Current Methodologies and Best Practices for Preparing Port Emission Inventories

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Why Do a Port Emissions Inventory?

- Development of a well-informed port emissions reduction strategy
- SIP development
- NEPA and CEQA analyses
Port Inventory Development Methodology Options

- **Detailed Inventory**
  - Requires details on deep sea vessel and land based equipment characteristics, activities, port geometry and ship paths
  - Used by larger sea ports
  - Resource Intensive

- **Mid-Tier Inventory**
  - Requires port-specific activity information by ship type then applies “typical” port emission rate averages for each ship type
  - Used by mid-sized and smaller ports in a non-attainment or maintenance areas
Streamlined Inventory

- Requires minimal port-specific details
- Extrapolates emission data from another port using US ACE ship trip data and RSZ speed and distance
- Provides a “back of the envelope” estimate of port emissions
- Used by smaller sea and Great Lake ports
- Low amount of resources required
Detailed Inventory Preparation
Deep Sea Vessels

\[ E = P \times LF \times A \times EF \]

Where
- \( E \) = Emissions (grams [g])
- \( P \) = Maximum Continuous Rating Power (kW)
- \( LF \) = Load Factor (percent of vessel’s total power)
- \( A \) = Activity (hrs)
- \( EF \) = Emission Factor (g/kWh)
Data Sources

**Pilot Data**
- Distance Between Docks
- Average Speeds for Each Time-in-Mode
- Tug Assist Speeds and Behavior

**Marine Exchange/Port Authority**
- Port Name
- LMIS Number
- Vessel Type
- WWT
- Vessel Speed
- Flag of Registry
- Date of Arrival
- Time of Arrival
- Date of Departure
- Time of Departure

**Lloyd's Register of Ships**
- Ship Name
- LMIS Number
- Ship Type
- DWT
- Vessel Speed
- Flag of Registry
- Engine Type
- Engine Power
- Engine Speed
- Build Date

**Calculated Average Vessel Movements**
- Calls
- Shifts
- Time-in-Mode
  - Cruise
  - Reduced Speed Zone
  - Maneuvering
  - Hotelling

**Average Vessel Characteristics**
- Ship Type
- Engine Type
- DWT
- Engine Power
- Vessel Speed
- Engine Speed
- Build Date
<table>
<thead>
<tr>
<th>Ship Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
</tr>
<tr>
<td>Barge Carrier</td>
</tr>
<tr>
<td>Bulk Carrier</td>
</tr>
<tr>
<td>Container</td>
</tr>
<tr>
<td>General Cargo</td>
</tr>
<tr>
<td>Miscellaneous</td>
</tr>
<tr>
<td>Ocean Going Tug</td>
</tr>
<tr>
<td>Passenger</td>
</tr>
<tr>
<td>Reefer</td>
</tr>
<tr>
<td>RoRo</td>
</tr>
<tr>
<td>Tanker</td>
</tr>
</tbody>
</table>
Engine Size

– Category 1
  • < 5 liters/cylinder
  • Mostly small harbor craft and recreational propulsion

– Category 2
  • > 5 liters/cylinder and < 30 liters per cylinder
  • OGV Auxiliaries, Harbor craft, smaller OGV propulsion

– Category 3
  • > 30 liters per cylinder
  • OGV propulsion
Marine Engine Types

Engine Speed
- Slow Speed
  • < 130 rpm
  • Mostly 2 stroke
- Medium Speed
  • > 130 rpm and < 1400 rpm
  • Mostly 4 stroke
- High Speed
  • > 1400 rpm
  • 4 stroke

Other Engine Types
- Steam Turbine
- Gas Turbine
## Auxiliary Engines

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Average Propulsion Engine (kW)</th>
<th>Average Auxiliary Engines</th>
<th>Auxiliary to Prop Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Power Each (kW)</td>
<td>Total Power (kW)</td>
</tr>
<tr>
<td>Auto Carrier</td>
<td>10,700</td>
<td>2.9</td>
<td>983</td>
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<tr>
<td>Bulk Carrier</td>
<td>8,000</td>
<td>2.9</td>
<td>612</td>
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<tr>
<td>Container</td>
<td>30,900</td>
<td>3.6</td>
<td>1,889</td>
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<tr>
<td>Cruise</td>
<td>39,600</td>
<td>4.7</td>
<td>2,340</td>
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<tr>
<td>General Cargo</td>
<td>9,300</td>
<td>2.9</td>
<td>612</td>
</tr>
<tr>
<td>RORO</td>
<td>11,000</td>
<td>2.9</td>
<td>983</td>
</tr>
<tr>
<td>Reefer</td>
<td>9,600</td>
<td>4.0</td>
<td>975</td>
</tr>
<tr>
<td>Tanker</td>
<td>9,400</td>
<td>2.7</td>
<td>735</td>
</tr>
</tbody>
</table>
Cruise
- From open ocean to RSZ
- At service speed

Reduced Speed Zone
- From pilot pick-up or other point to breakwater
- At reduced speed, usually 9 to 12 knots

Maneuvering
- From breakwater to berth
- At slow speeds – 3 to 8 knots – slower coming in than out

Hotelling
- Time at berth or anchorage with propulsion engine off
- Auxiliaries usually running unless cold ironing
Propulsion Load Factors

\[ LF = (\frac{AS}{MS})^3 \]

Where
\[ LF = \text{Load Factor (percent)} \]
\[ AS = \text{Actual Speed (knots)} \]
\[ MS = \text{Maximum Speed (knots)} \]

Minimum value 2%
# Propulsion Engine Emission Factors (g/kWh)

<table>
<thead>
<tr>
<th>Engine</th>
<th>NOx</th>
<th>CO</th>
<th>HC</th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>SO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD</td>
<td>18.1</td>
<td>1.40</td>
<td>0.60</td>
<td>1.05</td>
<td>0.96</td>
<td>10.3</td>
</tr>
<tr>
<td>MSD</td>
<td>14.0</td>
<td>1.10</td>
<td>0.50</td>
<td>1.11</td>
<td>1.02</td>
<td>11.1</td>
</tr>
<tr>
<td>ST</td>
<td>2.1</td>
<td>0.20</td>
<td>0.10</td>
<td>1.50</td>
<td>1.38</td>
<td>16.1</td>
</tr>
</tbody>
</table>
Low Load Adjustment Factor

![Graph showing the relationship between Load Factor and Low Load Adjustment Factor for different pollutants (NOx, CO, HC, PM)].
## Auxiliary Engine Load Factors

<table>
<thead>
<tr>
<th>Ship-Type</th>
<th>Cruise</th>
<th>RSZ</th>
<th>Maneuver</th>
<th>Hotel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>0.13</td>
<td>0.30</td>
<td>0.67</td>
<td>0.24</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>0.17</td>
<td>0.27</td>
<td>0.45</td>
<td>0.22</td>
</tr>
<tr>
<td>Container Ship</td>
<td>0.13</td>
<td>0.25</td>
<td>0.50</td>
<td>0.17</td>
</tr>
<tr>
<td>Cruise Ship</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.64</td>
</tr>
<tr>
<td>General Cargo</td>
<td>0.17</td>
<td>0.27</td>
<td>0.45</td>
<td>0.22</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.17</td>
<td>0.27</td>
<td>0.45</td>
<td>0.22</td>
</tr>
<tr>
<td>OG Tug</td>
<td>0.17</td>
<td>0.27</td>
<td>0.45</td>
<td>0.22</td>
</tr>
<tr>
<td>RORO</td>
<td>0.15</td>
<td>0.30</td>
<td>0.45</td>
<td>0.30</td>
</tr>
<tr>
<td>Reefer</td>
<td>0.20</td>
<td>0.34</td>
<td>0.67</td>
<td>0.34</td>
</tr>
<tr>
<td>Tanker</td>
<td>0.13</td>
<td>0.27</td>
<td>0.45</td>
<td>0.67</td>
</tr>
</tbody>
</table>
### Auxiliary Engine Emission Factors (g/kWh)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>% S</th>
<th>NOx</th>
<th>CO</th>
<th>HC</th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>SO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RO</td>
<td>2.7</td>
<td>14.70</td>
<td>1.10</td>
<td>0.40</td>
<td>1.11</td>
<td>1.02</td>
<td>11.1</td>
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<tr>
<td>MDO</td>
<td>1.5</td>
<td>13.90</td>
<td>1.10</td>
<td>0.40</td>
<td>0.71</td>
<td>0.66</td>
<td>6.16</td>
</tr>
<tr>
<td>MGO</td>
<td>0.5</td>
<td>13.90</td>
<td>1.10</td>
<td>0.40</td>
<td>0.38</td>
<td>0.35</td>
<td>2.05</td>
</tr>
</tbody>
</table>
Harbor Craft

- Assist tugboats
- Towboats/pushboats/tugboats
- Ferries and excursion vessels
- Crew boats
- Work boats
- Government vessels
- Dredges and dredging support vessels
- Commercial fishing vessels
- Recreational vessels
Harbor Craft Emissions Calculations

Survey Data

Engine Power
Load Factor
Operating Time
Energy Used
Emission Factors

Emission Estimate
Land Side Emission Sources

- **Cargo Handling Equipment**
  - Determine counts by equipment type
  - Determine activity
  - Use Nonroad Model to calculate emissions

- **Rail**
  - Information from Rail companies
  - Apply EPA guidance

- **On-road vehicles**
  - Determine fleet calling on port
  - Use MOBILE 6.2 to calculate emissions
Great Lake and Inland River Ports

Great Lake Ports
- Ship Types differ from Deep Sea Ports
  - Salties – Pass through the St. Lawrence River to the Ocean
  - Lakers – Stay within the lakes
- Significant amount of trips by tug/barge and Category 2 ships

Inland River Ports
- Entirely tug/barge and excursion vessels
- Entirely Category 2 ships
- Significant amount of traffic passes ports without stopping
Mid-Tier Method

- Trips / Calls on Port by ship type (trips/calls per year)
  - Ship types:
    - Bulk carrier
    - Container ship
    - General cargo
    - Passenger
    - Reefer
    - Roll-On/Roll-Off
    - Supply/support vessel
    - Tanker
    - Vehicle Carrier
    - Tugboats/pushboats
    - Barge carrier
    - Dry cargo barge
    - Liquid cargo barge

- Time in Mode by ship type (in hours)
  - Operating modes:
    - Cruise
    - Reduced speed
    - Maneuvering
    - Hotelling

- Power Consumption by ship type by operating mode (in horsepower)
  - Based on:
    - Main vs. Aux. Engines
    - Engine Cycle / Type
    - Engine Speed
    - Vessel Speed
    - Main Power
    - Auxiliary : Main Ratio

- Load Factors by operating mode
  - Based on:
    - Vessel Speed
    - Main and Aux. Engines

- Emissions Factors (in grams/hp-hr)
  - Based on:
    - Engine Speed
    - Low Load Adjusts
    - Engine Category

- Emissions (in tons per year)
**Streamlined Method**

1. **Select Port**
2. **Modeled or Like Port**
   - Modeled
   - Like
3. **Base Data**
4. **Determine Base Emissions**
   - by ship type
   - by operating mode
   - by engine type
5. **Total Base Emissions**
   - by ship type
   - by operating mode
6. **Select Best Paired Port**
7. **Scale Base Year to Common Year (1995)**
8. **Scale Modeled Port Emissions to Like Port for Common Year**
9. **Scale Like Port Common Year to Current Year (2002)**
10. **Any Necessary Corrections**
11. **Port-Wide Vessel Emissions (Tons per Year)**
More Information

- Lou Browning, ICF International
  - LBrowning@ICFI.com

- Kathleen Bailey, US EPA
  - Bailey.Kathleen@epamail.epa.gov

- EPA Marine Inventory Guidance
  - http://www.epa.gov/otaq/marine.htm

- EPA Port Sectors Website
  - http://www.epa.gov/sectors/ports