Fuel Cells for Power Generation on Ships in Port

A commercial study

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Summary

The essence of this report can be summarised as follows:

- The main objective of this study is to define and quantify the costs and benefits of different power generation alternatives for ships in port, and to establish under what conditions a fuel cell power supply system could become an attractive investment in the future
- The following power generation systems were selected for comparison: Diesel generator, Polymer Exchange Membrane Fuel Cell (PEMFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC), Dual Fuel Diesel Generator (DF) and Electrical Shore Connection (ESC)
- The following main aspects were selected for comparison: System Price, Technical Life Time, Cost of Operation & Fuel, Air Emission Performance, and Noise/Vibrations.
- At the present situation two technologies were identified as commercially competitive power generation alternatives for ships in port: Electrical shore connection (ESC) and Dual fuel diesel engines burning natural gas.
- Whereas offering significant environmental benefits in terms of reduced air emissions and low noise, today´s fuel cells have significant drawbacks in terms of high investment cost and limited technical life time.
- In a longer perspective high temperature fuel cells in particular have very promising prospects, based on projected improvements with regard to efficiency, cost and durability in combination with their ability to burn various types of fuel. Demonstration trials with this technology are underway.
- Low temperature fuel cells have the advantage of high power density and low complexity, which over time could make them an attractive alternative for power generation and propulsion of smaller vessels and leisure craft
- With regard to using hydrogen as fuel several issues need to be addressed, such as: Storage, transportation and safe handling. The relatively high cost compared to other fuels indicates that a shift to Hydrogen could only be motivated by substantial incentives, e g in the form of CO2 emission reduction trading.

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Introduction

Background

Ships´ power generation systems have the critical role of delivering an uninterrupted supply of electricity to onboard consumers such as accomodation facilities, cargo handling equipment and propulsion auxiliary systems - at all times; when at sea or in port.

The currently dominating technology is dieseldriven generators which have the disadvantage of high noise and air emission levels. This has led to public pressure and legislation initiatives to reduce pollutants resulting in a need to evaluate and develop alternative technologies.

Hydrogen fuel cells represent a promising alternative with potentially high efficiency and low environmental impact. However, as fuel cell technology is at a precommercial stage, more R&D and practical experience is needed.

General reference is made to information from and contacts with participants in the EU-sponsored fuel cell projects "FC-ship" and "Fellowship".

Purpose and objectives

The pre-study "Environmentally friendly power production onboard ships" has been initiated to evaluate the potential for fuel cells as an alternative power generation technology for ships, initially for operation when the ship is in port. The pre-study covers four separate reports:

- Technical Pilot Study – a pre-design of a 50 kW FC demonstration plant
- Environmental impact analysis – calculations based on the pilot project
- Market Analysis - a thesis paper on the fuel cell marine market potential

And this paper;

- Commercial Study – on the competitiveness of fuel cells in this market

The previous reports can be used as general references (ref. 1, 2 & 3) for this report which primarily aims to quantify the costs and benefits of different power generation alternatives.

The main objective is, from a shipowner´s perspective:

To clarify the competitive situation between shipboard power generation alternatives available today, and to establish under what conditions a fuel cell power supply system could become an attractive investment in the future.

The study addresses the following issues:

1. What is the actual status regarding cost and other critical "customer utilities", i e important performance aspects, for available alternative power generation systems today?
2. How do the different alternatives compare with regard to these customer utilities?
3. How could possible future developments change the scenario?

Power generation systems – present situation

The following is a description of applicable existing power generation alternatives and their general characteristics. The selection of technologies has been made based on perceived present and future performance potential.

Dieselgenerators – state of the art

The predominant technology for power generation on board ships is dieselelectric A/C generators fueled by Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO). Distribution normally goes via a common bus bar and through transformers, depending on the voltage of the receiving components onboard - most are operating in the range 220-440 V at 50 or 60 Hz. A certain level of redundancy is normally built into the system so that a single moving component failure will not disrupt the power supply, i e one generator is kept in surplus.

Environmental impact

Although quite efficient, marine diesel engines produce relatively high levels of air pollution, partly due to the often high sulphur content (average about 2,7%) and other contaminants in the fuels used by the shipping industry, but also due to the high pressure and temperature conditions during combustion (NOx levels). Shipping typically accounts for 40 - 95% of SOx emissions and 30 - 80% of NOx emissions in port areas (ref 4). Also noise levels are sometimes causing complaints by the surrounding community where ships are berthed.

Cost

Whereas the investment is reasonably low, spares, lubrication oil and maintenance hours represent a significant part of the total cost. Shaft power efficiency has gradually improved to reach up to 50% for 4-stroke engines (55% for 2-stroke) producing A/C electricity at about 48% efficiency.

For the purpose of this study the Wärtsilä Vasa 32LN has been chosen for comparison (ref 5).

Fuel Cell systems – available alternatives

Fuel cell function

The basic function of a fuel cell is a process by which hydrogen and oxygen (air) react to produce electric current, heat and water. The concept offers great potential for efficient, emission free and silent electricity production.

Electricity

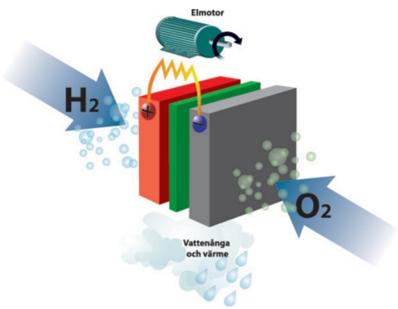


Figure 1 **Water + heat**

Fuel cell types

The different types of fuel cell technology are classified by the composition of the electrolyte in the middle of the fuel cell (ref 6). The three types described in the following are considered most suitable for marine applications:

Proton Exchange Membrane fuel cells (PEM): PEMFC, also known as polymer electrolyte fuel cells, are a type of fuel cell currently under development at most fuel cell companies. PEM fuel cells use a thin solid membrane as an electrolyte. These fuel cells deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. Low temperature operation (about 75 deg C) allows them to start quickly (less warm-up time), which makes them particularly well suited for transportation applications such as automobiles and fleet vehicles. PEM cells normally require pure hydrogen as fuel.

Molten carbonate fuel cell (MCFC): Molten carbonate fuel cells use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminium oxide (LiAlO2) matrix. These systems are large and operate at very high temperatures (in the range of 650ºC). They are very efficient when the heat produced is used for co-generation. MCFC fuel cells use a corrosive electrolyte, which makes durability a challenge. MCFC can use a range of gaseous and liquid fuels.

Solid Oxide fuel cell (SOFCs): Solid oxide fuel cells use a hard, non-porous ceramic compound as the electrolyte. SOFCs are highly efficient when their heat is recaptured for co-generation purposes, resulting in efficiencies up to 80 percent. Size, heat output and a long start-up time make this fuel cell suitable for stationary applications. SOFCs are at a relatively early stage of development compared to the other fuel cell technologies. SOFC can use a range of gaseous and liquid fuels.

Selected fuel cell alternatives

On a global basis there are a wide range of fuel cell manufacturers with products at different stages of development and production (ref 7-8). The following fuel cell suppliers have been selected for comparison in this study, mainly based on the maturity of technology, operating experience and availability of data:

Fuel cell type	Supplier/model	Output per unit	Fuel type(s)	Units in operation
PEM	Nuvera/Forza (ref 9)	120 kW	Hydrogen	na
MCFC	MTU/HotModule (ref 10)	250 kW	NG, Methanol, Ethanol, Propane, Butane, Biogas	12
SOFC	Siemens/SFC-200 (ref 11)	125 kW	As above	17

Table 1

Alternative technologies

The following represents alternative technologies or substitutes for onboard power generation when ships are at berth, selected on the basis of feasibility and competitiveness.

Dual fuel engines

Natural gas has in recent years entered the marine and power generation market as an alternative to diesel and other liquids. Dual fuel engines are equipped, and existing diesel engines can be converted at reasonable cost, to also burn natural gas with the potential of significantly reduced emission levels. With additional modifications it would be possible to burn also hydrogen up to about 90%, resulting in further emission reductions.

For the purpose of this study the Wärtsilä 32DF has been chosen for comparison (ref 12)

Electrical shore connections

Shore supplied electricity represents a viable alternative in cases where ships pay frequent visits to a limited number of ports with similar technological standards, such as short sea ferry and ro-ro operations. The investment and maintenance cost is relatively low, as well as energy supply depending on electricity market conditions. Local emissions are practically eliminated, whereas the overall environmental impact depends on sourcing of electricity on the local grid. One important limitation of this solution is of course that shore connections can only be used when at berth and do not have the potential for further performance improvements when underway.

Data for the shore connection has been obtained from Stena Line.

Gas turbines

With the development of combined cycle systems, where the exhaust heat is utilized for electricity generation in a steam turbine, the efficiency of gas turbine generators can be enhanced by abt 15% to reach 40-50% depending on the size of the plant. Gas turbines offer extremely high power density and can be cost competitive to diesels where output requirements are very high, e g for certain main propulsion systems. Gas turbines are mentioned for this reason but not included for comparison in this study.

Customer utilities and performance parameters

Supported by feedback from the market survey (ref 3), the following performance parameters have been defined for comparative evaluation of applicable power generation alternatives:

Performance parameter	Measurement unit	Description/comment	Customer survey ranking
Capital expenditure	Euro/kWh	Based on investment cost and technical lifespan	7, 6
Operation & maintenance cost	Euro/kWh	Based on spares, consumables and manhours	2
Fuel cost	Euro/kWh	Based on LHV efficiency, fuel energy content and fuel price	2
Availability	%	Where data available	5
Reliability	MTBF	Mean time between failures, where data available	3
Maximum transient load rate	kW/s	Response to load change, where data available	9
Environmental impact	g/kWh dBA @10m	Local air emissions of SOx, NOx, CO2, PM (particulate matter) and noise	4, 8
Installation aspects	kW/litre, kW/kg	Specific system volume and weight, where available	-

Table 2

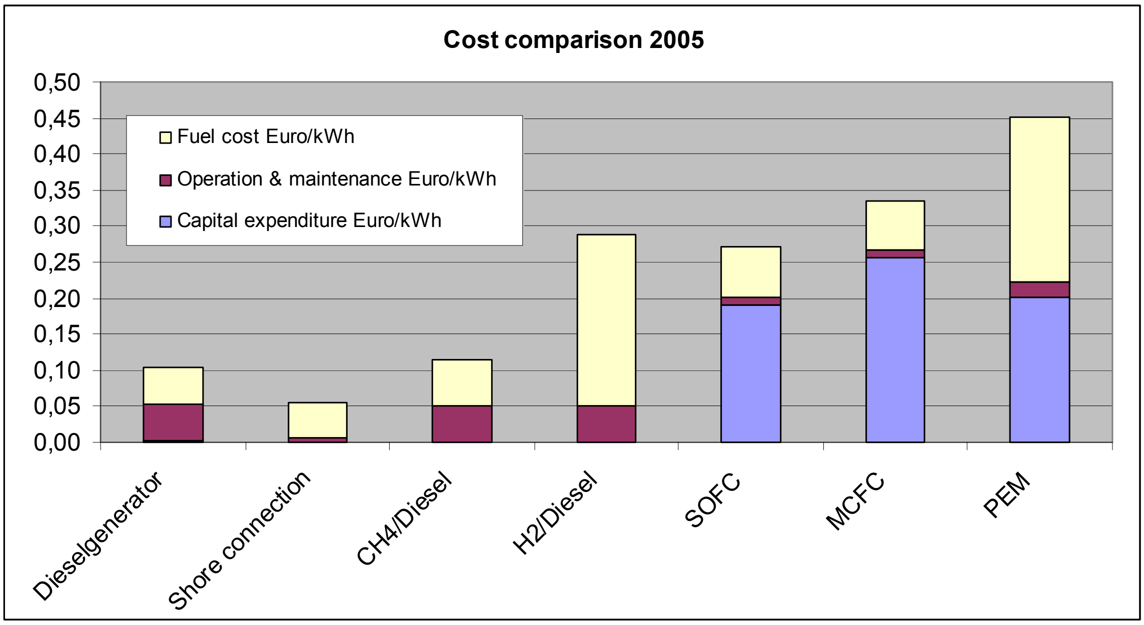
Aspects of a more qualitative nature, such as safety, are not included here.

Comparison of available power generation alternatives

Based on input from suppliers and end users performance data has been compiled for the selected power generation alternatives (Ref Appendix 1 table A)

How do fuel cells compare to other alternatives?

Graph 1 shows the cost per kWh for different power generation alternatives, based on compiled data. Please note that the chosen fuels are Low Sulphur Fuel Oil 1% for the Diesel and a choice of natural gas and hydrogen for the other alternatives.

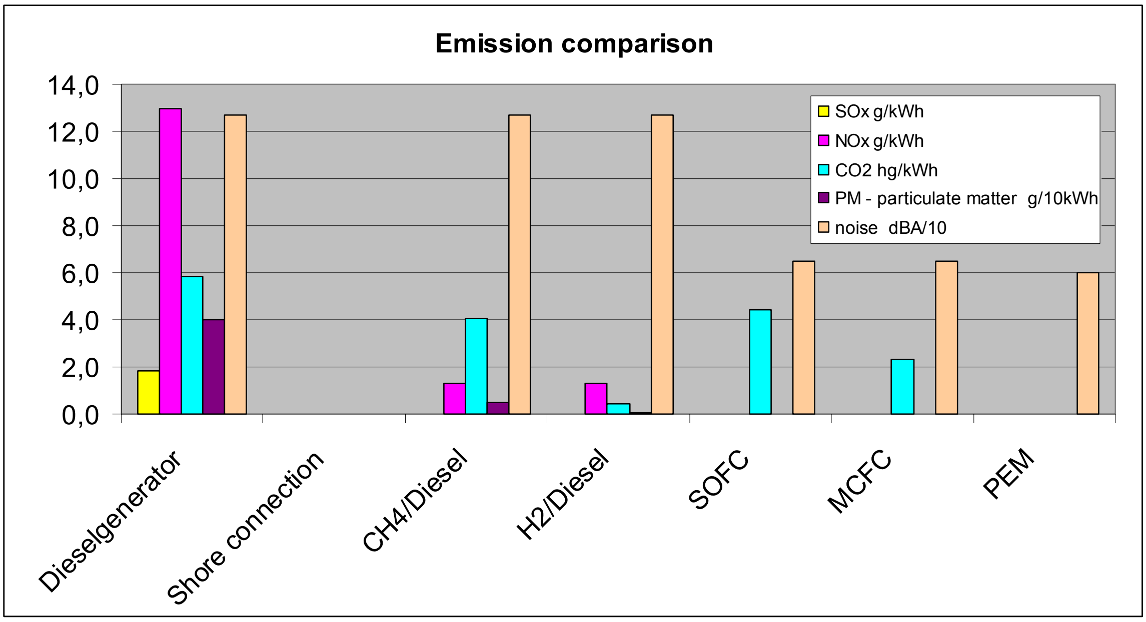


Graph 1

Looking at the cost picture a few observations can be made:

- Fuel cells have a significantly higher capital cost than other alternatives, resulting from a combination of high investment and low durability
- Fuel cells have a significant advantage in operational costs, when compared to diesel/internal combustion alternatives
- High temperature fuel cells have an advantage over PEM due to the ability to use different fuels, such as NG and methanol
- The choice of fuel type has significant cost implications, e g hydrogen appears unable to compete at the quoted price (see graph 3 below)
- Dual fuel gas burning is close to low sulphur diesel from a cost perspective
- Electrical shore connection appears to be the overall most economical alternative, where feasible

Graph 2 shows the different power generation alternatives from an environmental perspective. Air emissions are presented per kWh delivered and the data refers to local emissions only, i e the supply chain emissions for shore grid electricity and hydrogen are not included. Please note that scales have been adjusted for visibility.

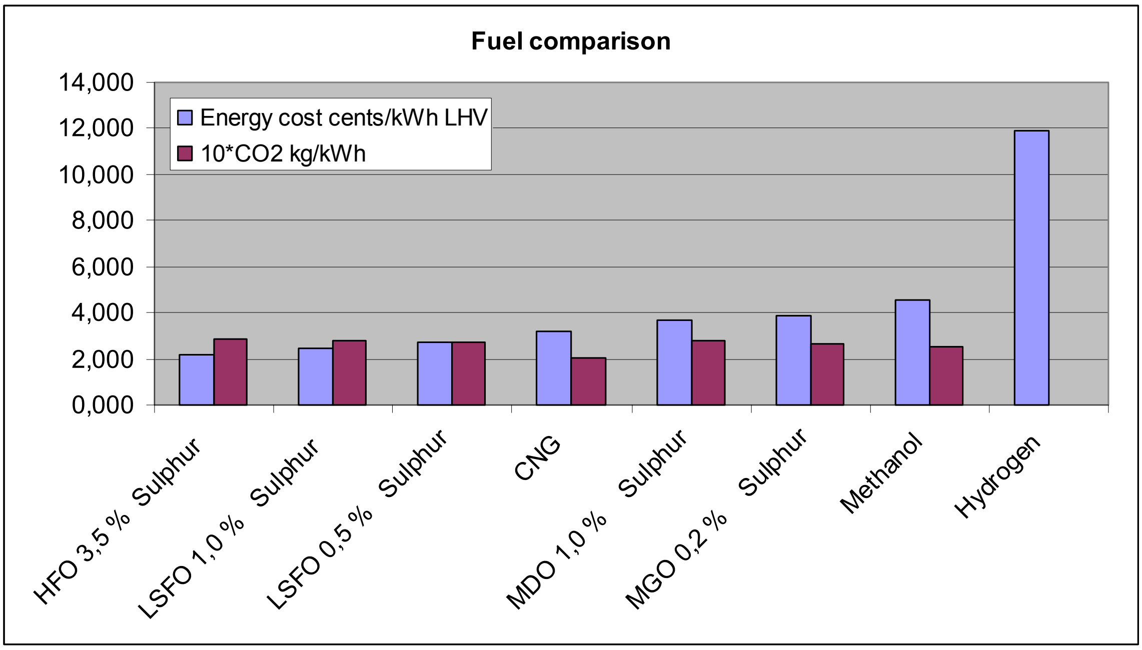


Graph 2

Looking at the environmental data the following comments can be made:

- NOx and SOx is practically eliminated in all fuel cell alternatives
- Only the electrical shore connection (ESC) and the hydrogen powered PEM fuel cell have zero harmful air emissions (i e, locally)
- Air emission levels are also linked to the choice of fuel (ref graph 3 below)
- NG/Dual fuel diesel offers relatively good cost/benefit
- Noise problems are practically eliminated with ESC and fuel cells

Graph 3 shows the cost and CO_2 content per kWh LHV energy unit (3,6 MJ) for different fuel alternatives, shore supplied electricity not included. The graph is derived from data in Appendix 1 table B. It should be noted that apart from sulphur there are significant differences between fuel oils (FO) and marine diesel (MDO) and gas oil (MGO) in other components, e g asphaltenes and carbon residue, which contribute to emissions, such as Particulate Matter (PM).



Graph 3

The choice of fuel influences both cost and environmental impact and therefore deserves to be commented separately:

- Marine HFO (heavy fuel oil) is cheapest, but also generating considerable pollution in terms of PM, NOx, SOx and CO_2
- With zero SOx and relatively low CO_2 natural gas appears to be an interesting alternative to conventional fuels – particularly in view of future SOx requirements.
- Whereas hydrogen provides CO_2 free combustion, there are at present no incentives for shipping to motivate the cost difference

Comments to the present situation comparisons

The foregoing comparisons indicate that there are a number of barriers to commercial introduction of fuel cells and hydrogen for power generation onboard ships, namely:

Investment Cost - The high manufacturing cost of fuel cells is partly related to expensive materials but also to the fact that the technology is still essentially in a pre-commercial stage and due to small production volumes economy of scale has not been achieved. This is a "catch 22" situation which is showing signs to be changing as more commercial products are gradually reaching the market.

Life expectancy - Due to limited production and operational experience the documented technical life expectancy is still relatively short – from 4000 hours to

40000 hours. With enhanced technology and experience durability has made significant progress and is gradually increasing.

Hydrogen challenges - Apart from the high cost the introduction of hydrogen in itself implies a series of barriers. The application of hydrogen fuel cells onboard ships has been addressed by several projects and initiatives (see references). While no definite showstoppers have been identified there are several challenges that need to be addressed, such as:

Technical Challenges

- H2 bunkering time
- H2 storage onboard vessels
- Practical design & operations

Operational challenges

- Crew qualifications
- Shore personnel qualifications – bunkering, etc
- Operational procedures

Infrastructure challenges

- H2 availability - production, storage, distribution
- H2 quality and purity

Societal challenges

- Risk perception
- Risk/benefit of changes

Regulatory/Political

- H2 infrastructure development needs political backing
- Complex regulatory process for H2
- No class/certification standards available for H2

These issues are likely to be resolved over time, which will also contribute to reduce the overall cost and price of hydrogen. Nevertheless, it seems unlikely that hydrogen will become competitive unless the benefit of zero CO_2 emissions can be turned into commercial advantage, e g through incentive schemes such as emission reduction trading.

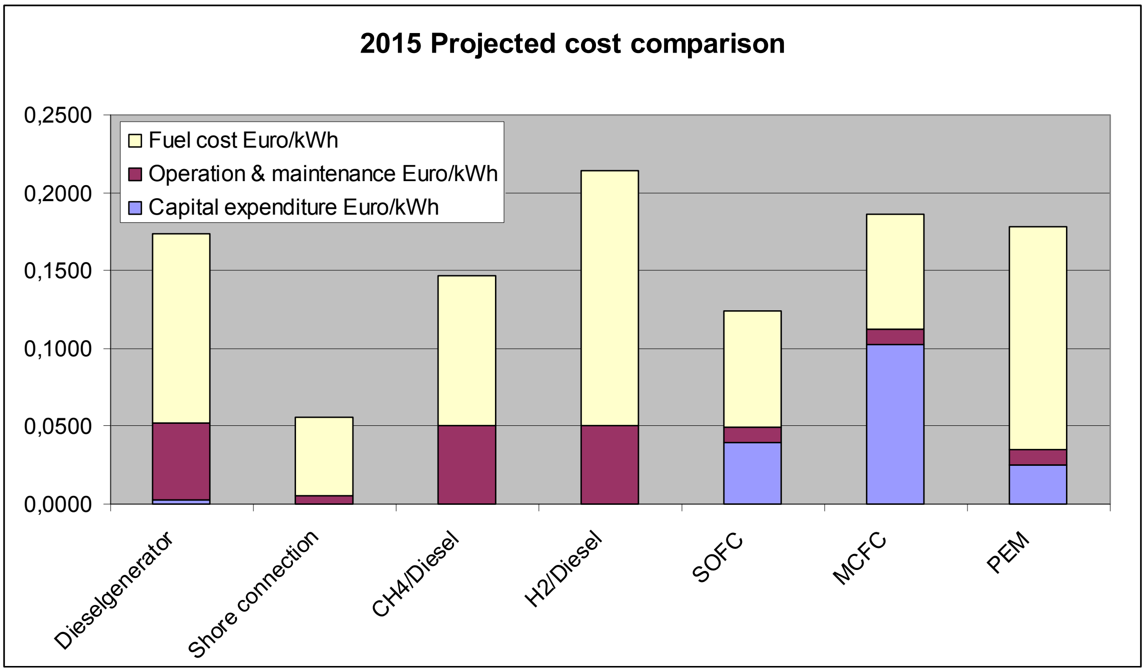
Future scenarios

Looking ahead in a 10-year perspective it can be of interest to simulate possible scenarios and study the resulting effects. The following example is based on a series of performance targets from e g fuel cell manufacturers, in combination with postulated fuel price developments.

Scenario 2015

The scenario in Graph 4 is based on the following assumptions, which are deemed to be realistic but with a high degree of uncertainty (ref to Appendix 1, tables B and C):

- Fuel prices in general + 50%, Hydrogen priced at an energy cost factor of 1,7 compared to Natural Gas (estimated cost of reforming)
- Diesel generator running on low sulphur MGO
- SOFC and MCFC efficiency improved to 65% (capturing turboelectricity)
- SOFC and MCFC 60% longer lifetime (target according to Siemens)
- SOFC and MCFC 67% and 35% lower cost respectively (targets according to Siemens and MTU)
- PEM cell price/maintenance cost is reduced by 75%/50% and life/efficiency increased by 100%/10% respectively
- Diesel efficiency improved by 2% (potential according to Wärtsilä)



Graph 4

Some comments to the scenario:

- Under these conditions the SOFC appears to be price competitive to the conventional diesel generator as well as the dual fuel engine
- Given projected improvements also the PEM cell appears to have a certain potential where CO2 free operation is of value, or in combination with a reformer to allow use of hydrocarbons
- Hydrogen comes out considerably more expensive than natural gas even with a substantial price reduction from today, indicating that incentives for CO2 free operation will be needed for H2 to become an attractive fuel alternative

Market developments

This part of the study identifies developments which are relevant to the marine power generation market, and elaborates on possible early movers.

What are the drivers towards a technology shift?

Legislation

- IMO SECA (Sulphur Emission Control Areas, ref 13) stipulating a maximum 1,5% sulphur content in marine fuels enter into force on May 19 2006 for the Baltic Sea, and in August 2007 for the North Sea. This is likely to drive a further price increase in low sulphur fuels (ref Appendix 1 table B)
- A EU sulphur directive will enter into force Jan 1, 2010 setting a 0,2 % maximum sulphur content for ships at berth in EU ports (ref 14)
- Schemes are underway to introduce Emission Reduction Trading as a tool to achieve emission targets in a cost effective manner and to encourage introduction of new technology. SOx, then NOx and eventually CO2 are possible subjects to such trading (ref 15).
- EU requirements for NOx levels is likely to move towards harmonization with land transportation, i e (ref 16).
- California Air Resource Board requirements within 24 miles of the California baseline: by 1 January 2007, the engine emission rate should correspond to a fuel sulphur content of no more than 0.5% by weight. Beginning 1 January 2010, the limit is 0.1% by weight (ref 17).
- IMO has decided to review MARPOL Annex VI by 2007, and to consider further air emission reductions (ref 13).

Community pressure

- Complaints from environmental activists and residents in port areas regarding funnel smoke and noise levels are detrimental to the reputation of individual shipping companies as well as the shipping in general, otherwise an environmentally competitive industry
- Growing public concern regarding sustainability issues such as global warming, generates strong incentives for industry to improve environmental performance and build a "green image" (e g Clean Cargo Group, ref 18)

Fuel availability and price development

- The general increase in global oil demand in combination with limited and unreliable supply is driving fuel prices higher and directing more focus on energy conservation and alternative fuels

Technology development and innovation

- Infrastructures for alternative energy sources and carriers are gradually maturing or evolving towards commercial markets, such as: natural gas, biogas, ethanol, methanol, wind/wave/solar power and hydrogen
- The cost and efficiency of alternative energy converters are gradually approaching competitive levels through innovation and development, aided by increased R&D funding. For example: Dual fuel combustion, gas turbine, hybrid and fuel cell technology

Comments

The above factors are all converging towards a situation where fuel cells are likely to become an attractive alternative to conventional technologies and the key question seems to be when, rather than if. This process is likely to take time and it is worth noting that, although such demands are sometimes raised, as of yet there is neither legislation proposed nor any direct incentives in place for the shipping industry to reduce their CO_2 emissions. Any such driving forces towards the use of hydrogen are not foreseen in the near future. Therefore - apart from cost - SOx, NOx, PM and noise are likely to be the key drivers for performance improvements in the short to medium term.

Which shipping market segments could be the first movers?

In a geographical perspective Europe seems to be at the forefront with regard to marine air pollution legislation, together with certain areas in the US. As developing parts of Asia are confronted with pollution problems, these regions are likely to implement similar and perhaps more radical measures.

The pressure of consumer sentiments and sustainable business policies tend to propagate primarily to shipping activities at the higher end of the value chain, such as passenger/cruise, car carrier and container services - as indicated by the customer survey performed in ref 3. Other possible segments are paper/forrestry transports and tankers, which are often employed by large global company brand names sensitive to reputational issues.

Examples of early adopters of new power generation technology are:

- Stena Line and DFDS (ferry lines) who have installed electrical shore connections at their terminals to eliminate emissions and noise while in port
- Wallenius-Wilhelmsen (car carriers) and Eidesvik (offshore supply vessels) who are at advanced stages of introducing smaller scale high temperature fuel cells for onboard power generation

Again, as there at present are no immediate economic benefits to a shipowner from introducing fuel cells, the key motivator for early adoption is to gain knowledge and competitive edge for the long term based on the future potential of this promising technology.

Conclusions

This study confirms that notwithstanding their significant environmental benefits fuel cells still need time to mature to become a commercially attractive alternative among available power generation technologies for ships in port. It should be emphasized that these findings represent a snapshot of the present situation based on certain assumptions, and that regular reassessments should be made as critical parameter values change over time. That being stated, the following conclusions and comments can be made:

- When at berth, an **electrical shore connection** seems to be the most effective alternative, environmentally and economically. However this should be viewed in the wider context that the main cost and environmental challenges for shipping lie in the total energy consumption when underway at sea, and this is where the potential benefits of fuel cell technology would be reaped in the longer term.
- At present, **Dual Fuel diesel engines** using natural gas appear to be competitive compared to conventional diesels, offering significant environmental benefits (except noise) at affordable cost – also having the advantage of being operable at sea when leaving berth
- **High temperature fuel cells**, SOFC in particular, seem to have great potential to become an attractive alternative In the longer perspective, mainly due to high electrical efficiency and the ability to use a variety of hydrocarbon fuels
- **Low temperature PEM fuel cells**, although limited by a relatively lower efficiency potential and the need to use hydrogen, have the advantage of high power density and low complexity which is of benefit for smaller vessels such as work boats and leisure craft. PEM FC competitiveness is likely to be greatly strengthened over time, e g through mass production cost reductions and the use of reformer technology for fuel flexibility
- **Hydrogen** has a very high and volatile price level which prevents commercial introduction. This is linked to significant challenges regarding production, transportation and storage which will hopefully ease over time. Still, as hydrogen is generally produced through refinement of other forms of energy, such as hydrocarbons or electrolysis, it is likely to always require a premium cost needing to be offset by tangible benefits and incentives, e g in the form of CO2 emission reduction trading. At present no such scheme is underway within the shipping industry, although a voluntary GHG indexing system has been developed by the IMO.

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Fuel Cells for Power Generation on Ships in Port
Appendix 1

Table A. Comparison matrix

Sources			**Stena-Wärtsi**	**Stena L**	**Wärtsilä**	**Wärtsilä**	**Siemens**	**MTU**	**Nuvera**	**Power Cell***	
Year	2005	Unit	Dieselgenerato	Shore con	CH4/Diesel	H2/Diesel	SOFC	MCFC	PEM	PEM	Comments
	Capital expenditure	Euro/kWh	0,0023	0,0003	0,0003	0,0004	0,1875	0,2444	0,2083	1,318	Interest not included
	Investment	Euro/kW	410	150	50	75	4500	5500	8333	26105	
	technical life	hours	175200	438000	175200	175200	24000	22500	40000	2,28	
	installed capacity	kW	2000	2000	2000	2000	125	250	120	50	
	Operation & maintenance	Euro/kWh	0,05	0,005	0,05	0,05	0,01	0,01	0,02	0,01	
	Fuel cost	Euro/kWh	0,053	0,050	0,067	0,248	0,070	0,068	0,229	0,227	
	LHVe efficiency	%	46%		48%	48%	46%	47%	52%	53%	
	fuel energy price	Euro/kWh	0,024		0,032	0,119	0,032	0,032	0,119	0,119	
	Fuel type		LSFO 1%		NG	H2	NG	NG	H2	H2	
Total cost	**Euro/kWh**	**Euro/kWh**	**0,105**	**0,055**	**0,12**	**0,30**	**0,27**	**0,32**	**0,458**	**1,556**	
	Relative dieselgenerator		**1,0**	**0,5**	**1,1**	**2,8**	**2,5**	**3,1**	**4,4**	**64,2**	
	availability	%	99%	99,9%	99%	99%	98%	95%	99%	99%	
	reliability	MTBF	5 years	5 years				>1 yr			
	max transient load rate	kW/s						+/-15%			
	Environmental impact (local)		6LN32		6DF32	6DF32	SCF-200	MTU-CFC	Forza		
	SOx	g/kWh	1,9	0	0	0	0	0	0	0	
	NOx	g/kWh	13	0	1,3	1,3	0,01	0	0	0	
	CO2	hg/kWh	6,1	0,0	4,2	0,4	4,4	4,3	0	0	
	PM - particulate matter	g/10kWh	4	0	0,5	0,05	0	0	0	0	
	noise	dBA/10	12,7		12,7	12,7	6,5	6,5	6	6	
	Installation aspects		6LN32		6DF32	6DF32	SFC-200	MTU-CFC	Forza		
	System volume (Specific)	kW/litre	0,022		0,022	0,022	0,0011	0,006	0,040		
	System weight (Specific)	kW/kg	0,042		0,042	0,042	0,005	0,010	na		

General comments
The spreadsheet data is believed to be reflecting reality insofar as giving relevant proportions to the different parameters for each alternative.
However, as the data is compiled from a variety of sources in a relatively short period of time there is bound to be certain inaccuracies, e g in terms of:
parameter definitions (e g system boundaries), practical verification and up-to-dateness of information
Certain fields for which data has proven difficult to obtain or verify have been left blank
Red text means that the data is unconfirmed and has a questionmark attached

* This is the projected demo system included for reference

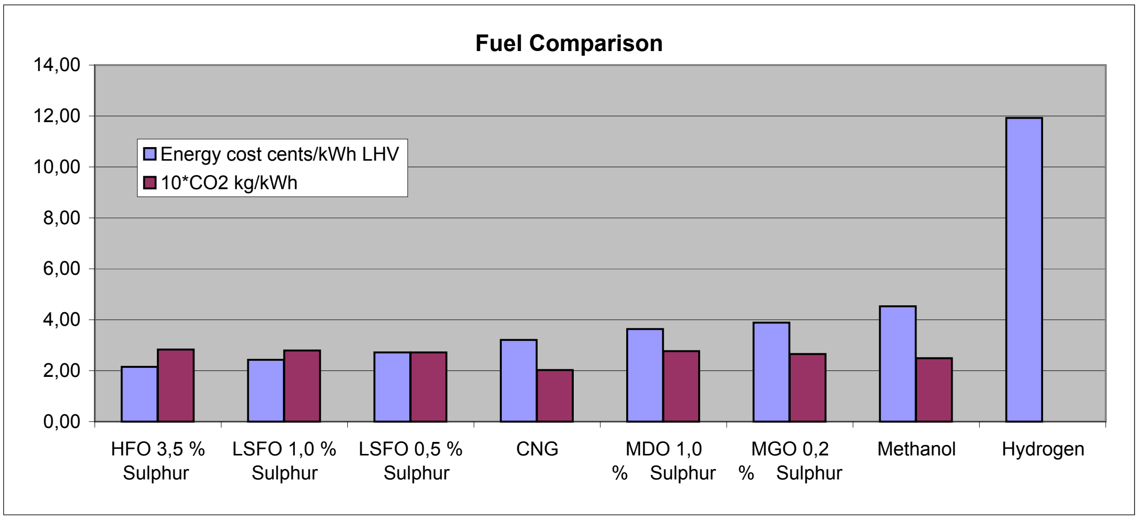
Fuel Cells for Power Generation on Ships in Port
Appendix 1

Table B. Fuel Data

	Energy cost cents/kWh LHV	10*CO2 kg/kWh	Density kg/m3	LHV kWh/kg	CO2 g/kWh	Price 2005* Euro/kWh	Price 2015** Euro/kWh
HFO 3,5 %	2,15	2,84	989,00	11,11	284	0,022	0,032
LSFO 1,0 %	2,42	2,79	973,00	11,28	279	0,024	0,036
LSFO 0,5 %	2,72	2,72	922,00	11,58	272	0,027	0,041
CNG	3,20	2,02	0,79	12,53	202	0,032	0,048
MDO 1,0 %	3,64	2,77	892,00	11,39	277	0,036	0,055
MGO 0,2 %	3,88	2,65	845,00	11,89	265	0,039	0,058
Methanol	4,52	2,49	793,00	5,53	249	0,045	0,068
Hydrogen	11,92	0,00	0,09	33,36	0	0,119	0,082

*Current H2 price basis estimated halving of today´s quoted price of 6,80 SEK/Nm3
**Assumed projections - ref to main report scenario assupmtions

Sources: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context
Version 1, December 2003 - http://ies.jrc.cec.eu.int/Download/eh
Stena oil
Preem
AGA -



Fuel Cells for Power Generation on Ships in Port
Appendix 1

Table C. Comparison matrix - projected costs 2015

Assumed projections - ref to main report scenario assupmtions

Sources			**Stena-Wärtsil**	**Stena L**	**Wärtsilä**	**Wärtsilä**	**Siemens**	**MTU**	**Nuvera**	
Year	2015	Unit	Dieselgenerato	Shore conn	CH4/Diesel	H2/Diesel	SOFC	MCFC	PEM	Comments
	Capital expenditure	Euro/kWh	0,0024	0,0003	0,0003	0,0004	0,040	0,102	0,026	Interest not included
	Investment	Euro/kW	410	150	50	75	1500	3500	2083	
	technical life	ys	20	50	20	20	4,38	4,11	9,13	
	installed capacity	kW	2000	2000	2000	2000	125	250	120	
	Operation & maintenance	Euro/kWh	0,05	0,005	0,05	0,05	0,01	0,01	0,01	
	Fuel cost	Euro/kWh	0,121	0,050	0,096	0,163	0,074	0,074	0,143	
	LHVe efficiency	%	48%		50%	50%	65%	65%	57%	
	fuel energy price	Euro/kWh	0,058		0,048	0,082	0,048	0,048	0,082	
	Fuel type		MGO 0,2%		NG	H2	NG	NG	H2	
Total cost	**Euro/kWh**	**Euro/kWh**	**0,174**	**0,055**	**0,15**	**0,21**	**0,12**	**0,19**	**0,179**	
	Relative dieselgenerator		**1,0**	**0,3**	**0,8**	**1,2**	**0,7**	**1,1**	**1,0**	
	availability	%	99%	99,9%	99%	99%	98%	95%	99%	
	reliability	MTBF	5 years	5 years				>1 yr		
	max transient load rate	kW/s						+/-15%		