

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

FCH Ships





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.

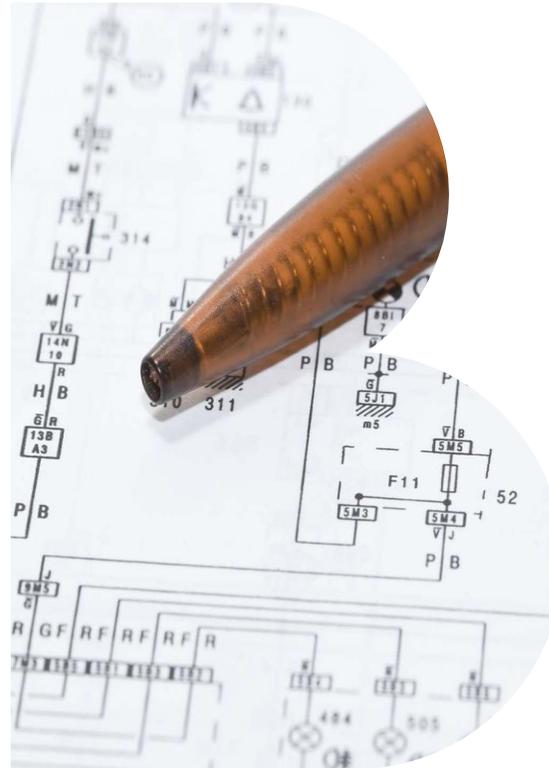
All information provided within this document **is based on publically available sources** and reflects the **state of knowledge as of August 2017**.



Table of Contents

Topic	Page
A. Technology Introduction	4
B. Preliminary Business Case	9

A. Technology Introduction



Currently pursued FCH hybrid ships are a lower emission and lower noise alternative to diesel, esp. for inner-city harbours

Fuel cell powered ships

1/4



Brief description: Fuel cell ships use compressed hydrogen as a fuel to generate electric power via an energy converter (fuel cell); the produced electricity powers an electric engine; **current concepts and prototypes mainly focus on auxiliary power supply for seagoing vessels**

Use cases: Cities and regions can use/promote fuel cell ships to reduce emissions and fuel use. Authorities and port operators can establish harbours as "environmental zones" and require other forms of electricity generation/supply in the harbours than from the fossil fuel engine of the ships

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

Key components	Fuel cell stack and system module, hydrogen tank, battery, electric motor
Fuel cell technology	Proton exchange membrane (PEM), solid oxide (SOFC)
Output ¹	50 – 500 kW
Fuel	Hydrogen, LNG, methanol, diesel
Approximate capital costs	n.a.
Original equipment manufacturers	Wartsilä Ship Design, Fincantieri, ABB
Fuel cell suppliers	Nuvera, PowerCell Sweden AB, Proton Motor Fuel Cell, Serenergy, FuelCell Energy (FCES)
Typical customers	Offshore companies, research organizations, logistics providers, tour operators
Competing technologies	Diesel, methane, LNG

1) Auxiliary power based on Project SchIBZ

Prototypes and demonstration projects mainly focus on auxiliary power supply – FCH propulsion applications still under development

Fuel cell powered ships

2/4

Overall technological readiness: Auxiliary power units for large scale ships and small- to medium-scale ships in prototype and demonstration phase (projects to field-test in relevant environments are now under way), fuel cell propulsion application still in early concept phase



Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
MARANDA		2017	165 kW (2 x 82.5 kW AC) fuel cell powertrain (hybridized with battery) for power to research vessel's electrical equipment, dynamic positioning during measurements. Partners: Powercell, ABB, OMB Saleri, PersEE, SYKE, Swiss Hydrogen	EUR 3.7 m
Orion® fuel cell stack prototype units test at Fincantieri		2013	Fincantieri and Nuvera agreed to build ships with Orion ® fuel cell stacks used as range extenders on marine vessels	n.a.
SMARTH2 project Elding		2007	125-ton cruiser previously used as rescue ship and retrofitted to be used for whale watching tours with up to 150 passengers. Hybrid 10 kW fuel cell system replaced a 50 kW diesel engine for auxiliary power	n.a.
e4ships		2009	Association of leading German dockyard and ship operators working on joint industry projects to significantly improve energy supply onboard large vessels using (high-temp.) PEM and SOFC as well as CHP. Funded under the National Innovation Program Hydrogen and Fuel Cell Technology (NIP)	EUR 35 m
FellowSHIP project Viking Lady Offshore Supply Vessel		2003	DNV 1A1 Supply Vessel, 2009 delivered to Eidesvik Offshore, chartered to Total, power requirements covered by LNG fuelled molten carbonate fuel cell	n.a.

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

FC powered ships could significantly decrease environmental impacts of maritime traffic (emissions, oil & diesel spills, noise)

Fuel cell powered ships

3/4

Use case characteristics

Stakeholders involved



- > Shipping companies (public & private)
- > Shipowners
- > Research organizations
- > Port authorities
- > OEMs and fuel cell technology providers

Demand and user profile



- > Shipping routes and use cases with sensitive ecologic environments requiring alternative propulsion systems
- > Shipping routes and use cases with harbours where main engines are turned off to minimize noise, vibration and air pollution

Deployment requirements



- > Hydrogen refuelling infrastructure (at harbours, possibility of coupling with electrolysis from renewable resources like solar or wind)
- > High safety standards for hydrogen storage and transportation

Key other aspects



- > Currently no demonstration of large ship solely powered by hydrogen fuel cells, focus on auxiliary systems (in addition to diesel engines)

Benefit potential for regions and cities

Environmental



- > Local zero-emission performance whenever fuel cell auxiliary systems are in use
- > Reduced noise level, therefore suitable in sensitive (urban or rural) environments
- > Potential to reduce environmental risk of accidents

Social



- > Increased public acceptance of boat services, especially in harbour cities (no harmful emissions)
- > Ultimately thanks to low/zero emission footprint: higher standard of living in critical areas

Economic



- > Eventually reduced cost in harbours, esp. in countries with high electricity prices where vessels have to rely on external electricity supply when in harbour
- > Depending on the development of oil prices, CAPEX reduction and cost of hydrogen – lower TCO in the long run

Other



- > Hydrogen infrastructure at berths can be used both for port operations and docked ships

Technological readiness as well as technical standards and hydrogen infrastructure as key challenges

Fuel cell powered ships

4/4

Hot topics / critical issues / key challenges:

- > **Technological readiness** (for now, no entirely fuel cell powered ship available; evolution to the next development stage necessary going beyond auxiliary power supply)
- > **Regulation** (lacking of consistent European as well as world wide regulation regarding the permission to use gaseous hydrogen in harbours)
- > **Technical standards** (derivation of technical standards for different types of ships varying concerning systems and performance)
- > **Hydrogen infrastructure** (storing and refuelling stations in harbours, challenging logistics of providing the infrastructure for remote areas)
- > **Eco-friendliness** (well-to-wheel emissions largely depend on resources used in hydrogen production)
- > **System Integration** (Efficient use of battery and fuel cell energy)
- > **Product cost** (reducing the cost of fuel cells and batteries)

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>

B. Preliminary Business Case



The shipping industry is very diverse, likely requiring highly customized FCH power solutions for each use case

Key dimensions for potential FCH power solutions for large vessels – SIMPLIFIED

Type of vessel



- > Container ship
- > Tankers
- > Short sea shipping
- > *Cruise ships*
- > Ferries
- > Yachts
- > Navy ships
- > Icebreakers
- > Tugs
- > Submarine

Application purpose



- > Full powertrain for propulsion and on-board energy supply (e.g. for (in-port) hotel services on cruise ships)
- > *Separate on-board power supply*

Relevant FC technologies



- > Low-temperature PEM FC
- > High-temperature PEM FC
- > Solid-Oxide FC (SOFC)

Dimensions of FC applications for ships

Available fuels



- > Pure hydrogen (liquid / gaseous)
- > Hydrocarbon compounds (with on-board reforming): Methanol, Diesel, Marine Gas Oil (MGO), Liquefied Natural Gas (LNG)

Refuelling options



- > *Initial fuelling at the port and on-board bunkering*
- > Direct on-shore energy supply provided by every port
- > Fuel/power supplied in port through pipelines, trucks or barges

Other dimensions

- > *to be discussed*
- > ...

To be considered in the exemplary use case on slide 8

Additionally, potential fuel cell application cases are very much dependent on vessel-specific energy requirements

Energy consumption of different types of vessels during lay time in port

Vessel Type	Power Required [in kW]			Run Time [in h]		
	Typical	Low	High	Typical	Low	High
Harbor Tug	100	7.5	410	4	1	6
Fishing Trawler	200	75	670	contin.	48	months
Bulk	200	150	300	48	-	-
Tanker (steam pumps)	700	550	800	48	24	72
Auto/RoRo	800	700	890	24	24	36
Container	1,400	500	8,400	48	24	72
Reefer	3,000	900	5,600	60	48	72
Cruise ships	6,000	3,500	11,000	10	10	12
Tanker (elec. pumps)	7,800	-	-	48	24	72



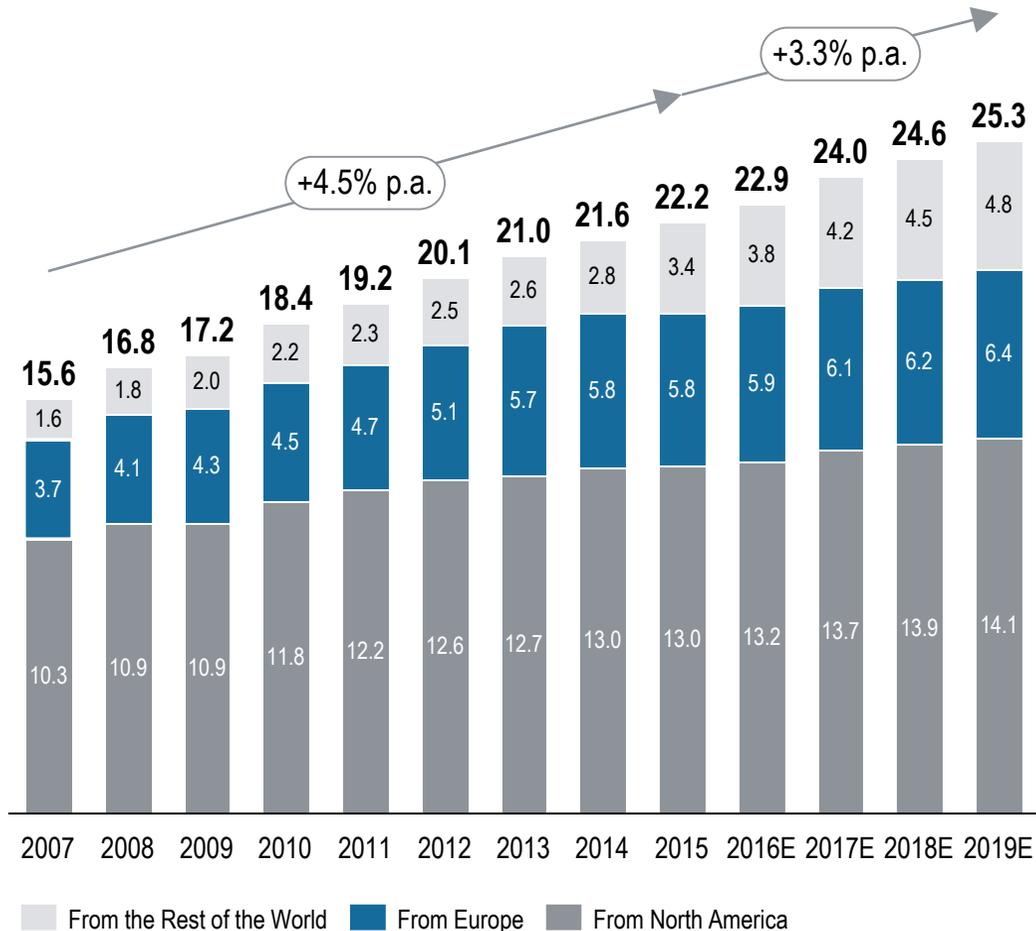
Implications

- > There is a **great variety of energy requirements** among different types of vessels, resulting in **different application cases for FC technology**
- > **Cruise ships** display among the **highest energy** requirements and will hence be **affected by EU / IMO requirements on emission restrictions more drastically**
- > **Autonomous, crew-less ships** might **reduce power requirements in the future**, making energy-demanding applications such as A/C and heating obsolete

Exemplary focus on the following slides

One example for a use case: energy supply for cruise ships – serving to a growing market with continuously increasing emissions

Cruise passengers per source region [m passengers; 2007-19E]



CAGR 07-15: 10.1%
CAGR 15-19E: 8.8%

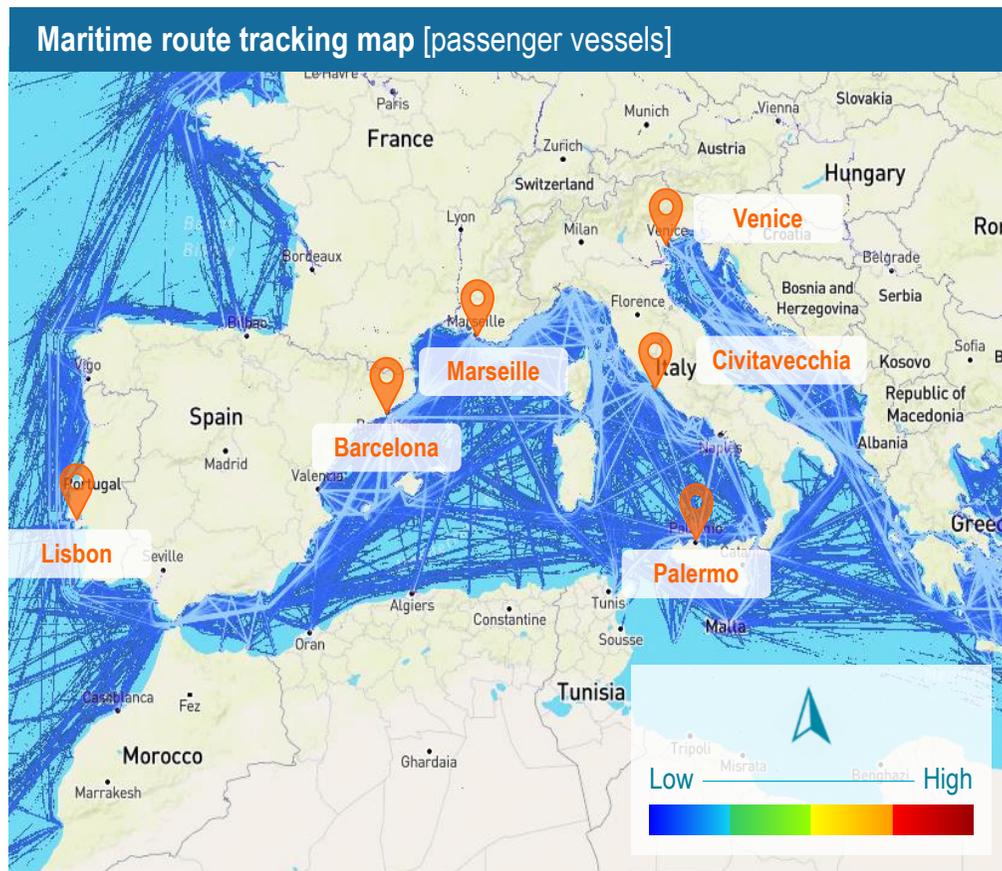
5.6%
2.5%

3.0%
2.0%

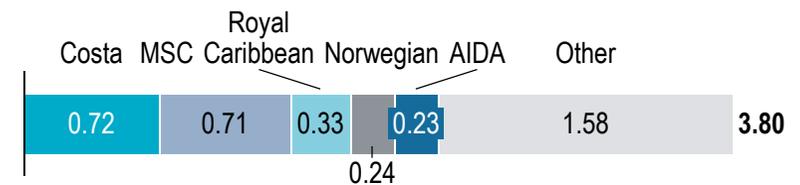
- > Cruise passengers should grow +3.3% p.a. from 2015 until 2019
- > Economic recovery from the 2009 crisis and growth of emerging cruising regions such as Asia or the Middle-East should drive cruise demand
- > Markets such as China and Australia grew by 40.3% and 14.6% in 2015 alone
- > The United States' cruise penetration rate has only risen slightly in recent years from 3.3% in 2011 to 3.5% in 2015
- > Globally, total emissions of greenhouse gases, pollutants and fine dust particles from cruise ships are increasing

Popular ports and routes will be disproportionately affected by increasing passenger numbers and resulting emissions

One example: Mediterranean cruise market



Top players [million passengers; 2016]



Key market dynamics



- > In 2015, the two largest ports in the Mediterranean were **Barcelona** and **Civitavecchia** with over **2 m cruise passenger movements** each and responsible for **9.3%** and **8.3%** of total passenger movements
- > **Civitavecchia** (major point of call for Rome) had the **largest number of calls** with 794, followed by the **Balearic Islands** at 788, **Barcelona** at 749

Separate on-board engines for in-port hotel services powered by FCH technology can drastically reduce emissions in cruise ship terminals

Context and use case of a typical cruise ship power supply application

Cities with inner-city cruise ship terminals are heavily affected by pollution (pollutants, fine-dust particles and greenhouse gases) from on-board energy supply during lay times



- > With energy demands between 6 and 12 MW (the "hotel load") a large cruise ship (capacity of more than 3,000 passengers) with a lay time of ~10 h requires 60-120 MWh of energy supply for in-port hotel services
- > If this energy demand is satisfied by using on-board combustion engines powered by fossil fuels (e.g. marine gas oil), 50-60 t of CO₂¹ are emitted into the atmosphere during this one stay, the equivalent of approx. 25-30 compact cars in 1 year
- > As an alternative, different technological solutions are available to reduce emissions:
 - **On-shore energy** via the port: here, sufficient supply and grid infrastructure must be in place
 - **Separate on-board engines for in-port hotel services:** Different types of technologies are available, including the usage of small additional diesel/MGO powered engines and FCH applications

1) Based on an energy demand of 9 MW

In principle, in-port energy supply can be provided by on-board generators or onshore power supply

Benchmarking of energy supply technologies for in-port energy supply – SIMPLIFIED

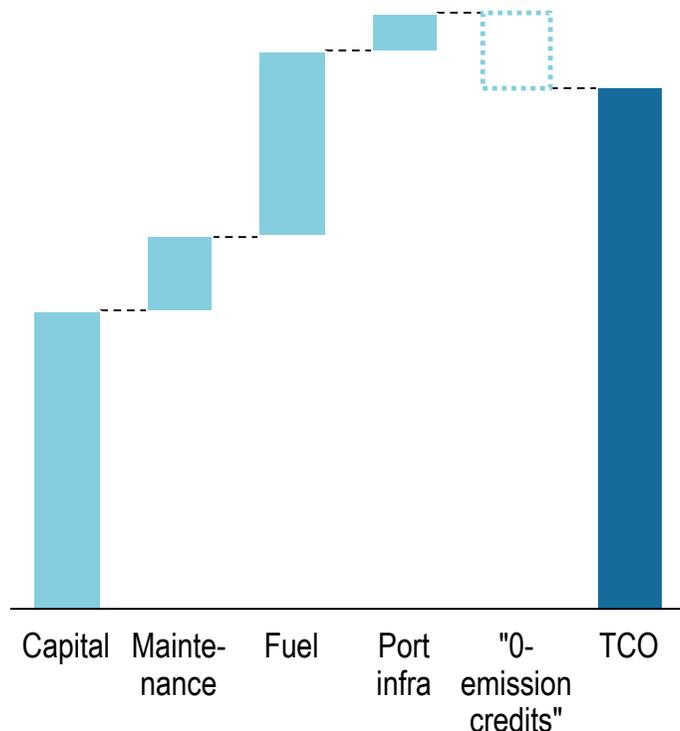
	1 Main propulsion engine	2 Separate generator – Diesel/LNG	3 Separate power supply – Fuel cell	4 Cold ironing (Shore-to-ship supply)
				
Description	Energy supply generated by (parts of) main ship engines	Energy supplied by separate diesel engines only used for (in-port) hotel services, main engines switched off	Separate engine for (in-port) energy demand powered by fuel cell technology, main engines switched off	Power provided directly by port, all on-board engines switched off
Fuel	Diesel/MGO/LNG/...	Diesel/LNG/ ...	Hydrogen/Methanol/LNG/...	Electricity
Maturity level	Operational & widespread	Operational & state-of-the-art	At conceptual stage	Operational & relatively rare
Important considerations	<ul style="list-style-type: none"> > Independent from port infrastructure > Reliable and controllable power supply > Usage of existing engines and fuel > Heavy in-port emissions of CO₂/ NO_x/SO_x/... 	<ul style="list-style-type: none"> > Independent from port infrastructure > Reliable and controllable power supply > Reduced, but still significant CO₂/NO_x/... emissions due to tailored engine capacity and usage of cleaner fuels > Additional space and maintenance requirements 	<ul style="list-style-type: none"> > Reliable and controllable power supply > Strong reduction or even elimination of CO₂/NO_x/... emissions > Additional space and maintenance requirements > Dependence on regular hydrogen/methanol/... supply in ports 	<ul style="list-style-type: none"> > In-port emissions and noise eliminated > Port infrastructure/ sufficient power supply only available in ca. 10 major ports worldwide – voltage capacity to be extended > On-board power grid and connection to be adapted for external power supply

Total Cost of Ownership for FC marine power systems have common drivers but heavily depend on the individual application

Schematic outline of TCO for FC marine power systems and its drivers – SIMPLIFIED

Total Cost of Ownership (TCO)

(e.g. in EUR per port call)



Capital cost

- > FC technology (i.e. LT PEM FC 1,900 – 2,300 €/kW)
- > Fuel (& reforming), bunkering
- > Power range (likely multi-MW)
- > Durability / lifetime
- > System integration

Maintenance cost

- > Spare parts
- > Labour and training
- > Maintenance routine

Fuel cost

- > Type of fuel and key input: electricity, natural gas
- > Production and supply
- > System efficiency (up to 60%_{el}, >90%_{comb.})
- > Fuel supply volumes and price

Port infrastructure cost

- > Allocation of additional port refuelling infrastructure investments and expenditure to shipping companies

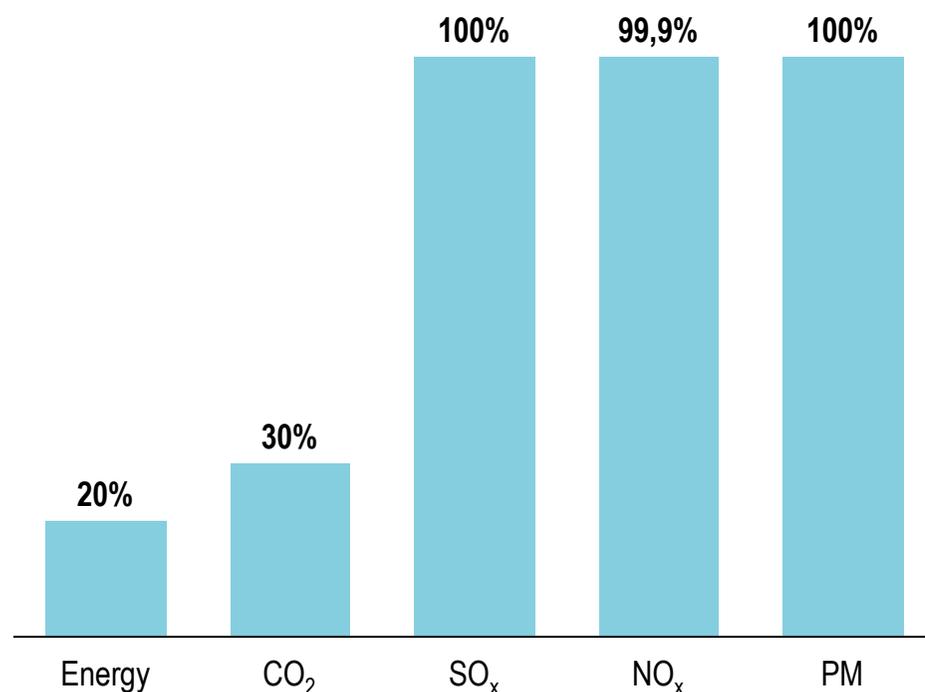
"0-emission credits"

- > Potential future policy measures to promote zero-emissions

Simulations show that fuel cells powered by low-carbon fuels can significantly reduce CO₂ and eliminate pollutant emissions

Environmental benchmarking of FC power systems vs. conventional systems

Potential energy and emission reductions of a typical cruise ship¹⁾



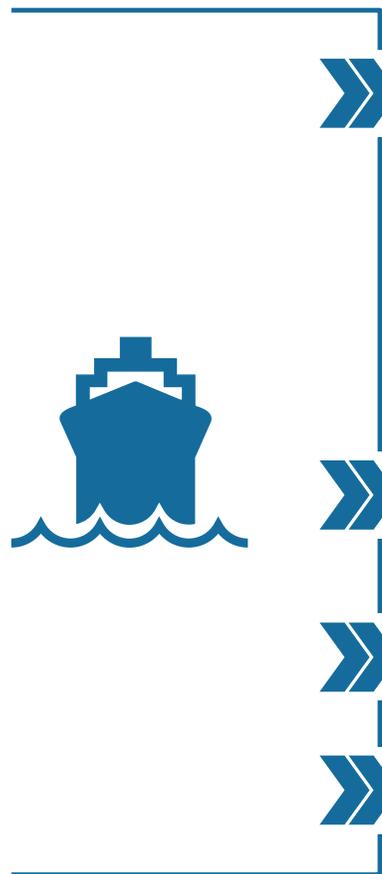
Implications

- > In comparison to a conventional diesel engine, **fuel cells powered by on-site reformed low-carbon fuels** lead to significant **reductions** in overall²⁾ **emissions of CO₂, pollutants and fine dust particles**
- > While **CO₂** can be **reduced by** approx. **30%**, **SO_x, NO_x**, and **PM** can almost be **eliminated**
- > **Higher efficiencies** of fuel cells lead to reduced primary energy consumption of approximately 20%
- > Please consult Joint Operation for Ultra Low Emission Shipping's conference documentation on [HT PEM Fuel Cells](#) for more information

1) Based on a methanol-powered fuel cell in comparison to a conventional diesel engine; 2) Includes fuel production as well as port operations

Decarbonisation is high on the agenda of cruise operators; FC power systems have to become part of the technology pool

Key considerations for looking at FC power systems for cruise operators



The **main drivers** to invest in alternative power supply systems is the increasing **importance to accelerate decarbonisation and other emission reductions**

- > **Supranational regulations** from IMO- or EU-level will soon require CO₂ monitoring, cap and trade policies might be introduced in a second step
- > **Stricter local emission regimes from port cities** will increasingly force aggressive curtailment of NO_x, SO_x and other pollutant emissions
- > **Customer awareness** is growing as well – the emissions footprint of cruises becomes an increasing concern for clients

With operating times of 25 to 30 years per ship and lead times of 5 to 10 years before start of operations, the cruise ship industry has to adopt a **long term focus – FCH need to start become part of the technology pool soon in order to be part of the solution**

Necessary size /power ranges, capital cost and fuel supply are among the major **hurdles** FC power systems have to overcome

Operators need to trial new technologies (as they have trialled LNG as new fuel in the past) – a **demo FC vessels** can be used to **finalise permitting, certification and other frameworks**

Please do not hesitate to get in touch with us

Contact information



Carlos Navas
FCH2 JU

Strategy and Market Development Officer

carlos.navas@fch.europa.eu

+32 2 221 81 37