Summary of Fuel Cell Feasibility

Potential for river ferries in London

This document is part of iTransfer, a North Sea Region Interreg programme project, which is funded by the European Regional Development Fund.

iTransfer (Innovative Transport Solutions for Fjords, Estuaries and Rivers) aims to make ferry transport more freely accessible and sustainable, and encourage more people to travel by water. In areas in the North Sea Region (NSR) there are opportunities to replace existing vehicle routes with passenger ferries as a viable alternative. Travelling by ferry is more sustainable, easier and quicker. It can also provide lifeline services to remote communities.

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Introduction

iTransfer (Innovative Transport Solutions for Fjords, Estuaries and Rivers) aims to make ferry transport more freely accessible and sustainable, and encourage more people to travel by water. In areas in the North Sea Region (NSR) there are opportunities to replace existing vehicle routes with passenger ferries as a viable alternative. Travelling by ferry is more sustainable, easier and quicker. It can also provide lifeline services to remote communities.

iTransfer has the aim to improve water-based public transport in Europe's North Sea Region by developing, demonstrating or piloting innovative and sustainable ferry technology, operation and policy. Ferries have the advantage of lower CO2 emissions and they can help to reduce congestion on roads.

To achieve its aim, iTransfer has projects

- to resolve technical issues including new designs for ferries and shore-side facilities;
- to improve ferry operations and integrate ferries with existing public transport networks;
- to support a policy environment that resolves current tendering problems and promotes barrier-free access for all passengers.

iTransfer takes a transnational approach by involving 16 organisations from different countries across the North Sea region with the Lead partner being the Institute for Sustainability. The organisations are from Belgium, Germany, Netherlands, UK and Denmark. In this way the partners can pool their knowledge from different countries on the operation of ferry services and share best practice. iTransfer is funded by the North Sea Region programme, part of the EU Inter-regional (Interreg) initiative. Interreg is 50% financed through the European Regional Development Fund, the remaining 50% is provided by the project partners.

Peter Slade completed a "Feasibility study for a fuel cell powered river ferry in London" Master thesis in 2011 at the Imperial College London, relevant to the iTransfer aims to improve the sustainability of ferries and use of alternate fuels. The thesis examines the services offered by Thames Clippers, the leading passenger ferry service on the Thames, and its potential to improve its environmental performance through the use of fuel cells to power ferries.

Background

Thames Clippers is a regular ferry service providing its services to tourists as well as to daily commuters. It was founded in 1999 and has since then grown to a fleet of 13 vessels with over 8500 passengers per day. The passenger numbers are still increasing, and therefore there are plans to increase the number of ferries in operation and to develop a new cross-river ferry between Surrey Quays and Canary Wharf. Like most ferries, Thames Clippers runs on marine diesel oil which produces a range of pollutants. The aspirations of Thames Clippers to become more sustainable are in line with the "Mayor's Transport Strategy" which sets the ambitions for London to lead the world in new green transport technology over the next 20 years. Currently, London is one of the most polluted places in Europe and has struggled to meet the European Union pollution levels.

Summary of the study

The 'Feasibility study for a fuel cell powered river ferry in London' has examined if a fuel cell powered river ferry is feasible in London from a technical, environmental and economic point of view. The potential for using low to zero carbon marine propulsion technologies will improve the sustainability of ferry services, and is of interest to ferry operators in the North Sea region and beyond. To assess the suitability the power profiles for three different services offered by Thames Clippers have been modelled and the weight and volume of the required system components for a fuel cell powered ferry calculated. Then the carbon emissions have been assessed for the conventional and the alternative technology in order to determine the reductions. Finally, the costs for the application of the fuel cell technology have been estimated.

The following section provides information about fuel cells in general and then reports the results of the technical, environmental and economic assessments before coming to a short conclusion. The findings of the assessments are summarized in a table which is in the appendix.

Fuel cells

The use of marine diesel oil leads to the production of a range of pollutants. These include CO_2, PM10 (particulate matter of 10 µm diameter or less), nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxide (CO) and volatile organic compounds (VOCs). Emissions of NOx and SOx are usually significantly higher for marine transport than for road transport due to differences in engine design and the type of fuel used. Contrary to marine diesel engines, fuel cells avoid the combustion process and the associated high levels of emissions. The reason is that fuel cells are electrochemical cells that produce electrical energy directly from the chemical energy in fuels. In addition to reduced emissions, fuel cells have the advantages of increased efficiency and quiet operation. There is considerable scope for the use of fuel cells in marine transport. To date, the primary use of fuel cells has been limited to the provision of auxiliary power, rather than being used as the primary means of propulsion. There have been a number of demonstration projects for the use of fuel cells in marine transport. In 2008 the FCS Alsterwasser became the first inland passenger ferr y with a carrying capacity of up to 100 passengers to use fuel cell technology. It operates on the Alster, an inland lake in the heart of Hamburg. The FCS Alsterwasser had received significant funding from the EU and other operators, such as Thames Clippers will also need similar investment support.

There are different types of fuel cells available. The proton exchange membrane fuel cells (PEMFCs) use hydrogen as fuel and produce water as the only by-product. They operate at relatively low temperatures, thereby enabling quick start-up times and are more durable than other types of cells. Due to these properties they are used for the majority of marine propulsion fuel cells. Two other two types of fuel cells (solid oxide fuel cells and molten carbonate fuel cells) were also examined, but these are not explained in more detail, as they were not feasible for the use in the Thames Clippers due to excessive weight. The fuel for the PEMFCs, hydrogen, can be produced from primary energy sources including renewable as well as non-renewable sources. The most cost effective way of producing hydrogen is from the steam reforming of natural gas.

The durability and lifetime of fuel cells depend on their mode of operation. Switching fuel cells on and off regularly, running them without drawing power and imposing fluctuating power demands impair their performance. It is possible to hybridise fuel cells with batteries so that fuel cells can be used as the primary power source with the batteries acting as a buffer. This has the advantage of improving the durability and lifetime of the fuel cells, as it allows them to run under optimal conditions. The majority of current hybrid fuel cell vehicle applications employ Lithium-Ion or lead-acid battery technology. Lead-acid batteries offer lower energy and power densities than Lithium-Ion batteries and would therefore be inapplicable for the Thames Clippers due to their required weight and size.

Technical assessment

For the calculation of the technical feasibility, the different services of Thames Clippers were assessed:

1. Commuter Service operates between the Royal Arsenal, Woolwich and the London Eye
2. Tate to Tate Service runs from Bankside to Millbank via Embankment
3. Cross river Hilton Ferry Service operates between Hilton Docklands Riverside and Canary Wharf.

The key method for evaluating the feasibility was to consider the weight and volume of the existing engines and fuel tanks and to compare them with the key components of a fuel cell demonstrator. Comparable weights and volumes offer the opportunity to retrofit an existing vessel which is more straightforward and cost effective. The dimensions of the fuel tanks were estimated by the fuel capacity, and the engine sizes were calculated by determining the power and energy requirements for the vessels. The power requirements of the ferry services differ depending on the distances covered by them and hence their travel times. Moreover, the Hilton Ferries are smaller and have less powerful vessels than the ferries in the main fleet. A sizing-design methodology was used to evaluate the feasibility of hybrid systems, fuel cell only systems and battery only systems. Information about the weight and volume requirements for the different technologies can be found in the appendix. The result is that the Tate to Tate Service offers realistic feasibility using a PEMFC/Li-ion hybrid with the weight and volume being comparable to the currently used diesel technology. A fuel cell only system is technically feasible for the Tate to Tate service and the Hilton Ferry Service.

Environmental assessment

For the determination of the environmental impact reduction, the carbon reduction in total as well as the reduction per passenger was calculated. The calculations are based on the assumption that hydrogen is produced via steam reforming of natural gas.

A PEMFC powered Tate to Tate Service would produce 451 tonnes CO_2 emissions per year compared to 828 tonnes CO_2 with a diesel ICE powered engine resulting in a saving of 377 tonnes per year. Analogously, the Hilton Ferry Service could have a reduction of 580 tonnes per year.

Assuming that the ferries run at approximately 50% capacity, the PEMFC powered Tate to Tate Service would yield 7.3 g CO_2 per passenger km and the Hilton Ferry Service 15.9 g CO_2 per passenger km. This compares to 13.4 g and 29.0 g CO_2 per passenger km for the equivalent diesel ICE powered services. These figures correspond to a reduction of 45%.

In regards to other pollutants, the PEMFCs do not produce VOC, PM10, SOx or NOx contrary to marine diesel engines. However, for the Thames Clippers the SOx emissions are negligible as Thames Clippers uses zero sulphur fuel.

Economical assessment

An economic assessment was conducted for the use of PEMFC and PEMFC/Li-ion hybrid powertrains by estimating the capital expenditure (CAPEX) and the operational expenditure (OPEX). The CAPEX includes the costs for the key components of the powertrain such as the PEMFCs, Li-ion batteries and hydrogen storage whereas the OPEX refers to the cost of hydrogen fuel. OPEX is influenced by the carbon price and its value might change in future if The European Union Emissions Trading Scheme extends its coverage to marine transport.

The total estimated costs for the Tate to Tate service are around 877 100 € for the PEMFC/Lithium-Ion hybrid and around 521 800 € for the PEMFC technology. By contrast, the costs for the diesel technology are about 121 200 €. The costs for the Hilton Ferry Service are about 623 000 € for the PEMFC technology in comparison with 182 000 € for the current technology.

The composition of the total costs in regards to their CAPEX and OPEX components is listed in the appendix. The table indicates that the CAPEX costs for the fuel cell technology are significantly higher than for the diesel technology. In contrast, the OPEX costs, though still being higher for the fuel cell technology, are in a similar range as the diesel technology.

Future optimistic estimates indicate that PEMFCs can become cost competitive with diesel ICEs by 2030. Nevertheless, the total CAPEX for a PEMFC powertrain will be considerably higher than for a diesel ICE powertrain due to the costs for hydrogen storage. Therefore the development of low cost hydrogen production technologies and hence the reduction of OPEX will be vital to offset the high costs.

Conclusion

The study identified that it is technically feasible to develop a fuel cell powered ferry to operate on the Thames for short distance services. The Tate to Tate Service could be powered by a PEMFC or a PEMFC/Li-ion hybrid system and the Hilton Ferry Service by a PEMFC system. The use of the fuel cell technology would result in carbon savings of about 45 % when using steam reforming of natural gas for the hydrogen production and in the avoidance of other pollutants. The costs for fuel cells are significantly higher than for conventional diesel powertrains. This is particularly due to the high CAPEX costs caused by the costs for the hydrogen storage. The OPEX costs are in a similar range and could become competitive in the future.

Outlook

The substitution of marine fuels with hydrogen, generated through steam reforming of natural gas, offers the potential for a significant reduction of the CO_2 emissions, but there is scope for further improvements. Consideration should be given to the hydrogen production and its associated infrastructure required for its transport, distribution and storage. The use of alternative production methods such as the production from biomass and municipal waste or through the splitting of water would lead to considerably lower CO_2 emissions. In future, there may be the possibility to produce hydrogen from a sustainable source for the Thames Clippers. For example, a possible source is a gasification plant planned for the development of the London Sustainable Industries Park which will produce hydrogen from 2015 on. Additionally, there is also a hydrogen refuelling capacity available in Leyton which supplies eight PEMFC buses which are part of the Clean Urban Transport for Europe (CUTE) trial. Transport for London is currently involved in the Clean Hydrogen in European Cities (CHIC) project that is leading the commercialisation of these buses. Hydrogen for the CHIC project is sourced from a production plant in Rotterdam, but there is scope for local sourcing of hydrogen within the Greater London area. Further research of potential hydrogen storage and refuelling facilities are required. These facilities will also affect the costs for the fuel cell technology. A further factor which would influence the price is the possible inclusion of the marine sector into the carbon market.

The fuel cell technology is not only beneficial for carbon reduction, but as well as for the avoidance of other greenhouse gases such as sulphur dioxide. Though this might not be of interest to Thames Clippers, as they use zero sulphur fuel, it may be of relevance to other ferry operators. The Directive 1999/32/EC which regulates the limit of sulphur in fuels is adopting increasingly stricter limits. The limit for the sulphur content of marine fuels in Sulphur Emissions Control Areas (the Baltic Sea, the North Sea and the English Channel) will be 1% until 31 December 2014 and 0.1% as from 1 January 2015. Outside this area, the limit of 0.5 % will be mandatory in EU waters by 2020 compared to the current limit of 1.5% for passenger ships operating on a regular service outside SECA. In future, there may also be stricter limitations for NOx, as the International Maritime Organisation introduced the possibility to establish NOx Emission Control Areas (NECAs) and associated stricter NOx standards in its Marine Pollution Convention (MARPOL).

PEMFC only systems as well as PEMFC/Li-ion hybrid systems are feasible for the Tate to Tate Service. Both systems have advantages and disadvantages so that an optimization analysis would be necessary to determine the preferable option from a lifetime cost perspective.

Alternative hybrid systems could be further explored, especially in regards to the Commuter Service.

A feasibility study could also be conducted for the planned cross-river ferry between Surrey Quays and Canary Wharf. Moreover, the methodology used in this study is transferable to assess the feasibility of other ferries which cover short distances.

Appendix

Table 1 Data of the technical, environmental and economic assessments

Service	Technology	$Weight_{total}$ (kg) [1]	V_{total} (L) [2]	gCO_2 per passenger km [3]	CO_2 reductions (tonnes y^{-1})	CAPEX (€) [CAPEX (£)] [4]	OPEX (€ y^{-1}) [OPEX (£y^{-1})]
Tate to Tate	PEMFC/Li-ion hybrid	9814	11778	7.3	377	692.1K [561K]	185K [150K]
Tate to Tate	PEMFC	5061	7645	7.3	377	336.8K [273K]	185K [150K]
Tate to Tate	Diesel ICE engine	9600	10376	13.4	0	9.3K [7.5K]	111.9K [90.7K]
Hilton Ferry	PEMFC	6987	10580	15.9	580	336.8K [273K]	286.2K [232K]
Hilton Ferry	Diesel ICE engine	n.a.	n.a.	29.0	0	9.3K [7.5K]	172.7K [140K]

[1] The $Weight_{total}$ refers to the weight for the fuel cells, batteries and hydrogen storage systems or the diesel engines and fuel tanks. Other components which may have significant weights such as the transmission system have not been considered.

[2] The $Volume_{total}$ refers to the volume for the fuel cells, batteries and hydrogen storage systems or the diesel engines and fuel tanks.

[3] These figures are calculated under the assumption that that the ferries run at approximately 50% capacity.

[4] For the conversion of the currency from £ to € the website http://ec.europa.eu/budget/contracts_grants/info_contracts/inforeuro/inforeuro_en.cfm was used with the exchange rate from December 2012 which was about 1 £ = 1.23 €.

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