The Use of Carbon Composite for Commercial ferries - a case of radical Eco-innovation

based on the “Eco Island Ferry” Project and S@il hybrid propulsion project

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Sustainability, Innovation and Policy
Aalborg University
My talk on carbon composite ferries

• The context (Denmark, cleantech, shipping)
• Technical issues
• Implementation (policy, business models)
• Innovation aspects
• Conclusions
The Context

5.6 Million people
43,000 km²
Energy and waste situation in Denmark 2013

District heating covers more than 61% of space and water heating, mainly produced from combined heat and power plants.

Waste incineration account for approx 20 % per cent. Most municipal household waste is incinerated.
Environmental challenges are changing (ashore)

The nature of the environmental problem

- Global/Complex
- Local/Simple causality

- Noise
- Dust
- Smell
- Water and air pollution
- Chemicals
- Climate Change
- Sustainable development
- Environmental impacts of products

(time)

yesterday
tomorrow
Is the environment benefiting of CleanTech?

Yes, emissions in Denmark are decreasing

...and yes, the air on Jagtvej in Copenhagen is getting cleaner

Source: "Natur og Miljø 2009" Danish EPA, 2010
Other CleanTech benefits for Denmark?

Big Business: approx. 50 Billion Euro turnover

- Klimaforandringer
- Arealanvendelse og biodiversitet
- Jordforurening
- Kemikalier
- Affald
- Råvare- og materialeforbrug
- Vand
- Luftforurening

...and 120,000 employees in 720 companies

Source: "Natur og Miljø 2009" Danish EPA, 2010
Industry’s **preventive** approaches to environmental challenges

- **1st step** Cleaner production - resources + emissions
- **2nd step** Environmental management - continuous improvements
- **3rd step** Cleaner products - life cycle thinking
- **4th step** Sustainability

Shipping 2005

End-of-pipe...

Dilution
Denial: no problem!
A new wave is approaching: environmental regulation at sea
What does it consist of?

Legislation:
• MARPOL convention fra IMO
• new Annex VI (2008-11)
• EU’s sulphur directive
• Californian legislation

Demand driven:
• Carbon footprint?
• Other aspects?
SOx and NOx Emissions are regulated by the International Maritime Organisation (IMO)

**MEPC 57 IMO Fuel-sulphur Content**

Equivalent methods may be used as alternative

- **Global**:
  - 2000: 4.5
  - 2010: 3.5
  - 2020: 0.5

- **SECA**:
  - 2000: 1.5
  - 2010: 1.0
  - 2020: 0.1

**NOx emission limit schedule according to IMO (Int. Maritime Organisation)**

- 2000
- 2011
- 2016 (ECA’s only)
Environmental improvement options in shipping

Optimal operation (weather routes, lean, reduced speed, maintenance)

Technical changes
  – New design (propulsion, hull, bulb, lightweight, surfaces, fins)
  – Add-on (micro bubbles, Scrubbers, catalysts, EGR, Ballast water treatment)

Cleaner fuels
  – Low sulphur fuels (diesel)
  – Gas (LNG)
  – Biofuels...
  – Electric and hybrid systems

On-shore power supply
CO₂ emission for ships and trucks

CO₂ emissions for bulk carriers versus trucks

- 12 m truck carrying 24 t cargo
- Bulk carrier (fully loaded)

<table>
<thead>
<tr>
<th>Ship size (ton deadweight)</th>
<th>CO₂ emissions per ton cargo per km (g/m/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200000</td>
<td>38</td>
</tr>
<tr>
<td>150000</td>
<td>38</td>
</tr>
<tr>
<td>100000</td>
<td>38</td>
</tr>
<tr>
<td>60000</td>
<td>38</td>
</tr>
<tr>
<td>40000</td>
<td>38</td>
</tr>
<tr>
<td>20000</td>
<td>38</td>
</tr>
<tr>
<td>10000</td>
<td>38</td>
</tr>
</tbody>
</table>

Hans Otto Holmegaard Kristensen 29-11-2010
Conclusions from DMU (2010)

In 2007, the average contribution of shipping to air pollution in Denmark was:

- $\text{SO}_2$ 33%
- $\text{NO}_2$ 21 %
- $\text{mPM2.5}$ 18 %
- $\text{PM2.5}$ 9%
- $\text{CO}_2$ globally: 2.7 % (IMO, 2009)

Scenario calculations show significant reductions when IMO’s sulphur criteria are implemented in 2020. For $\text{NO}_2$ and $\text{PM2.5}$ the calculated effect is smaller.
NOx reductions: not very shipping related

Figur 6  Beregnede koncentrationer af NO₂ i μg/m³. Til venstre er vist situationen i 2007, til højre situationen i 2020. Der sker NÆSTEN INGEN ÆNDRING (ed.:HR) i udslipet af NOₓ fra skibstrafik mellem de to tidspunkter, mens der er markante reduktioner for landbaserede kilder.
Model calculation for 2007 and 2020

Concentration of SO$_2$, $\mu$g/m$^3$

<table>
<thead>
<tr>
<th>Concentration Range</th>
<th>2007</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 0.50$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50 - 0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00 - 1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25 - 1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.50 - 1.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.75 - 2.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00 - 2.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.25 - 2.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.50 &lt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Christer Ågren, 28-11-2010
Aim of the Eco Island Ferry project

The idea is:

To work out a basis for comparing two small passenger ferries built of either carbon composites or steel.

- life cycle costs
- environmental impact

To inspire shipowners and naval architects to consider modern materials for ship building when fuel consumption and environmental impact have high priority

Support from The Danish Maritime Fund and Västra Götaland Region
Three small Danish companies share a common interest for small composite ferries

Dec. 2010
1st MARKIS Conference: The Danish companies meet Swedish Experts

June 2010: Three small Danish companies share a common interest for small composite ferries

May 2011
Application from 8 partners (DK+SE)

Autumn 2011: Funding from:
- Västra Götaland Region
- Danish Maritime Fund
- Private participants
- SP Techn. Res. Inst. of Sweden

Project starts

Timeline for the Eco Island Ferry Project

What if similar advanced techniques were applied to ensure environmental improvements in mainstream segments?

As if environmental impacts matter

(Lead user innovation made possible by the navy and luxury superyachts)
Not a commercial project
- No ferry actually constructed (the reference ferry was in operation)
- All materials and analyses are publicly available
- Maximum dissemination of results and publicity

The real anticipated outcome:
- Change of perspective among shipowners and authorities
- Competence building in industry
- Capacity building in Danish and Swedish maritime authorities
- The basis for a follow-up commercial project (= real ferries)
Market Research

What does the market look like in different nearby countries?

- Number of vessels?
- Age?
- Size?
- Business models/costs?
- Ferry landing?
- Operational hours per day?
The Markets: Denmark

- 70 ferries (incl back-up)
- 10 recent newbuilds
- Still, 30 are more than 25 years old (average age: 44)
- Business model?
Tunø Ferry – existing and new

Reference ship: Tunø-ferry
- EC directive, D-class
- Construction material: Steel
- 200 Passengers & 6 Cars
- approx. 30 meters
- 9,5 knots
- Displacement 340 T
- Installed engine power: 2 X 294 kW

The Challenger…

Replacement for the Tunø-ferry
- EC directive? D-class, SOLAS
- Construction material: FRP (Carbon comp.)
- 200 Passengers & 6 Cars
- approx. 30 meters
- 9,5 knots
- Displacement 120 T
- Expected engine power: 2 x 110 kW
## Structure weight

<table>
<thead>
<tr>
<th>Overall structure weight</th>
<th>[%]</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>67</td>
<td>56</td>
</tr>
<tr>
<td>E-Glass/foam sandwich</td>
<td>52</td>
<td>43</td>
</tr>
<tr>
<td>Carbon/foam sandwich</td>
<td>37</td>
<td>31</td>
</tr>
</tbody>
</table>

Slide by Niels Hjørnet
What is composite?
A mixture of *resin* and *fibres*
## Comparison

**Steel - carbon**

<table>
<thead>
<tr>
<th>Material properties</th>
<th>E-modulus [GPa]</th>
<th>Tensile/yield strength [MPa]</th>
<th>Density [kg/m³]</th>
<th>Specific strength [kNm/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>210</td>
<td>355</td>
<td>7850</td>
<td>45</td>
</tr>
<tr>
<td>Carbon T300/Epoxy</td>
<td>57</td>
<td>540</td>
<td>1418</td>
<td>381</td>
</tr>
</tbody>
</table>

Slide by Niels Hjørnet
Comparison
Steel – carbon/foam sandwich

Same stiffness: $EI = 3.431 \times 10^4 \text{ Nm}^2/\text{m}$

Weight:
- Sandwich: $5.5 \text{ kg/m}^2$
- Steel: $98.2 \text{ kg/m}^2$

Slide by Niels Hjørnet
Results: Environment

- Global warming
- Human toxicity, carcinogens
- Human toxicity, non-carc.
- Respiratory inorganics
- Ozone layer depletion
- Ecotoxicity, aquatic
- Ecotoxicity, terrestrial
- Nature occupation
- Acidification
- Eutrophication, aquatic
- Eutrophication, terrestrial
- Respiratory organics
- Photochemical ozone, vegetat.
- Non-renewable energy
- Mineral extraction
Ferry operation (fuel) is the reason

- Eco Island Ferry
- Tun Island Ferry

Disposal
Operation
Maintenance
Construction

Respiratory inorganics
Global warming
Photochemical smog

- Disposal
- Operation
- Maintenance
- Construction
Lower draft (1.4 m) saves 3,2 nautical miles a day and 5 min on each trip.

More direct route possible.

Shortest actual route nov. 2012.
Results Payback: Break-even after 8.6 years use

Assumptions:
• 3 % increase on fuel price (also shown for 0%, 5% and 10%)
• 4 hours daily operation = 2 return trips
• Salaries not included! (considered equal)
• 4 % interest rate
• 2.1% inflation rate

Figure 6 Contribution from different phases in the life cycle cost, presented at current price
Life Cycle Costs and break-even

Highly sensitive to operational hours:

<table>
<thead>
<tr>
<th>Trips per day</th>
<th>Operation Break-even</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 hours daily use)</td>
<td>12.1 yrs</td>
</tr>
<tr>
<td>2 (4 hours daily use as today)</td>
<td>8.6 yrs</td>
</tr>
<tr>
<td>3 (6 hours daily use)</td>
<td>6.5 yrs</td>
</tr>
<tr>
<td>4 (8 hours daily use)</td>
<td>5.3 yrs</td>
</tr>
</tbody>
</table>
Results: Identified institutional barriers

1. Considering Life Cycle Costs in public tendering
2. New green business models to finance extra investment
3. Allowing ferries in carbon composites - in a more simple way
   1. Eu Ferry directive requirement: ”Steel or similar”
   2. National approval for specific route - cheap but export difficulties
   3. SOLAS requirement ”risk analysis based approval” (rule 17). For unrestricted use (expensive)
4. High speed Code - extra manning (expensive)
Four planned outputs from Øko-Ø:

1. A general arrangement, scantling, propulsion calculation, specification for a carbon composite ferry.

2. Life Cycle Cost analysis. Assessing total cost of ownership and pay-back time for extra initial costs (design and construction).

3. Life Cycle Assessment – mapping environmental inputs and outputs throughout the whole life time of the ferry and an assessment of the environmental impacts of these.

4. "Rule 17 analysis". Which alternative constructions and arrangements are necessary to get approval for a small displacement lightweight composite ferry?

= No real ferry, only paper
Triple helix innovation

Authorities
- Søfartsstyrelsen
- Västra Götaland Region
- Sv. Transportstyrelsen
- Erhvervshus Nord

Research
- 2.-0 LCA consultants
- SP Technical Research
- Aalborg University
- Danish Yachts
- Niels Hjørnet Yacht Design
- Coriolis AB
- Kockums AB
- Private industry
Three enthusiastic innovators and how they learned

Jens Otto Sørensen, Danish Yachts
sailed submarines
learned modular design for navy

Mats Hjortberg, Coriolis AB
Composites and tender problems

Niels Hjørnet,
”homebaker” of racing boats:
”Leave ashore what you won’t need”
How can Odder Municipality save 263.345 kg CO₂ on transportation each year?

Alternative 1:

Alternative 2:

Shift all cars to hybrid: Exchange public cars Fiat Panda Dual 1.2 dynamic (127 g CO₂/km) with Yaris hybrids (78 g CO₂/km)

183 X
The future: More than just paper

- Interest
- Presentations
- Teaching
- Press
- Serious meetings
- EU ferry directive revision
- Izmir Municipality:
  
  Let’s have 15 of those (starting 2014)
Waves can be used positively
...but you must know where and when they are coming
Are new wave-causing impacts approaching?

”Observatory” Research, Industry and authorities
MARKIS (DK, N, S) Network, facilitating triple helix
How can the wave creation be influenced?

Knowledge
Interests
Power
Technology and solutions
Network
Key points

Anticipate upcoming env regulation! - and influence it

Shipping is different:
Global competition
Instruments and enforcement
Marked-based efforts?

Solutions exist

Institutional Implementation barriers
References and Contact:


Smith, J.H. and Watson J (2013) Eco Island Ferry - Comparative LCA of island ferry with carbon fibre composite and steel based structures. 2.-0 Lca Consultants Aalborg

More info on www:
Eco-island.dk

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Your questions