Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities

FCH Ferries

Brussels, Fall 2017

This compilation of application-specific information forms part of the study ***"Development of Business Cases for Fuel Cells and Hydrogen Applications for European Regions and Cities"*** commissioned by the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2 JU), N° FCH/OP/contract 180, Reference Number FCH JU 2017 D4259 .

The study aims to **support a coalition of currently more than 90 European regions and cities** in their assessment of fuel cells and hydrogen applications to support project development. Roland Berger GmbH coordinated the study work of the coalition and provided analytical support.

All information provided within this document **is based on publically available sources** and reflects the **state of knowledge as of August 2017**.

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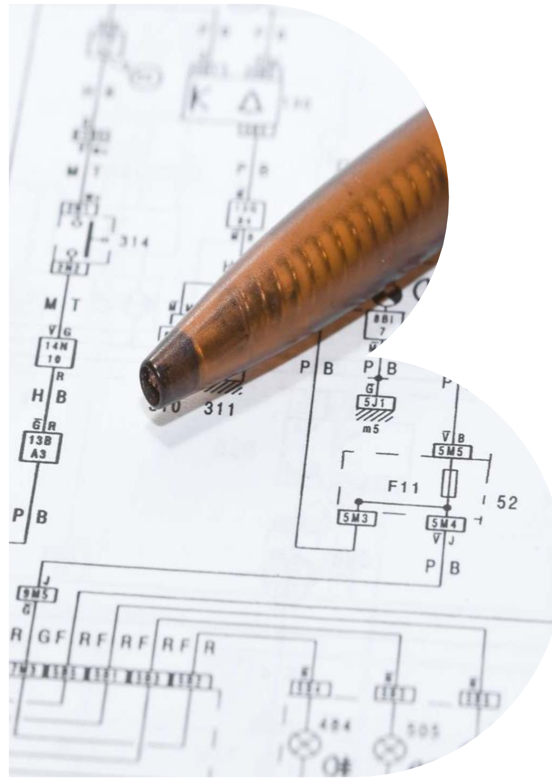
A. Technology Introduction



FC powered ferries offer a zero emission and low noise polluting alternative especially for short distance connections

Fuel cell powered ferries

Brief description: Fuel cell ferries use compressed hydrogen gas as a fuel to generate electric power via an energy converter (fuel cell); the produced electricity powers an electric motor

Use cases: Cities and regions can use/promote fuel cell ferries as alternative to heavy-oil ferries to connect remote areas as well as to establish connections within a city or region. Authorities and port operators (region- or municipality-owned) can establish harbors as "environmental zones"

Fuel cell powered ferries (typically use-case specific, i.e. depending on route serviced)

Key components	Fuel cell stack and system module, hydrogen tank, battery, electric motor
Output	12 kW – 2.5 MW
Fuel	Hydrogen (stored at 350 bar)
Speed	6 - 35 knots
Passenger capacity	12 - 150
Approximate capital cost	EUR 255,000[1)]
Original equipment manufacturers	*TBC*
Fuel cell suppliers	Auriga energy, Ballard Power Systems, Proton Motor
Typical customers	Logistics operators, water taxi operators, ship owners
Competing technologies	Diesel, LNG

1) Based on Hydrogenesis (Bristol)

Source: Roland Berger

So far, only small ferries are in prototype demonstration – Larger ferry applications still in concept phase

Fuel cell powered ferries

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Overall technological readiness: Application overall at prototype stage, to be demonstrated in relevant environment over the coming months and years

TRL*: 1 Idea · 2 · 3 Tech. formulation · 4 · 5 Prototype · 6 · 7 · 8 Fully commercial · 9

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
HYBRIDShips		2017	Pilot model of a hybrid-powered ferry, which will be in operation in 2020. Main propulsion based on H_2 fuel cells, To ensure energy-efficient operation, batteries will also be used. Project partners: Fiskerstrand Holding AS, Norwegian Maritime Authority (NMA)	n.a.
MF Ole Bull		2016	Demonstration project at Osterøy car ferry between Valestrand and Breinstein. One of the ferry's two diesel engines will be replaced by an electric motor powered by a 200 kW PEM fuel cell. Project partners: Christian Michelsen Research Prototech (CMR) GreenStat	n.a.
HYSEAS III		2016	As continuation of Hyseas 2 project , Hyseas III aims to take the concept of a hydrogen powered passenger and vehicle ferry through to a construction project. HYSEAS III consortium managed by Fergusson Marine Engineering Limited: Fergusson Marine (shipbuilder), Caledonian Assets Management ltd. (ship owner/Scottish Government owned), Kongsberg Maritime (R&D), St. Andrews University, Ballard Power Systems, Transport Scotland (associate)	n.a.
Hydrogen Ferry Demonstration Project in Bristol "Hydrogeneisis“		2010-2014 & since 2016	6-month trial with a 11 m steel ferry in Bristol. Powered by four 12 kW fuel cells, the ferry carries 12 passengers and two crew. The hydrogen fuel and refueling station for the ferry are supplied by Air Products.	EUR 255,000.

*) Technology Readiness Level ≤ 5 6-7 8-9

Source: Roland Berger

FC powered ferries could dramatically decrease environmental impacts of ferry services (emissions, oil & diesel spill, noise)

Fuel cell powered ferries

Use case characteristics

Stakeholders involved

- Municipality-owned and/or private transport companies operating water taxis and car ferries
- Ship owners
- Port authorities
- OEM & utility providers

Demand and user profile

- Sensitive ecologic environments requiring alternative (zero emission, low noise pollution) propulsion systems
- Peak demand in high seasons (need for fast charging and intensive use)

Deployment requirements

- Refueling infrastructure
- High safety standards for hydrogen storage and transportation
- Possibility of coupling with electrolysis at harbor from renewable resources like solar or wind

Key other aspects

- Significant reduction of dependency on fossil fuels or energy imports (depending on the type of hydrogen production)

Benefit potential for regions and cities

Environmental

- Zero local emissions (pollutants, CO_2)
- Reduced noise level, therefore suitable in sensitive environments, such as rivers, lakes and oceans
- Beneficial to the wild life of rivers, lakes and oceans

Social

- Increased public acceptance of boat services (no harmful or disruptive emissions)
- Ultimately thanks to low/zero emission footprint: lower health insurance expenses, reduced social security expenses and higher standard of living

Economic

- Eventually reduced cost in harbors of countries with high electricity prices where vessels are not allowed to use diesel for electricity production and instead have to rely on external electricity
- Depending on the development of oil prices, lower TCO in the long run

Other

- The University of the Highlands and Islands, Orkney College, elaborated a concept for a Hydrogen Vessel Training to familiarize ship crews with fuel cells. A 75 kW fuel cell is used to mimic the fuel cell on a vessel

Source: Roland Berger

Technological readiness and regulatory limits as well as the provision of a hydrogen infrastructure are among the key challenges

Fuel cell powered ferries

Hot topics / critical issues / key challenges:

> **Technological readiness** (systems still in proof-of-concept phase and not yet commercially available). For now, only prototype demonstrations for smaller passenger ferries. However, several car ferry demonstration projects are in the planning stage and will start to operate by the year 2020

> **Hydrogen infrastructure** (storing and refueling stations in harbors, challenging logistics of providing the infrastructure for remote areas)

> **Eco-Friendliness** (well-to-wheel emission largely depends on resources used in hydrogen production)

> **Product cost** (cost reduction of fuel cells and batteries)

> **Regulation** (unresolved regulatory issues such as certification of the equipment; emergency protocols; permitting of hydrogen use)

Further recommended reading:

> EMSA study on the use of fuel cells in shipping: www.emsa.europa.eu/emsa-documents/latest/download/4545/2921/23.html

Key contacts in the coalition:

Please refer to working group clustering in stakeholder list on the share folder

https://sharefolder.rolandberger.com/project/P005

Source: Roland Berger

B. Preliminary Business Case

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Use case and applications determine capital, fuel, O&M and infrastructure cost that in turn make up the operator's TCO

Key elements of FCH maritime applications' TCO – SCHEMATIC, SIMPLIFIED

Operator's perspective …

The task / scenario at hand: use case, deployment context, target operating model, e.g.

> Route definition and length
> Target capacity
> Target roundtrip-time, target schedule for operations
> Target availability
> Oceanographic and meteorological conditions
> Fleet size
> Energy cost
> Carbon intensities
> …

FCH vessel / system specifications and performance

> Volume, weight, etc.
> Maximum / cruising speed
> Powertrain design, e.g. power output of fuel cell
> Fuel cell technology
> Efficiency / fuel consumption
> Hydrogen storage system
> Degradation
> Lifetime
> Availability
> …

Hydrogen infrastructure specifications and performance – sharing ratios

1. Capital cost

> Investment / depreciation,
> Financing cost

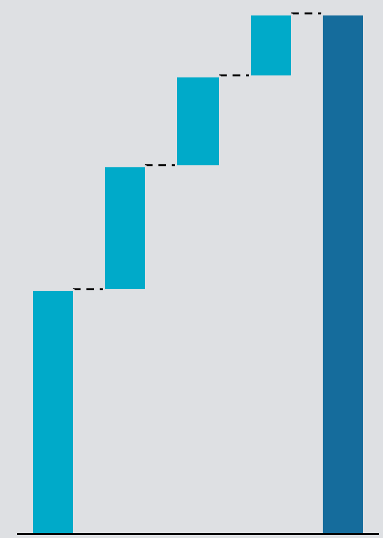
2. Fuel cost – H_2 consumption, H_2 price (dep. on production, distribution, volumes, input prices, etc.)

3. Other O&M cost, e.g. for vessel maintenance, personnel, utilities, fees/levies, taxes[1]

4. Infrastructure cost

> Investment / depreciation
> O&M cost

Total Cost of Ownership (TCO) in EUR p.a. or EUR/nm



1) Largely excluded for preliminary business case analysis, more detailed consideration in Project Phase 2

Source: FCH2 JU, Roland Berger

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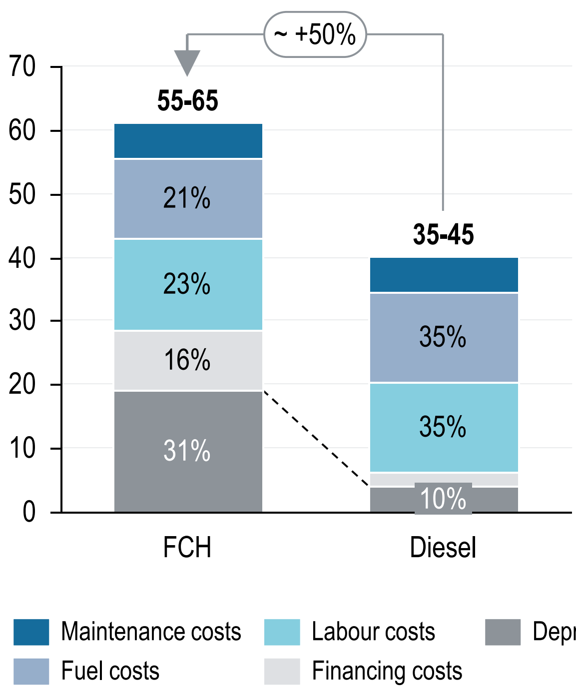
#91 – What's 'nm' in the unit? Is it nautical mile?

An initial FCH ferry would likely yield a significant cost premium over a diesel ferry – significant CO_2 savings expected, esp. with green H_2

Business case and performance overview – INDICATIVE, PRELIMINARY

Economic[1]

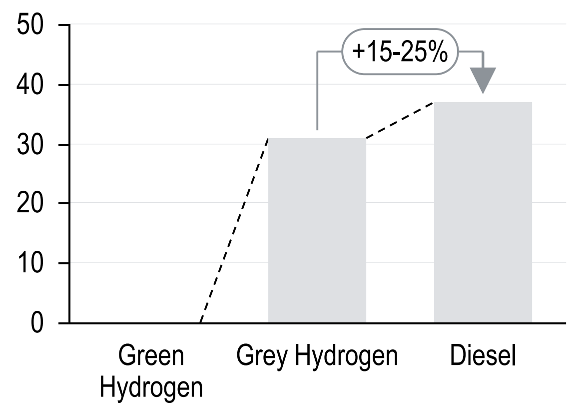
Estimated annualised Total Cost of Ownership [EUR/nm]



Environmental[1]

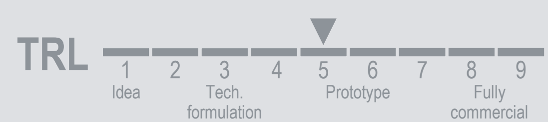
> Zero local emissions of CO_2, pollutants such as NOx, fine dust particles when using green hydrogen
> CO_2 emissions well to wheel dep. on fuel source and fuel efficiency; in this example, a green hydrogen fuel cell ferry saves nearly 1,250 t CO_2 p.a. – comparison of CO_2 emissions

[kg CO_2/nm]



Technical/operational

> Pure FCH electric ferries are currently in a development phase, first pilot demonstration projects with prototypes will be starting within the next 5 years
> Medium-term commercialisation unlikely, initial priorities are successful demonstration projects in areas with high need for decarbonisation of maritime public transport, e.g. Scandinavia, Mediterranean
> Challenges: initial regulatory framework and permitting (e.g. refuelling protocols, FCH powertrain for maritime appl.), hydrogen supply (quantities, cost efficiency)
> Potential to meet same operational requirements (range, refuelling time) – like diesel/MGO ferries



1) Initial rough estimate based on concept work on a high-speed passenger ferry for daily public transport in Northern European coastal waters (see following slides)

Source: Roland Berger

CAPEX of ferry and infrastructure as well as cost of hydrogen are key determinants for the business case at hand

Key sensitivities and assumptions for this use case – INDICATIVE, PRELIMINARY

> Capital cost of FCH ferry and hydrogen infrastructure:

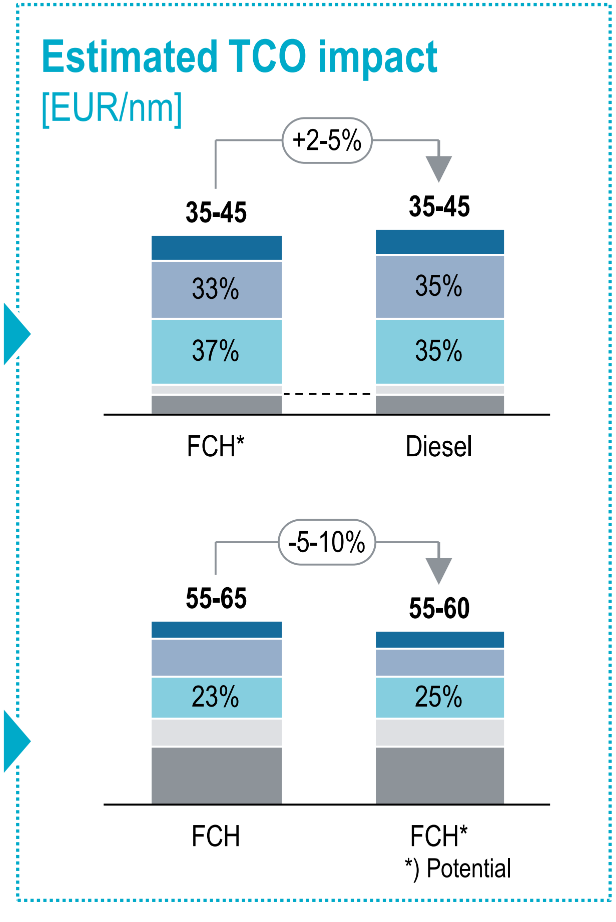
– Highly dependent on the **technical specifications** which in turn derive from the **deployment use case** (capacity, route length, target roundtrip-time, oceanographic and meteorological conditions, etc. determine necessary maxima of cruising speed, power range, operating model and efficiency of fuel cells) **– strong regional differences**; initial costs for development, testing and permitting/certification as well as cost of refuelling infrastructure (as attributed) are decisive factors

– Here: If capital cost of ferry and refuelling infrastructure were reduced to diesel levels, TCO would fall below diesel levels (all other things equal)

> Hydrogen supply and cost of hydrogen:

– Relatively **high volumes of hydrogen consumption** (e.g. here nearly 400 kg per day and vessel) require large supplies, storage and refuelling capacities – supplying green hydrogen from large-scale electrolysis with cheap renewable electricity might be the ideal long-term solution

– Here: Reducing the price of hydrogen to 2.50 EUR/kg leads to a reduction in TCO of 2-5 EUR/nm (or -5-10%) **– strong regional differences**



Source: Roland Berger

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For analytical purposes, we consider a hypothetical ferry use case in Europe based on interviews with industry experts

Preliminary business case components and key assumptions – PRELIMINARY

Applications and technologies

initial deployment	**FCH Ferry**	**Diesel Ferry**
Technical data		
-- Ferry length	30 m	30 m
-- Passengers	100	100
-- Powertrain	2 x 800 KW PEM FC	2 x 800 KW Diesel Eng.
Lifetime	25 years	25 years
CAPEX[1]	~ EUR 11-15 m	~ EUR 3-3.5 m
Fuel	Hydrogen (250 bar[2])	Diesel
Fuel consumption	3.4 kg/nm	14 l/nm
Maintenance	2.76 EUR/nm	2.53 EUR/nm
Infrastructure	HRS	RS
-- CAPEX	3,000,000 EUR	345,000 EUR
-- OPEX	100,000 EUR/y	100,000 EUR/y

Use case and exogenous factors

Strongly dependent on reg. circumstances

> Starting in 2021, a fuel cell powered passenger ferry will offer daily public transportation between to cities along the costal line of a European province with ~100,000 inhabitants

> With a top speed of ~28 kn and average speed of ~22 kn, the ferry will offer 360 round trips à 115 nm per year, requiring one (overnight) refuelling at the home port

> Resulting annual operations in this use case:
- Total annual distance travelled: ~ 33,800 nm
- Annual energy requirements: ~1,870,000 kWh (~6,300 kWh/d)
- Annual hydrogen consumption: ~122,500 kg (~390 kg/d)

Strongly dependent on reg. circumstances

> Source of hydrogen: electrolysis from (low-cost) hydropower

> Cost of hydrogen: 3.5 EUR/kg

> H_2 refuelling infrastructure: one refuelling station at the home port, synergies with other port-related FCH applications (e.g. forklift trucks)

> Cost of Diesel: 1.01 EUR/l

> CO_2 footprints of green / grey hydrogen : 0 / 9 kg CO_2/kg

> CO_2 footprints of diesel : 2.64 kg CO_2/l

> NO_X footprints of diesel: 0.004 g/l

1) Incl. cost of initial development, testing, permitting/licensing/approvals (excl. possibly necessary fuel cell stack replacements)
2) Alternative tanks pressure between 200 -700 bar
Source: Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger