>175 MW</td>
<td>28-40(^4)</td>
</tr>
<tr>
<td>Autos(^1)</td>
<td>14</td>
<td>130</td>
<td>2300</td>
<td>56</td>
<td>2.7 MW</td>
<td>180,000</td>
</tr>
<tr>
<td>Aircraft</td>
<td>3</td>
<td>17</td>
<td>2100</td>
<td>8.7</td>
<td>240 MW</td>
<td>72(^5)</td>
</tr>
<tr>
<td>Heavy trucks</td>
<td>30</td>
<td>17</td>
<td>2800</td>
<td>16</td>
<td>20 MW</td>
<td>5,500</td>
</tr>
<tr>
<td>Rail</td>
<td>76</td>
<td>9</td>
<td>3500</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All figures for the United States. All figures rounded to two significant digits. (1) Includes both automobiles and light trucks. (2) Computed using estimated actual emissions and fuel use. (3) End user expenditures divided by carbon emissions. (4) Total of companies in the large U.S. ports providing international marine fuels (@ 4-10 per port). (5) Large hub airports.

**Ships may be preferred niche market for new technology innovation**
Building Empirical Network

~9000 segments & ~1700 ports
~170,000 ship trips/yr in North America

Derived from 1983-2002 ICOADS.
Spatial Distribution in Multimodal Context