Green Ship Design & Technology

by

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Southampton, 11 July – 2 September 2011
Green Ship Design & Technology

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Seoul, Korea
Pollution from Ships

- Regulations
- EEDI
- Green Ship Design
- Energy Saving Devices
- Future Issues
Pollution from Ships


Key Actions by IMO

Ship Design:
  EEDI (Energy Efficiency Design Index)

Ship Operation:
  SEEMP (Ship Energy Efficiency Management Plan)
  EEOI (Energy Efficiency Operational Indicator)

Ship Market:
  MBM (Market-Based Measure, Market-Based Mechanism)
Pollution from Ships

**Air pollution on voyage**
- SOx
- NOx
- GHG*
- PM*
- VOC*

**Water pollution on voyage**
- Waterproof oil
- Bilge water
- Cooling water
- Grey water
- Antifouling materials
- Ballast water
- Noise

**Ground pollution on voyage**
- Precipitates
- Wastes
- Chemical residues
- Oil residues

**Pollution on ship recycling**
- Paint
- Plastic
- Electrical product
- Sealed gas
- Chemical product

*GHG (Green House Gas; CO2)
*PM (Particulate Matter)
*VOC (Volatile Organic Compound)
Pollution from Ships

Environmental Aspects and Impacts

Source: APL (MTEC 2011)
Pollution from Ships

Ship is the most efficient transportation in view of CO$_2$ emission

**CO$_2$ emissions (grammes) to carry 1 ton of cargo 1km**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Emissions (grammes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container ship (3,700 TEU)</td>
<td>12.97</td>
</tr>
<tr>
<td>Rail* (diesel)</td>
<td>17</td>
</tr>
<tr>
<td>Road* (heavy truck)</td>
<td>50</td>
</tr>
<tr>
<td>Air* (Boeing 747-400)</td>
<td>552</td>
</tr>
</tbody>
</table>

*Source: The Network for Transport and the Environment*

**Energy used (kilowatts) to carry 1 ton of cargo 1km**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy (kilowatts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container ship (3,700 TEU)</td>
<td>0.026</td>
</tr>
<tr>
<td>Rail* (diesel)</td>
<td>0.067</td>
</tr>
<tr>
<td>Road* (heavy truck)</td>
<td>0.18</td>
</tr>
<tr>
<td>Air* (Boeing 747-400)</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Source: The Network for Transport and the Environment*
Pollution from Ships

Ship is the most efficient transportation in view of CO$_2$ emission

* Source; Second IMO GHG Study 2009.

**CO$_2$ efficiency** = CO$_2$ / (tonne * kilometre) ≈ Fuel consumption

CO$_2$ = total CO$_2$ emitted from the vehicle within the period
tonne*kilometre = total actual number of tonne-kilometres of work done within the same period
GHG emissions from ships are predicted to be at least doubled by 2050.

* Source: Second IMO GHG Study 2009.
Pollution from Ships
Regulations
Concept of EEDI
Green Ship Design
Energy Saving Devices
Future Issues
## MARPOL 73/78 Regulations for Prevention & Control of Pollution from Ships

<table>
<thead>
<tr>
<th>MARPOL ANNEX</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Oil</td>
</tr>
<tr>
<td>II</td>
<td>Noxious liquid substances in bulk</td>
</tr>
<tr>
<td>III</td>
<td>Harmful substances in packaged form</td>
</tr>
<tr>
<td>IV</td>
<td>Swages</td>
</tr>
<tr>
<td>V</td>
<td>Garbage</td>
</tr>
<tr>
<td>VI</td>
<td>Emissions</td>
</tr>
</tbody>
</table>
### Emission Regulations - NOx

<table>
<thead>
<tr>
<th>RPM</th>
<th>Tier 1 (current)</th>
<th>Tier II (from 2011.1.1)</th>
<th>Tier III (from 2016.1.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 130</td>
<td>17.0 g/kWh</td>
<td>14.4 g/kWh</td>
<td>3.4 g/kWh</td>
</tr>
<tr>
<td>130 ~ 2000</td>
<td>45.0×n(-0.2) g/kWh</td>
<td>44.0×n(-0.23) g/kWh</td>
<td>9×n(-0.2) g/kWh</td>
</tr>
<tr>
<td>Over 2000</td>
<td>9.8 g/kWh</td>
<td>7.7 g/kWh</td>
<td>2.0 g/kWh</td>
</tr>
</tbody>
</table>

**IMO NOx Tier II** : Adopted on MEPC 58 (2008.10)
- After 1 January 2011 (Keel Laying)

**IMO NOx Tier III** : Tentative Assent
- After 1 January 2016 (Keel Laying)
### Emission Regulations - SOx

#### Sulfur Content

<table>
<thead>
<tr>
<th>Regulation or Area</th>
<th>2010</th>
<th>2012</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Limit</td>
<td>4.5 %</td>
<td>3.5 %</td>
<td>0.5 %</td>
<td></td>
</tr>
<tr>
<td>IMO ECA</td>
<td>1.5 %</td>
<td>1.0 % (after 2010.07)</td>
<td>0.1 %</td>
<td></td>
</tr>
<tr>
<td>EU Port</td>
<td></td>
<td>0.1 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USCG (within 24NM)</td>
<td>0.5 %</td>
<td></td>
<td>0.1 %</td>
<td></td>
</tr>
</tbody>
</table>

- **Residual Fuel (IFO380 or LS380)**
- **Distillate Fuel (MGO)**
Emission Regulations - CO₂

EEDI (Energy Efficiency Design Index) – Technical Regulation

**Goal of EEDI**
- Mitigate CO₂ emissions
- Increase cargo carrying capacity
- Enhance speed performance

If using LNG as ship fuel,
- Reducing CO₂ emission of Main engine & Aux. engine
- Reducing EEDI
EEOI (Energy Efficiency Operational Indicator) – Operational Regulation

**Voyage Specific**

\[ EEOI = \frac{\text{CO}_2 \text{ Emissions (g)}}{\text{DWT} \times \text{Miles (ton – knot)}} \quad = [\text{g / ton – mile}] \]

\[ = \left( \sum_{i=1}^{\text{FuelType}} FC \times C_{\text{carbon}} \right)_{\text{FuelType}1} + \left( \sum_{i=1}^{\text{FuelType}} FC \times C_{\text{carbon}} \right)_{\text{FuelType}2} + \left( \sum_{i=1}^{\text{FuelType}} FC \times C_{\text{carbon}} \right)_{\text{FuelType}3} + \ldots \]

- **Carbon content of fuel**
- **Fuel consumption**
- **Distance of voyage**
- **Transportation capacity**

**Effect of slow steaming**

<table>
<thead>
<tr>
<th>Ship speed</th>
<th>Engine power</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 % Service Speed</td>
<td>90% MCR</td>
</tr>
<tr>
<td>70 % Service Speed</td>
<td>30% MCR</td>
</tr>
<tr>
<td>50 % Service Speed</td>
<td>15% MCR</td>
</tr>
</tbody>
</table>

Service speed = guarantee speed at NCR with 15% sea margin

Slow steaming as 70 % of design speed

- Reducing fuel consumptions down to abt. 30 %
- Reducing EEOI
Key Words in Current Green Ship Technology

1. Technical Energy Saving and CO2 Reduction
   - Hull optimization appendages
   - New propulsion system
   - Waste energy recovery and renewable energy utilization

2. Slow Steaming Operation
   - Lower ship speed

3. Increase Ship Capacity
   - Increase DWT
### CO2 Reduction Potential by Known Technology and Practices

<table>
<thead>
<tr>
<th>Category</th>
<th>Fuel/CO2 Saving</th>
<th>Combined</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DESIGN (New ships)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept, speed &amp; capability</td>
<td>2 ~ 50%</td>
<td></td>
<td>10 ~ 50%</td>
</tr>
<tr>
<td>Hull and superstructure</td>
<td>2 ~ 20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power and propulsion systems</td>
<td>5 ~ 15%</td>
<td>10 ~ 50%</td>
<td>25 ~ 75%</td>
</tr>
<tr>
<td>Low-carbon fuels</td>
<td>5 ~ 15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewable energy</td>
<td>1 ~ 10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust gas CO2 reduction</td>
<td>0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OPERATION (All ships)</strong></td>
<td></td>
<td>10 ~ 50%</td>
<td></td>
</tr>
<tr>
<td>Fleet management, logistics &amp; incentives</td>
<td>5 ~ 50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voyage optimization</td>
<td>1 ~ 10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy management</td>
<td>1 ~ 10%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Source: IMO 2nd GHG Study
EEDI

\[
EEDI = \frac{CO_2 \text{ Emissions (g/hr)}}{DWT \times \text{Speed (ton-knot)}} = [\text{g/ton-mile}]
\]

\[
EEDI = \left( \prod_{j=1}^{M} f_j \sum_{i=1}^{nME} C_{FMEi} SFC_{MEi} P_{MEi} \right) + \left( \prod_{j=1}^{M} f_j \sum_{i=1}^{nPTI} P_{PTI(i)} \right) - \left( \sum_{i=1}^{nWHR} \frac{f_{eff(i)} P_{AEeff(i)}}{P_{MEi}} \right) - \left( \sum_{i=1}^{nPTI} f_{eff(i)} P_{AEeff(i)} \right) \left( C_{FMEi, SFC_{MEi}} \right)
\]

\[
\text{Correction factor (by ship type)}
\]

\[
\text{Capacity factor}
\]

\[
\text{Weather factor (wave, wind)}
\]

\[
\text{Transportation capacity & speed}
\]

\[
EEDI = \frac{CO_2 \text{ from propulsion} + CO_2 \text{ from Auxiliaries} - \text{Efficient use of energy}}{f_t \cdot (DWT) \cdot (\text{ship speed}) \cdot f_w}
\]
EEDI Reduction

**Propulsion power reduction**
- Lower resistance mechanisms
- Hull form optimization
- Course Optimization
- Propulsion efficiency
- Energy saving appendages
  - Propulsion machinery efficiency
  - Fuels with less carbon, e.g. LNG

**Reduction of aux power**
- Reduce hotel load
- HVAC
- Lighting
- Aux machinery efficiency
- Fuels with less carbon

**Clean energy and recovery**
- Waste Heat Recovery (WHR)
- Wind power, e.g. Sails, Kite, Flettner rotors
- Solar power
- CO2 capturing

\[
\text{EEDI} = \frac{CO_2 \text{ from propulsion} + CO_2 \text{ from Auxiliaries} - \text{Efficient use of energy}}{f_t \cdot (DWT) \cdot (\text{ship speed}) \cdot f_w}
\]

**Increase capacity**
- Higher speed with same power
- Speed reduction
- Reduce ship weight
- Lighter material
- Larger ship and/or payload
- Structural optimization
Key Strategy of EEDI Reduction

Speed reduction, Increased Capacity, Improved technology

EEDI Reference Line (IMO)
(Average, ordinary ship)

DWT increase (a)
Speed Reduction (b)
Technologies (c)

Efficiency Improvement

Modified Ship

Deadweight
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk</td>
<td>Over 20K</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>10K-20K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-20</td>
<td>0-30</td>
</tr>
<tr>
<td>Gas Tanker</td>
<td>Over 10K</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2K-10K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-20</td>
<td>0-30</td>
</tr>
<tr>
<td>Tanker</td>
<td>Over 20K</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>4K-20K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-20</td>
<td>0-30</td>
</tr>
<tr>
<td>Containership</td>
<td>Over 15K</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3K-15K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-20</td>
<td>0-30</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>Over 15K</td>
<td>0</td>
<td>10</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3K-15K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-15</td>
<td>0-30</td>
</tr>
<tr>
<td>Refrigerated Cargo Ship</td>
<td>Over 5K</td>
<td>0</td>
<td>10</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3K-5K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-15</td>
<td>0-30</td>
</tr>
<tr>
<td>Combination Carrier</td>
<td>Over 20K</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>4L-20K</td>
<td>N/A</td>
<td>0-10</td>
<td>0-20</td>
<td>0-30</td>
</tr>
</tbody>
</table>
Estimated Time-Scale for Realization of Energy Efficiency Measures

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational measures*</td>
<td>10</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Technical measures#</td>
<td>-</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>(excluding fuels)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* new & existing ships  # newbuildings

Source: IMO – MEPC 58 / Info 14

We need quick action in ship operation. Technology development requires longer-term activity.
## Green Ship Design Based on EEDI Evaluation

### Expected CO2 Reduction in Different Methods

<table>
<thead>
<tr>
<th>Category</th>
<th>Method</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>LNG Fueled Propulsion</td>
<td>23%</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Optimized Hull Form Design</td>
<td>2~3%</td>
</tr>
<tr>
<td></td>
<td>High Efficiency Propeller Design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bulbous Bow Optimization</td>
<td></td>
</tr>
<tr>
<td><strong>Device</strong></td>
<td>Shaft Generator</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Pre-Swirl Stator (PSS), Ducted PSS, Rudder Bulb Fin</td>
<td>3~6%</td>
</tr>
<tr>
<td></td>
<td>Waste Heat Recovery System (WHRS)</td>
<td>3~4%</td>
</tr>
<tr>
<td></td>
<td>NOx Reduction Device, SOx Reduction Device</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Cavity System, Micro Bubble</td>
<td>7~10%</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>Advanced A/F Paint</td>
<td>2~5%</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td>Trim Optimization</td>
<td>3~4%</td>
</tr>
<tr>
<td></td>
<td>Optimum Weather Routing</td>
<td>4~5%</td>
</tr>
</tbody>
</table>
## Green Ship Design Based on EEDI Evaluation

### Resistance Components of Commercial Ships

<table>
<thead>
<tr>
<th>Components</th>
<th>% in calm water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave resistance</td>
<td>5~30%</td>
</tr>
<tr>
<td>Air (wind) drag</td>
<td>1~5%</td>
</tr>
<tr>
<td>Frictional drag</td>
<td>60~80%</td>
</tr>
<tr>
<td>Form drag</td>
<td>10~30%</td>
</tr>
</tbody>
</table>

- Increases in actual sea condition: 10~50%
- Effective, but hard to reduce
- Hull design optimization

*Strategy should be different for different ship types.*
Strategy Example: VLCC (15kt) and Containership (22.5 kt)

(N. Sasaki, NMRI)
Hull form design to reduced added resistance

- Added resistance is a key parameter in power reduction in waves.
- Optimum hull form design is needed in the viewpoint of added resistance.
Green Ship Design Based on EEDI Evaluation

Ship Design Procedure based on EEDI Concept

1. **Ship Design**
   - **Modification**
   - **Calculate EEDIs**
   - **Satisfy?**
     - **Manufacturing**
     - **Sera Trial**
     - **Acceptance Criteria: Required EDEI**

2. **EEDI Verification**
   - **Satisfy?**
     - **Certificate**
     - **Operation**
     - **Sea Trial**
Strategy of Operation (e.g. Lloyd’s Register)
Effects of Slow Steaming

Source: N. Sasaki (NMRI)
Reduction of 3 knots will reduce about 20~30% of EEDI and 40~50% of FOC.
## Generation of Containerships

<table>
<thead>
<tr>
<th>Generation</th>
<th>Length</th>
<th>TEU</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (1956~1970)</td>
<td>~200m</td>
<td>~800</td>
<td></td>
</tr>
<tr>
<td>2 (~1980)</td>
<td>~215m</td>
<td>~2,500</td>
<td></td>
</tr>
<tr>
<td>3 (~1988)</td>
<td>~290m</td>
<td>~4,000</td>
<td><strong>Panamax Class</strong></td>
</tr>
<tr>
<td>4 (~2000)</td>
<td>~305m</td>
<td>~5,000</td>
<td><strong>Post Panamax Class</strong></td>
</tr>
<tr>
<td>5 (~2005)</td>
<td>~335m</td>
<td>~8,000</td>
<td><strong>Post Panmax Plus Class</strong></td>
</tr>
<tr>
<td>6 (~2010)</td>
<td>~400m</td>
<td>~14,500</td>
<td></td>
</tr>
<tr>
<td>7 (2011~)</td>
<td>~440m ?</td>
<td>~20,000?</td>
<td><strong>Ultra Large</strong></td>
</tr>
</tbody>
</table>
Trend of Ship Size

Delivered in 2000~2008 (2003 is missed)
Containership Orderbook

Capacity w.r.t. Contract Date

Green Ship Design Based on EEDI Evaluation
Economies of scale have dictated an upward trend in sizes of container ships in order to reduce costs. However, there are certain limitations to the size of container ships. Primarily, these are the availability of sufficiently large main engines and the availability of a sufficient number of ports and terminals prepared and equipped to handle ultra-large container ships. Furthermore, the permissible maximum ship dimensions in some of the world's main waterways could present an upper limit in terms of vessel growth. This primarily concerns the Suez Canal and the Singapore Strait.

In 2008 the South Korean shipbuilder STX announced plans to construct a container ship capable of carrying 22,000 TEU, and with a proposed length of 450 metres and a beam of 60 metres. If constructed, the container ship would become the largest seagoing vessel in the world.

Since even very large container ships are vessels with relatively low draft compared to large tankers and bulk carriers, there is still considerable room for vessel growth. Compared to today's largest container ships, Maersk Line's 15,200 TEU "Emma Maersk" type series, a 20,000 TEU container ship would only be moderately larger in terms of exterior dimensions. According to a 2011 estimate, an ultra-large container ship of 20,250 TEU would measure 440m x 55m, compared to 397.71 x 56.40m for the "Emma Maersk" class. It would have an estimated deadweight of circa 220,000 tons. While such a vessel might be near the upper limit for a Suez Canal passage, the so-called Malaccamax concept (or Straits of Malacca) does not apply for container ships, since the Malacca and Singapore Straits' draft limit of about 21 metres is still above that of any conceivable container ship design. In 2011, Maersk announced plans to build a new "Triple E" family of containerships with a capacity of 18,000 TEU, with an emphasis on lower fuel consumption.

In the present market situation, main engines will not be as much of a limiting factor for vessel growth either. The steadily rising cost of fuel oil has prompted most container lines to adopt a slower, more economical voyage speed, of about 21 knots, compared to earlier top speeds of 25 or more knots. Subsequently, new-built container ships can be fitted with a smaller main engine. Engine types fitted to today's ships of 14,000 TEU are thus sufficiently large to propel future vessels of 20,000 TEU or more. Maersk Line, the world's largest container shipping line, nevertheless opted for twin engines (two smaller engines working to separate propellers), when ordering a series of ten 18,000 TEU vessels from Daewoo Shipbuilding in February 2011. The ships will be delivered between 2013 and 2014.

Maersk Line ordered a series of ten 18,000 TEU vessels to Daewoo Shipbuilding in February 2011.
Green Ship Design Based on EEDI Evaluation

Youtube:
Maersk Line Triple-E Smarter design, with room for 18,000 containers
Green Ship EEDI Reduce Plan: Example of DSME

**Dimension (Lbp x B x D x Td x Ts x Cb)**

\[320 \times 60 \times 30.5 \times 21 \times 22.5 \times 0.82\]

**DWT (Ts):** 319,600 MT

**Vs (Serv.):** 16.2 → 15.9 Kts

**DFOC:** 101.6 → 94.9 MT/day

Case 3) LFS design to be developed further

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Design</th>
<th>Improved (Case 1)</th>
<th>Improved (Case 2)</th>
<th>Improved (Case 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applied Econologies</strong></td>
<td>7S80MC-C8.2</td>
<td>←</td>
<td>←</td>
<td>7S80ME-C8.2-GI</td>
</tr>
<tr>
<td>N/A(derated)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prop Dia. 10.0 m</td>
<td></td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>MCR (kW) x RPM</td>
<td>29,260 kW x 78.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEDI speed (knots)</td>
<td>15.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SFOC at 75% MCR (g/kWh)</td>
<td>168.1</td>
<td></td>
<td></td>
<td>141.2</td>
</tr>
<tr>
<td>CO2 Emission (g/h)</td>
<td>12,075,373</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEDI (g/ton-mile)</td>
<td>2.515</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEDI/Reference line (%)</td>
<td>112 %</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* LFS; LNG Fueled Ship
## Energy Saving Devices

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft Generator</td>
<td>1%</td>
</tr>
<tr>
<td>Pre-Swirl Stator (PSS)</td>
<td>3~6%</td>
</tr>
<tr>
<td>Ducted PSS</td>
<td>3~6%</td>
</tr>
<tr>
<td>Rudder Bulb Fin</td>
<td>3~6%</td>
</tr>
<tr>
<td>Waste Heat Recovery System (WHRS)</td>
<td>3~4%</td>
</tr>
<tr>
<td>Air Cavity System, Micro Bubble</td>
<td>7~10%</td>
</tr>
</tbody>
</table>

*Choice is dependent on ship type, cost, available space, etc.*

*Performance is dependent on ship type, operation condition, device type, etc.*

*Higher FOC Performance, but Higher Ship Cost*
Shaft Generator

Shaft generator and WHRS of Siemens
Micro Bubble Injection

- Producing thin layer of bubbles
- Drag reduction by air bubbles
- The film of air generated by air injection on ship surface covered with very water repellent layer

Reduction of viscous frictional drag
Air Cavity System

Potential up to 15% CO2 reduction
- Pressured air injection on ship bottom
- Air pressure injection requires some additional power (1~3%), but significant drag reduction is expected.
- Pay-back time 2-4 years
Contra/Counter Rotating Propeller (CRP)

- Recovery of rotating energy loss originated by a propeller through the use of a contra rotating propeller
- Improves propulsion efficiency by 10% to 15%
- Reduces cavitation
- Benefits mainly at cruising speeds
- Complicated design and higher costs
Hull appendages

• Typical concepts to increase propulsion efficiency
  - Making uniform stern flow
  - Reducing rotating energy loss
  - Generating more thrust by appendage
• Improves propulsion efficiency by 3% to 5%

Pre-Swirl Stator (Daewoo Shipbuilding & Marine Engineering)
SAVER Fin (Samsung Heavy Industry)
Energy Saving Devices

Hull appendages

Sumitomo’s Fin

IHIl’s Fin

Thrust fin (Hyundai Heavy Industry)
Duct Propeller

- Thrust gain by duct
- Increase propeller efficiency by making stern flow uniform
- Many variations in application
- Improves propulsion efficiency by 3% to 8%

SSD (Super Stream Duct)
SDS (Semi-circular Duct System)
SILD (Sumitomo Integrated Lammeneren Duct)
Mewis duct
Typical Energy Saving Devices: Their Efficiency

Source: N. Sasaki (NMRI)
Energy Saving Devices

Clean Energy Devices: Skysail

- Kite operated in 100~500m height
- Expect 10~30% fuel reduction

Ship with Skysails
Energy Saving Devices

Clean Energy Devices: Solar Power

NYK Ship with solar cell

Concept design of AquaSailor with solar sail
Energy Saving Devices

Strategy: e.g. Lloyd’s Register

Propulsion Devices

- Applicable to RoRo and Ferry
- Reduction of fuel consumption when vessel operates at variable loads

Contra Rotating propellers 9%
Wing thrusters 15%
Pulling thrusters 16%
Propeller monitoring and maintenance 8%
Propeller coatings and paints 8%
Propulsion efficiency monitoring 8%
Propeller – rudder combinations 9%
Nozzles 8%
Boss cap fin 5%
Ducts 9%
Winglets 5%

Monitoring systems
Polishing
Coatings
Alternative Fuel/Energy for Ships: LNG as fuel

- Strong candidate for future propulsion engine
- Dual fuel: Diesel + LNG (ME-GI)
- Relatively cheap cost
- 15~25% Reduction of CO2
- Dramatic reduction of Nox, Sox, and air dust pollution
- e.g. 14,000TEU containership => 14M$/year reduction of fuel cost (DSME)
Alternative Fuel/Energy for Ships: Electric & Nuclear

- Hybrid electric-diesel system, fuel cell, pod propulsion system
- Excellent performance for noise and vibration
- Good performance for constant thrust power and controllability
- Flexible arrangement
- Heavy machinery system
- Lower shaft transmission efficiency (about 7~8% less than other system)

- No air pollution
- 3-4 year operation with one supply
- Low fuel cost
  - (1g uranium = 2 ton crude oil)
- No heavy duct system or large space for fuel
- Critical environmental problem in failure case
- Heavy safety system
- Very high ship cost
- Complicated system and many operators
More Emerging Technology

- Hull Painting and Ultrasonic Hull-Surface Coating
- Bio-diesel
- FOC Reduction by Path Optimization
- Fuel Machinery System Optimization
- Structural Material
- Optimum Ship Structural Design

...... (many more)
Which will be more?
**Econology** = **Ecology** + **Economy** + **Technology**

### High Performance Ship Design
- Optimum Dimensions
- Excellent Speed Performance
- Maximum Capacity (DWT, VOL)
- Competitive FOC
- Safety

### Green Enhanced Design
- **F**uel(= CO₂) Saving Max. (EEDI)
- **E**fficient Operation (EEOI)
- **E**mission Reduction
- **L**ess Maintenance

New Requirements of Environmental Associations & Shipping Industry

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**Hi-Performance & Environment Friendly Ship**
APL’s Concept for Environmental Friendly Ship

Building environmentally friendly ships of the future...

Source: Poh (MTEC 2011)
Super Eco Ship 2030 (NYK, Japan)

We need to consider all the aspects for green ship.
Some green innovative programs are already underway at ports around the globe to reduce their carbon footprint.

- Cleaner fuel (Ultra low sulphur fuel) & energy efficient engine
- Renewable source of power to port facilities as solar, wind energy system
- Green lease agreement, green building standards for new construction
- Shore-side power / “cold ironing”
- LNG, hybrid incl. hydrogen fuel cell, CNG, electric cargo handling equipment & trucks
- Modal shift from trucks to coastal shipping and train
- Carbon, capture and storage
- Smart grid application in port
- LNG, hybrid incl. hydrogen fuel cell, CNG, nautical services (tugboats, pilot, etc)

The mitigation measures can be accomplished with the help of a regulatory and political framework promoting such innovation into an industry.

Source: Svensen (MTEC 2011)
Environment Friendly
Economical Operation

Through Green Ship Technologies
Acknowledgment for presentation materials

Daewoo Shipbuilding & Marine Engineering
Korean Ministry of Knowledge and Economy

References

• S. Hirdaris, Lloyd’s Register Strategic Research in short and long term technologies, 2011
• H.O.H. Kristensen, Model for Environmental Assessment of Container Ship Transport, 2010
• O.Y. Kwon, DSME GreenShip 18,000TEU Container Carrier, 2011
• N.B. Mortensen, Reduction of Green House Gas Emissions from Ships, Tripartite Meeting, 2007
• SIMENS, Solutions for Green Ship Operation, Asia Pacific Maritime, March 2010
• G. T. Poh, Global Approach towards Green Shipping: Strategies and Perspectives of a Shipping Line, MTEC 2011
• N. Sasaki, An application of GHG emission reduction technologies in the future: The concept of GHG technologies road map, 2009
• C. Schack, Green Ship of the Future, 2009
• T.E. Svensen, Trends of Green Issues and Impact on Shipping and Ports, MTEC 2011