Energy efficiency of inland water ships
- and how to improve it

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Energy efficiency of inland water ships

We propose to use the energy efficiency index EEFI as benchmarking index. The index EEOI will have the same relevance, as is obtained by data of ship operation.

\[ EEDI = \frac{C_F \times SFC \times P}{Capacity \times V_{ref}} \]

In fact, this simple expression shows

**CO2 Emission / transport performance**

Slow and large ocean vessels will obtain a value of about 5 gr CO2/tkm and RoRo ships or ferries will reach 50 gr. CO2/tkm
Influence of the water depth on transport efficiency

The water depth will have an influence two main aspects of transport efficiency:

• The load capacity of the ship
• The speed of the ship
Influence of the water depth on transport efficiency

The load capacity

For any ship, keel clearance is necessary to advance and to manoeuvre. The keel clearance should be greater than 0.3 m. As function of the water depth, the load capacity starts at zero and increases until the design draught of the ship is reached.

![Graph showing the load capacity as a function of water depth](image-url)
Influence of the water depth on transport efficiency

Ship speed

The practicable ship speed will increase, more or less proportionally to the root of the water depth. Typical IWS can reach a speed of 22 km/h, depending on the engine power and the hull form. For this speed level, a water depth of abt. 9 m will be necessary.
Influence of the water depth on transport efficiency

Example: Specific energy consumption

A IW cargo vessel works 12h per day, the transport distance being 200 km. The transport volume per day depends on load capacity and speed and is therefore a function of water depth:

![Graph showing the transport volume per 12 h workday against water depth. The transport volume increases with water depth up to a certain point and then plateaus.](image-url)
Influence of the water depth on transport efficiency

The fuel consumption depends also on the water depth. As at low water depth, the travel will take longer, there will be strong influence on fuel consumption.
Influence of the water depth on transport efficiency

The fuel consumption has to be seen in relation with the transport volume.

In our example it is obvious that the specific energy consumption will reach a low level at water depth larger than 2.5 m.
Influence of the water depth on transport efficiency

The same applies to the specific $\text{CO}_2$- Emission.

Interesting to see that at water depth larger then 4 m, the IWS transport reaches its best transport efficiency.
Improving transport efficiency

Ship type
Scale effect
Propulsion
Ship weight
Hull form
DST report 1701 investigated how the transport cost of different ship types is related to water depth. Obviously, there are big differences in transport cost.
There is also a scale effect in transport efficiency...

\[ h = 5.0 \text{ m}, \ T = 2.5 \text{ m}, \ V = 13 \text{ km/h} \]

<table>
<thead>
<tr>
<th>Typ</th>
<th>L x B [m]</th>
<th>V [m³]</th>
<th>dW [t]</th>
<th>ms [t]</th>
<th>P_B [kW]</th>
<th>D_P [m]</th>
<th>CO₂ [g/tkm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peniche</td>
<td>39,0 x 5,1</td>
<td>450</td>
<td>366</td>
<td>84</td>
<td>309</td>
<td>1,10</td>
<td>47,1</td>
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<tr>
<td>Gustav Koenigs</td>
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<td>935</td>
<td>243</td>
<td>549</td>
<td>1,40</td>
<td>31,3</td>
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<tr>
<td>Johann Welker</td>
<td>80,0 x 9,5</td>
<td>1672</td>
<td>1272</td>
<td>400</td>
<td>421</td>
<td>1,50</td>
<td>17,6</td>
</tr>
<tr>
<td>Gütermotorschiff</td>
<td>110,0 x 11,4</td>
<td>2750</td>
<td>1900</td>
<td>850</td>
<td>230</td>
<td>1,85</td>
<td>6,4</td>
</tr>
<tr>
<td>Jowi-Klasse</td>
<td>135,0 x 17,0</td>
<td>4745</td>
<td>3335</td>
<td>1410</td>
<td>480</td>
<td>3 x 1,74</td>
<td>7,7</td>
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<tr>
<td>Langschiff</td>
<td>150,0 x 15,0</td>
<td>4904</td>
<td>3404</td>
<td>1500</td>
<td>390</td>
<td>2 x 1,76</td>
<td>6,1</td>
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<tr>
<td>Schubverband 2spurig-2gliedrig</td>
<td>193,0 x 22,8</td>
<td>8600</td>
<td>6260</td>
<td>2340</td>
<td>1365</td>
<td>3 x 2,05</td>
<td>11,6</td>
</tr>
<tr>
<td>Schubverband 2spurig-3gliedrig</td>
<td>269,5 x 22,8</td>
<td>12550</td>
<td>9390</td>
<td>3160</td>
<td>2100</td>
<td>3 x 2,05</td>
<td>11,9</td>
</tr>
<tr>
<td>LKW ( V_{mittel} = 72,5 \text{ km/h} )</td>
<td>-</td>
<td>-</td>
<td>26</td>
<td>14</td>
<td>320</td>
<td>-</td>
<td>37,4</td>
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<tr>
<td>PKW ( V_{mittel} = 100 \text{ km/h} )</td>
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<td>-</td>
<td>0,5</td>
<td>1,4</td>
<td>75</td>
<td>-</td>
<td>240</td>
</tr>
</tbody>
</table>
Improving transport efficiency

Propeller efficiency plays a key role

CO₂-emission of a large cargo motor ship
(L x B x T = 110,0 m x 11,4 m x 2,5 m)

<table>
<thead>
<tr>
<th></th>
<th>PB [kW]</th>
<th>spezifischer CO₂-Ausstoß [g/tkm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>zu Berg upstream</td>
</tr>
<tr>
<td>freier Propeller free propeller B-series</td>
<td>715</td>
<td>25,3</td>
</tr>
<tr>
<td>Kaplan-Propeller in Düse ducted propeller K-series</td>
<td>572</td>
<td>20,2</td>
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<tr>
<td>Skew-Propeller in Düse ducted skew-propeller</td>
<td>536</td>
<td>18,9</td>
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</table>
## Improving transport efficiency

### Ship light weight

<table>
<thead>
<tr>
<th>Typ</th>
<th>$T_{\text{max}}$ [m]</th>
<th>$m_s$ [t]</th>
<th>$dW$ [t]</th>
<th>$dW / ms$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peniche</td>
<td>2,5</td>
<td>84</td>
<td>366</td>
<td>4,36</td>
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<tr>
<td>Gustav Koenigs</td>
<td>2,7</td>
<td>243</td>
<td>1276</td>
<td>5,25</td>
</tr>
<tr>
<td>Johann Welker</td>
<td>2,9</td>
<td>400</td>
<td>1940</td>
<td>4,85</td>
</tr>
<tr>
<td>Gütermotorschiff</td>
<td>3,2</td>
<td>850</td>
<td>2681</td>
<td>3,15</td>
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<tr>
<td>Jowi-Klasse</td>
<td>3,2</td>
<td>1410</td>
<td>4761</td>
<td>3,38</td>
</tr>
<tr>
<td>Langschrift</td>
<td>3,5</td>
<td>1500</td>
<td>5406</td>
<td>3,60</td>
</tr>
<tr>
<td>Schubverband 2spurig-2gliedrig</td>
<td>Pushing train 2+2</td>
<td>4,0</td>
<td>2340</td>
<td>4,79</td>
</tr>
<tr>
<td>Schubverband 2spurig-3gliedrig</td>
<td>Pushing train 2+2+2</td>
<td>4,0</td>
<td>3160</td>
<td>5,32</td>
</tr>
<tr>
<td>LKW</td>
<td>14</td>
<td>26</td>
<td></td>
<td>1,86</td>
</tr>
</tbody>
</table>
Improving transport efficiency

Ship light weight

Marginal influence of ship weight reduction
Improving transport efficiency

Hull form

Small changes in the hull form may produce a big difference
Improving transport efficiency

Hull form

CFD calculations are detecting flow separation areas
Improving transport efficiency

Hull form

Hull with variable geometry
Improving transport efficiency

Ship type
... As large as the waterway allows

Scale effect
... high performance propellers and nozzles

Propulsion
... don’t expect too much

Ship weight

Hull form
... still decisive and pays off research