Zero-Emission Ferry Concept for Scandlines

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Abstract

FutureShip has designed a zero-emission ferry for Scandlines' Vogelfluglinie (linking Puttgarden (Germany) and Rødby (Denmark), which could be deployed by 2017. The propulsion is based on liquid hydrogen converted by fuel cells for the electric propulsion. The hydrogen could be obtained near the ports using excess electricity from wind. Excess on-board electricity is stored in batteries for peak demand. Total energy needs are reduced by optimized hull lines, propeller shape, ship weight and procedures in port.

1. Introduction

The "Vogelfluglinie" denotes the connection of the 19 km transport corridor between Puttgarden (Germany) and Rødby (Denmark), Fig.1. This corridor has been served for many years by Scandlines ferries, which transport cars and trains. Four ferries serve two port terminals with specifically tailored infrastructure, Fig.2. The double-end ferries do not have to turn around in port, which contributes to the very short time in port. Combined with operating speed between 15 and 21 kn, departures can be offered every 30 minutes. After decades of unchallenged operation, two developments appeared on the horizon which changed the business situation for Scandlines fundamentally:

1. New international regulations would curb permissible thresholds for emissions from ships in the Baltic Sea: Starting from 2015, only fuels with less than 0.1% sulphur, i.e. a 90% reduction compared to present operation, will be permissible for Baltic Sea shipping. Starting from 2016, Tier III of MARPOL's nitrogen oxides (NOx) regulations will become effective. This will impose a 75% reduction of NOx. Taken together, these regulations impose major changes on the machinery side requiring at least major refits if not replacement of current ships.
2. Plans for Fehmarn Belt fixed link have been discussed for a long time, but the project lay dormant until 2007 when Germany and Denmark signed an interim agreement for the construction of a fixed link. Earlier plans for a bridge were abandoned in favour of an immersed tunnel. The project has attracted criticism both for ecological and economical reasons.

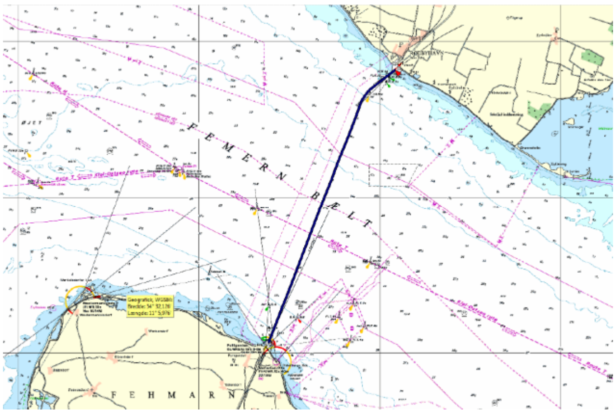

Fig. 1. Vogelfluglinie linking Germany and Denmark

Fig. 2. Aerial view of ferry terminal

Against the background of these "game changers", Scandlines decided to take the initiative and move radically ahead with a new generation of ferries that would offer similar transport services as the traditional ferries but outperform the projected fixed link ecologically and economically.

2. Functional requirements

From beginning it was clear that a revolutionary "new design" rather than evolutionary "trimming of the edges" was needed. The new design should not just meet the 2015/2016 regulations, it should go way beyond this and attract high-level attention not just in the region. The idea of a zero-emission ferry was born. The key requirements were simple to postulate, even though nobody had illusions about the technical challenges:

- Zero emissions of CO_2 (currently 3 t per trip)
- Zero emissions of NO_x (currently 50 kg per trip)
- Zero emissions of SO_x (currently 20 kg per trip)

These key requirements meant that new pathways had to be explored on the engineering side:

- New energy sources
- New energy carriers
- New energy converters

On top of these, all classical levers for energy consumptions would have to be employed to create an ultra-efficient ship fit for future market and regulation challenges. Around the time Scandlines had formulated the key requirements, GL Group attracted a lot of attention in the maritime industry with a pioneering feasibility study for a zero-emission container feeder ship for the North Sea and Baltic Sea, Fig.3, *Rohde and Sames (2012)*. The design for this ship was developed by GL Group's subsidiary FutureShip, which specializes in energy efficiency services for ships in design and operation. The concept design convinced, not least because it employed only commercial-off-the-shelf technology and no speculation about potentially evolving equipment that might or might not become available in due time. It was only logical that FutureShip and Scandlines pooled know-how and resources then in 2012 to develop the zero-emission ferry design presented in the following.

Fig. 3. Zero-emission design for a container feeder ship

The specifications for the new ferry design were detailed early in the project, including:

- The transport service should be essentially unchanged from present operation:
  - The ferries on the Puttgarden-Rødby route operate on a 30 min schedule.
  - Four ferries are permanently in service during the day. At night, usually one ferry is taken out of service
  - On average, one cycle (loading, sailing, unloading) takes 60 min.
  - Yearly total operation time is ~8500 h per ferry.
  - During loading and unloading, up to 1500 passengers are entering the car deck and passenger decks within 5 min.

- The zero-emission ferry shall be designed for a mean crossing time of 47 min. This corresponds to a maximum speed of 15.5 kn (considering speed reduction in leaving and approaching the terminals). A required minimum crossing time of 42 min corresponded to a maximum transit speed of 18 kn.

- The zero-emission ferry should incorporate improvements that enable time savings in port.
- The design shall be "zero emission" in operation with energy needed for the vessel's operation coming from sustainable sources. The zero-emission requirement does not apply to the construction of the vessel.
- There are no limitations with regard to the materials used on the zero-emission ferry.
- Ferries are presently carrying 24 h fuel reserves, but the fuel backup strategy shall be reconsidered for the zero-emission ferry.
- The zero-emission ferry shall have at least 1600 lane meter.

3. Design description

3.1. Main dimensions and general arrangement

The cargo and passenger spaces as well as the hull of the zero-emission ferry were designed as for any other modern but conventional ferry, Table I. At first glance, the general arrangement is also fairly standard for a double-end ferry, Fig.4. The only unusual features that stand out are the Flettner rotors above the ship superstructure. The ferry has larger capacity than the predecessors, with truck capacity moving from 30 to 96, and passenger capacity from 1150 to 1500.

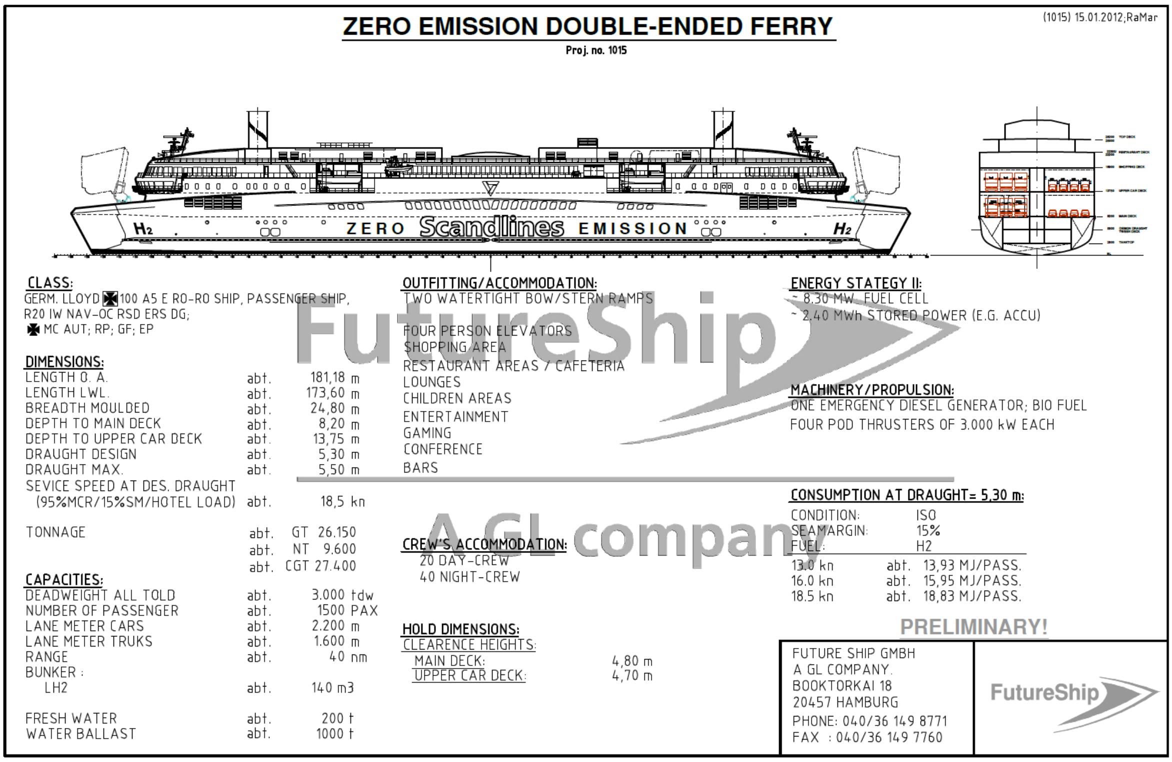

Fig. 4. General arrangement plan

Table 1. Main particulars of zero-emission ferry

Length in waterline	173.60 m	Speed	18.5 kn
Length overall	181.18 m	Deadweight	3000 tdw
Breadth moulded	24.80 m	Lane meters	2200 m
Depth	8.20 m	Passengers	1500 pax
Draft	5.50 m	Gross Tonnage	26200 GT

Several measures were identified as effective levers contributing to the overall energy efficiency of the design:

- Time in port was further reduced, e.g. by intelligent lighting on car decks. Quick dispatch in port allows then slower transit speed in crossing, a most effective lever for energy efficiency.
- Formal optimisation of hull for speed profile, *Hochkirch et al. (2013)*
- Formal optimisation of propellers
- Assorted improvements on subsystems, such as exclusive use of premium insulation.

3.2. Machinery, equipment & outfit

The fundamental innovations in the zero-emission ferry came naturally in the ship machinery. In a pre-study, a wide variety of potential solutions were discussed looking at energy providers and consumers, Fig.5. On the one hand, there was the power requirement from the main consumers:

- Propulsion
- HVAC
- Other hotel load

The total power requirement and mix of the various components vary over the transit cycle and environmental variations (wind, water depth, etc). Looking at the power requirment over a transit cycle, a decomposition into a ”base power” (required for a large part of transit) and a ”booster power” (temporary overload) suggested itself.

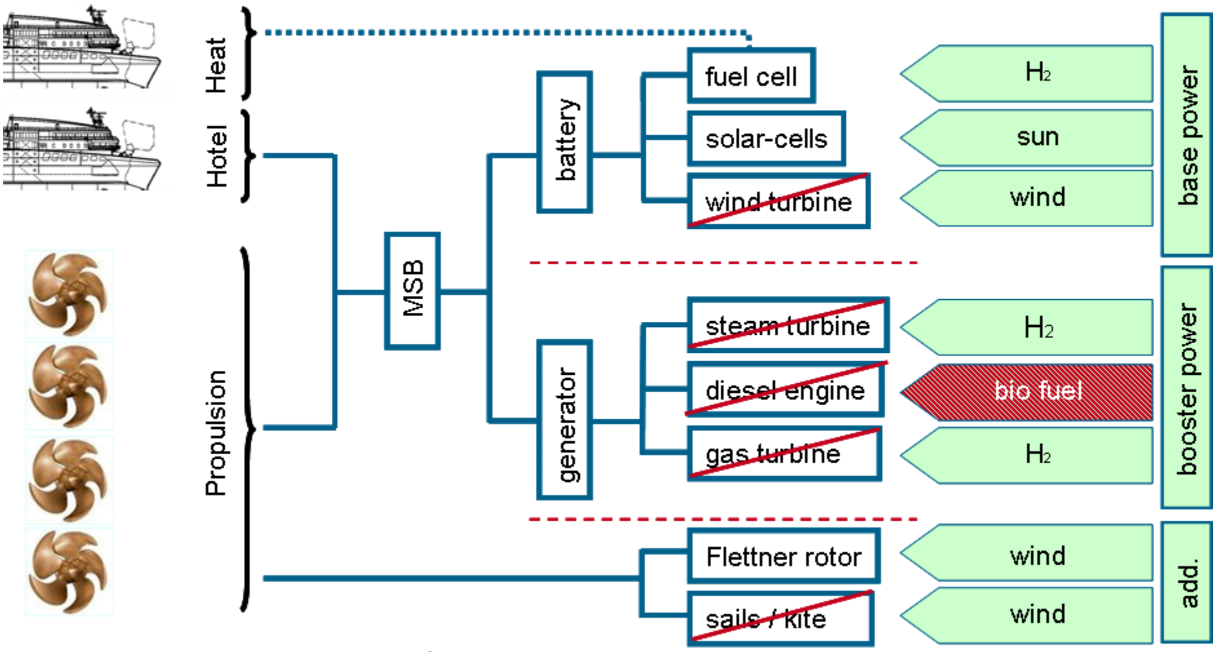

Fig. 5. Energy providers and consumers on ferry

On the other hand, there were various potential sources of energy:

- Solar power (for heating and part of the hotel load at best)
- Wind power (directly on board, with large fluctuations in availability)
- Liquid hydrogen (storing excess wind energy from wind power plants)
- Biofuel (disregarded due to visible emissions during voyage; subject to re-evaluation as second generation biofuel technology matures)

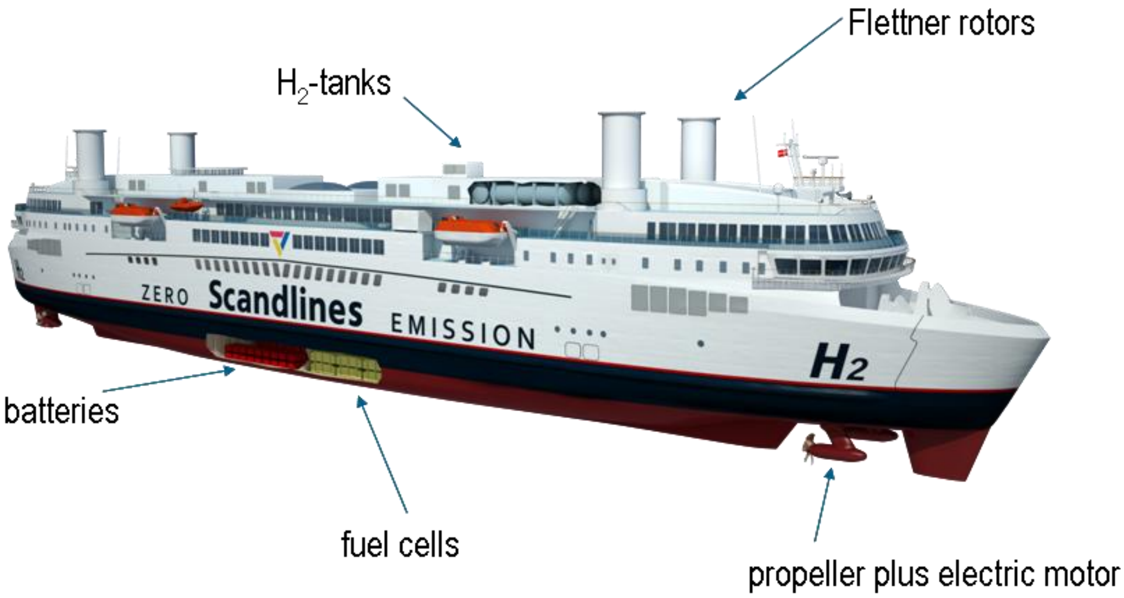

Fig. 6. Overall energy concept on zero-emission ferry

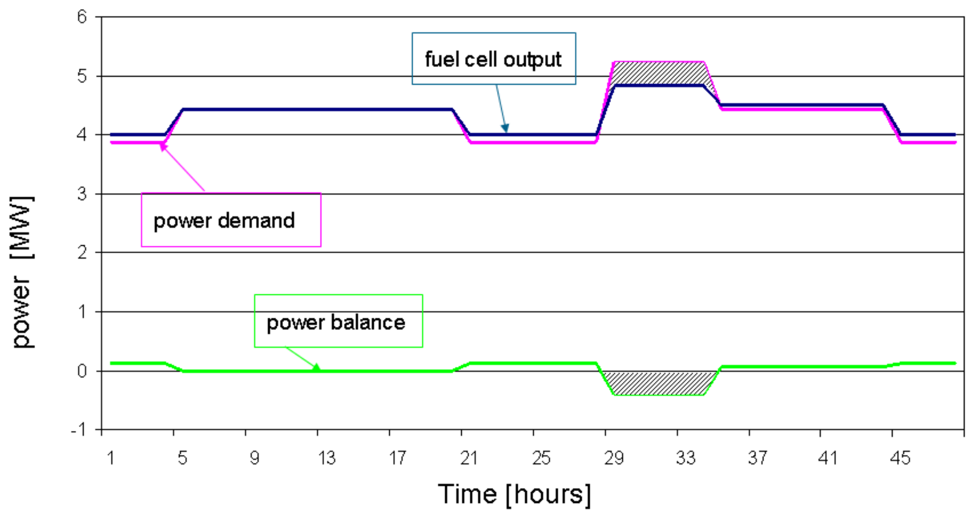

Fig. 7. Load profile with base load from fuel cells and booster load from batteries

The final concept resembles the machinery concept of the zero-emission feeder ship, Fig.6:

- Power generation is essentially based on liquid hydrogen. The hydrogen is stored in C-type tanks on deck. Tank capacity is 140 m^3, enough for 48 h operation. Liquid hydrogen in turn is pro-duced by excess wind power from wind power plants near the terminals. See Appendix 1 for a more extensive discussion of reasons and practicalities of liquid hydrogen as energy storage medium for excess energy from wind power plants.
- High-temperature fuel cells (8300 kW) convert the liquid hydrogen to electricity. High-temperature fuel cells are highly efficient, but slow responders for changing loads. The fuel cells are thus complemented by battery systems (2400 kWh) that store excess electricity from the fuel cells and supply booster power rapidly when needed, Fig.7. Waste heat from fuel cells is used for on-board heating.

- Ship propulsion and manoeuvring is based on four steerable pods of 3 MW each. The high manoeuvrability of pods saves time in harbour approach and terminal docking.
- Solar panels on the roof feeds additional electricity into the electrical board system.
- Four Flettner rotors (8 m height x 4 m diameter) harness wind power for propulsion when possible. Flettner rotors were the preferred choice for wind assistance for this service:
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    - Compact dimensions allowing relatively easy integration into the overall design
    - No danger of entanglement as with kites on closely passing ferries

3.3. Further aspects

Not surprisingly, a zero-emission ferry comes at a (higher) price. Table II lists the relative increase in cost items as compared to a modern ”conventional” ferry that would be just compliant with the upcoming MARPOL emission regulations for 2015/2016:

- Outfitting I includes anchor, winches, ramps, elevators etc.
- Outfitting II includes heating and ventiation, sewage and treatment
- The zero-emission ferry does not require diesel engines, reducing this cost item drastically.
- On the other hand, electric systems (including fuel cells and batteries) become much more expensive.
- Navigation became more expensive due to the double end concept in comparison to a single ender
- Accommodation is not affected at all.
- Coating became more expensive due to the selection of better quality and low resistance paint

In sum, the zero-emission ferry would be 13% more expensive. This appears to be acceptable

Table 2. Changes in cost items for zero-emission ferry compared to a modern Scandlines ferry

General	+11%
Shipbuilding	+ 3%
Outfitting I	+11%
Outfitting II	+ 3%
Engine	- 46%
Electric	+33%
Navigation	+29%
Accommodation	± 0%
Coating	+11%
Inventory	+11%
Construction	+ 2%

4. Conclusion

The zero-emission design uses exclusively technology that is commercially available and tested in practice. The ferry could be built as designed and could be in operation as early as 2017, Fig.8. The technology is successively implemented by Scandlines. In 2013, Scandlines developed the world’s largest battery pack on board the “Prinsesse Benedikte”. In 2014, Scandlines will start testing fuel cells on board and implement assorted energy saving measures identified in the zero-emission ferry project. The intention is to have verified the suitability and reliability of new technologies in daily ferry operation before they are implemented on a zero-emission ferry.

The zero-emission ferry has been presented to politicians in Germany and Denmark, and stimulated a renewed debate on the Fehmarn Belt fixed link. The concept has been greeted with great interest also on EU level as zero-emission shipping is widely seen a key technology for future European short sea shipping.

Even if a tunnel were built, Scandlines is dedicated to pursuing the zero emission ferry. Scandlines sees a number of good reasons to stay in the market:

- Truck drivers and bus drivers need a 45 min mandatory break every 4 hours. Unlike the ferry, the tunnel cannot provide this.

- One third of the private cars are travelling to Scandlines Bordershop in Puttgarden and receive a discount on their way back on the ferry. These customers will stay with the ferries.
- Some people do not like to be submersed in a tunnel for 19 km. They will also stay with the ferries.

Fig. 8. Zero-emission ferry could be operational by 2017

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Appendix 1: Hydrogen as a fuel

Wind power has been extensively used both in northern Germany and in Denmark. In addition to the already existing onshore wind farms, offshore wind farms operating in the German Exclusive Economic Zone (EEZ) are targeted to reach an installed capacity of 3 GW by 2020. One of the disadvantages of renewable energy in its current form, however, is the problem of matching the intermittent nature of the supply with consumer demand. Studies have estimated that as much as 30% of an offshore wind farm's potential energy generation cannot be fed into the grid. Liquid hydrogen (LH2) is an attractive option to store this excess energy, as it features more than 60 times the energy density than alternative energy storage technologies, *Schindler et al. (2009)*.

Production, transport, and intermediate storage of liquid hydrogen lead to significant losses, particularly if longer transport and repeated liquefaction cycles are involved. For the considered zero-emission ferry service between Puttgarden and Rødby, the losses are estimated to be approximately 50% based on current technology and exploiting the fact that there are large wind farms in the vicinity of the terminals, Fig.9. The shown Sankey diagram is based on 4 ferries and 24 h operational time.

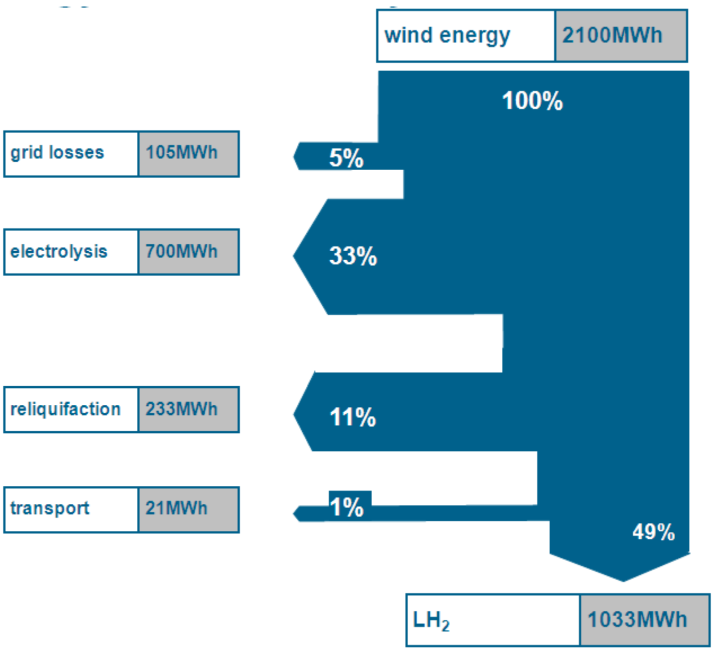

Fig. 9. Sankey diagram of energy losses on liquid hydrogen from wind farm to bunker station

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