FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

Making Hydrogen and Fuel Cells an everyday reality

Lionel Boillot

Tokyo, 21st February 2018

Human responsibility to address climate change

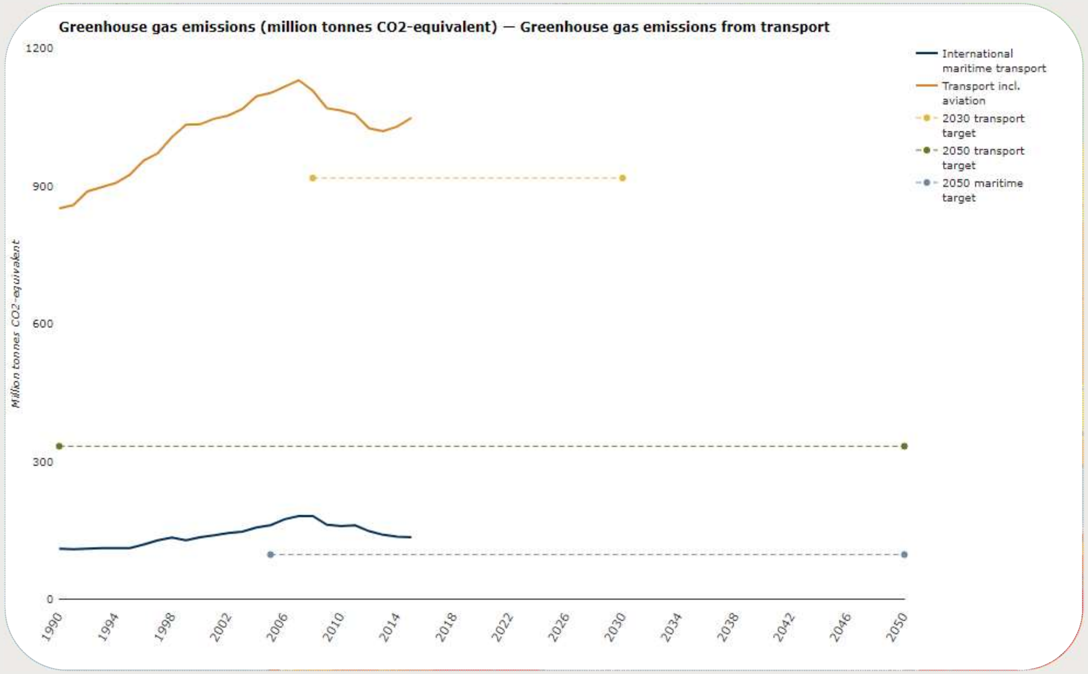
CO_2 emissions and pollution are a common problem

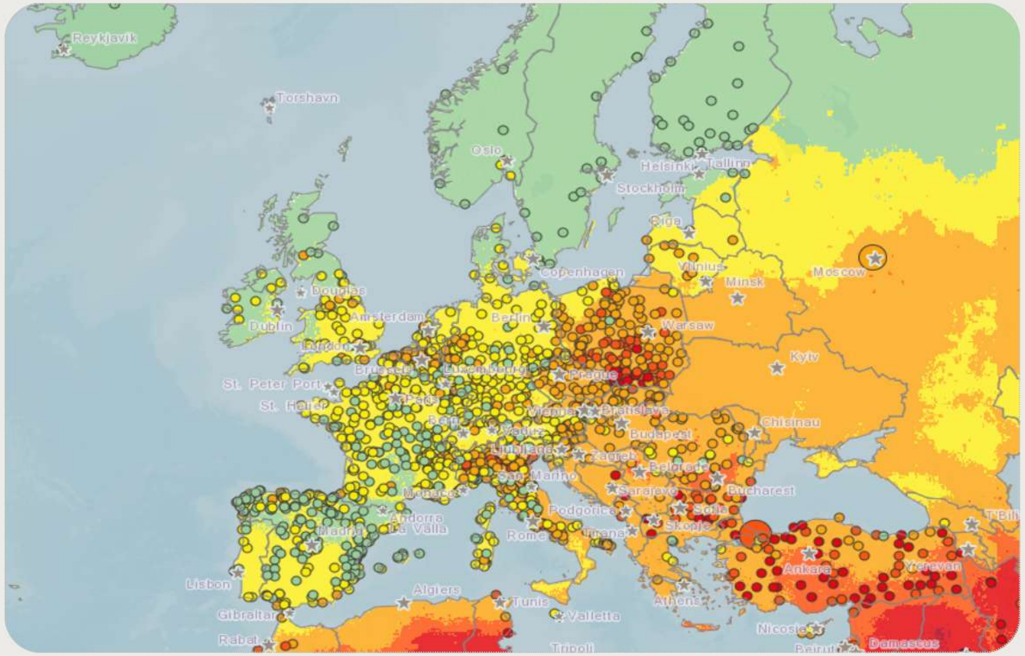
A) CO_2 problem, utilize renewables and improve efficiency

- Transport CO_2 evolution on yearly basis vs 2030/2050 decarbonisation targets
- EC energy outlook – Transport CO_2 share

B) Pollution

- Air pollution is a real problem for the health of EU citizens (467.000 premature deaths - EEA)
- EU cities forced to shut down due to high concentration of pollutants





Source: European Environmental Agency

The EU regulation until 2020

Powertrains
CO_2 standards for cars and vans:
95g/km limit for cars in 2020 (including super-credits for ultra-low carbon vehicles)

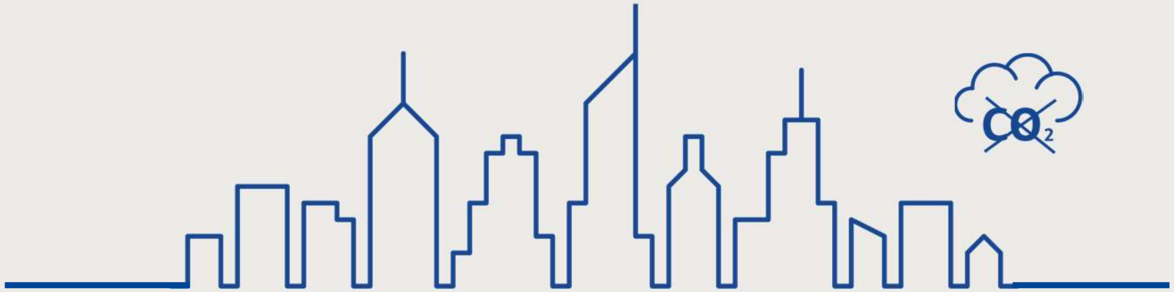
Energy
Renewable energy Directive:
Fuel quality directive: oil companies to reduce by 6% the carbon content of their fuels by 2020

Quality of air
Ambient Air Quality directive & National Emissions Ceiling Directive (NECD):
Limiting the concentration of pollutants (PM & NOX - Transport is a big contributor to these emissions).

Infrastructure for alternative fuels
Directive on the deployment of alternative fuels infrastructure: Obligation for MS to establish binding national policy frameworks for the deployment of alternative fuels by 18 November 2016.
-MS to achieve their H_2 infrastructure targets (optional) by 31 December 2025

The EU vision

The overall target is 60% cut in transport CO_2 emissions by 2050



Specific targets are:

By 2030 - 2050

Conventionally-fuelled cars in cities: -50%

By 2050

Aviation uptake of low-carbon sustainable fuels in aviation: 40%

By 2050

EU CO_2 maritime bunkers: - 40% (or 50%)

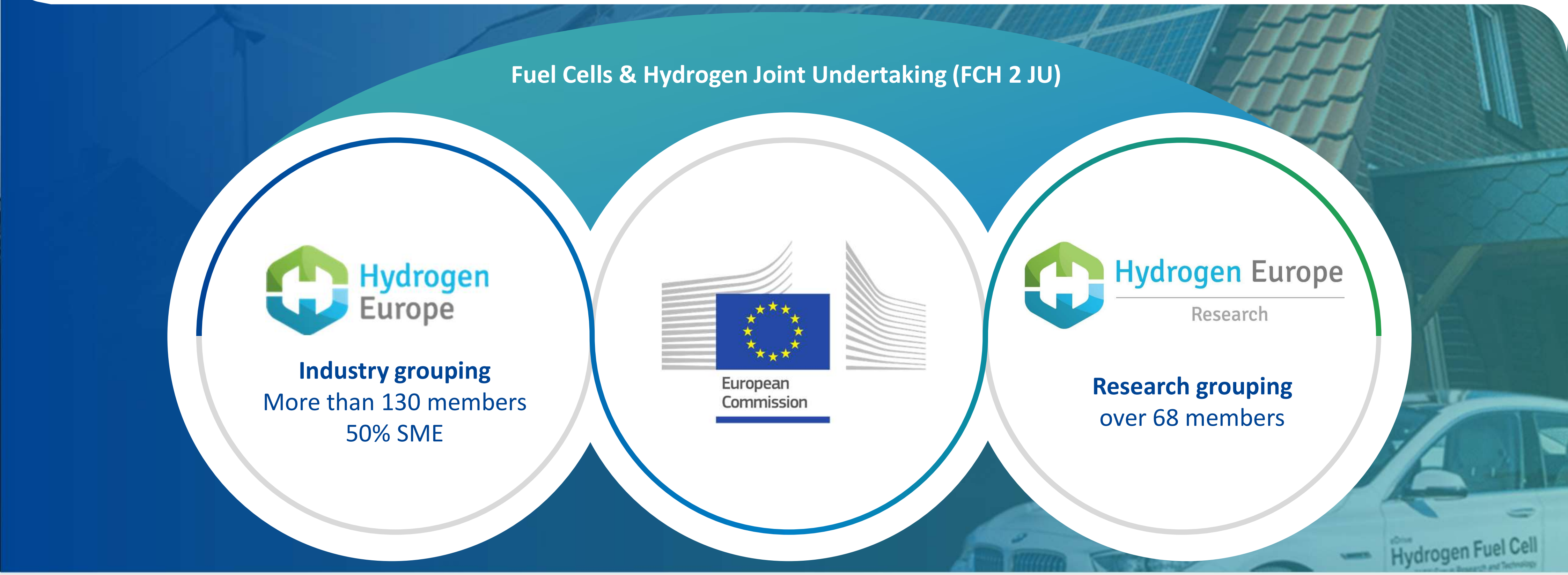
2050

50% freight on rail

** EU transport White Paper 2011*

Strong public-private partnership with a focused objective

EU Institutional Public-Private Partnership (IPPP)



To implement an *optimal research and innovation programme* to bring FCH technologies to the point of market readiness by 2020

FCH JU programme implementation

About 350M€ for clean transport

Energy

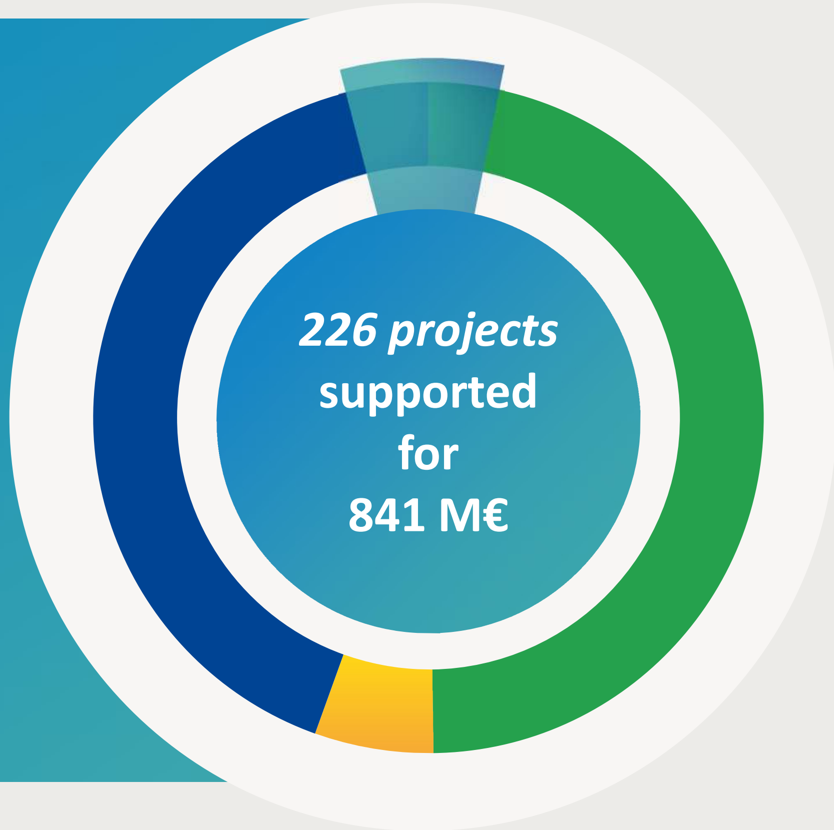
- Hydrogen production and distribution
- Hydrogen storage for renewable energy integration
- Fuel cells for power & combined heat & power generation

Transport

- Road vehicles
- Non-road vehicles and machinery
- Refuelling infrastructure
- Maritime rail and aviation applications

Cross-cutting

- E.g. standards, safety, education, consumer awareness …



48%
401 M€
128 projects

41%
351 M€
58 projects

6%
47 M€
37 projects

5%
42 M€
3 projects

Similar leverage of other sources of funding: 886 M€

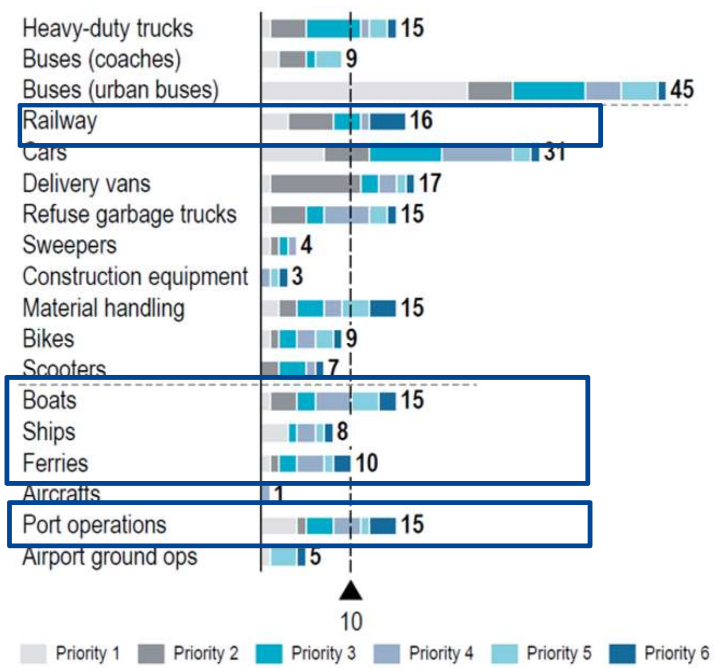
1€ = 135 ¥

A study to create "Hydrogen valleys"

88 Regions and Cities from 22 countries representing ca. one quarter of Europe

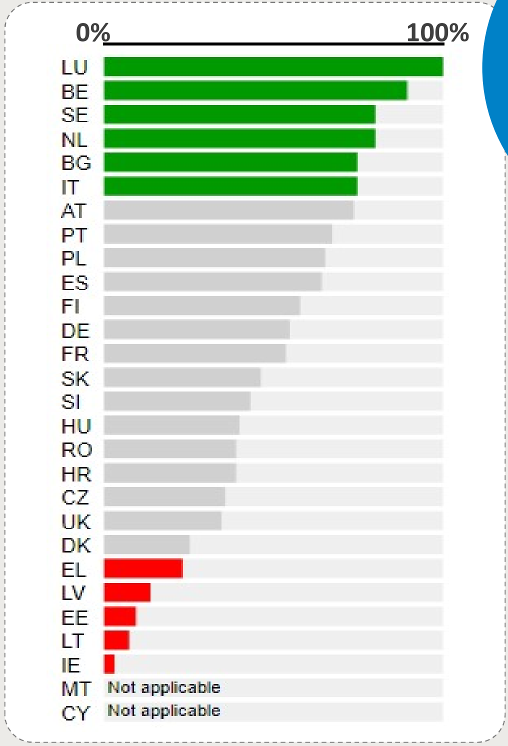
- Support regions in assessing various FCH applications
- Identify and maximize the use of regional and Europe-wide funding/financing options
- Develop roadmaps and concepts for the months after the study, prepare and implement deployment projects from 2018
- Support the participating regions/cities to engage their stakeholders

« Please rank up to six FCH applications according to their potential for future deployment in your region/city »



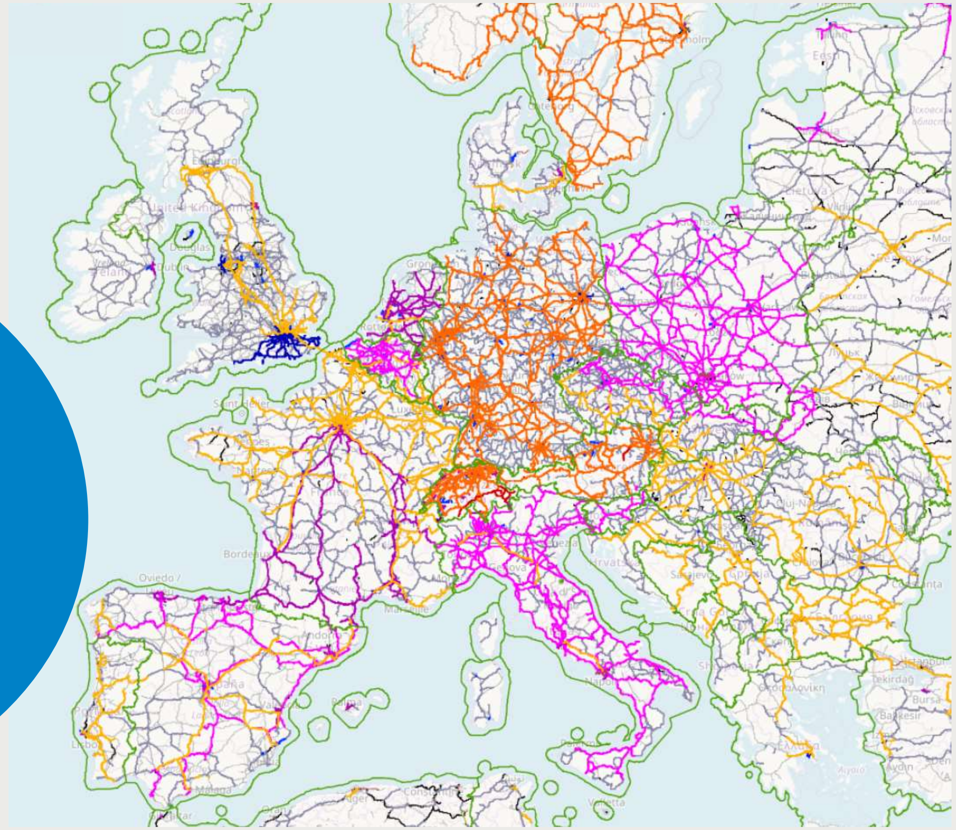
RAILWAYS APPLICATIONS

European Railways: a long way to go full electric



Percentage of electrified railway lines (out of total lines in use)

Railway electrification system
for passenger railways, color-coded by voltage and system. Colored lines are used for electrified lines and **grey lines are used for non-electrified lines**



Source: *Union Internationale des Chemins de Fer synopses*, *IRG-Rail annual reports* (BE, DE, FR), *national statistics, Eurostat, estimates.*
http://product.itoworld.com/map/68?lon=18.28087&lat=48.55440&zoom=5&open_sidebar=map_key

EU policies for clean railways

Policy: « Europe on the move », An agenda for a socially fair transition towards clean, competitive and connected mobility for all – May 2017

Importance of rail in Europe

- 212.800 km network (52% electrified)
- Annual GHG emission of 7.4MtCO_2eq
- Strong industry and public/private operators
- About 900.000 direct jobs (operators only)

Overall policies

- Opening the rail transport market to competition
- Improving the interoperability and safety of national networks
- Developing trans-European rail transport infrastructure

What are the challenges?

- Rising traffic demand, congestion, security of energy supply and climate change
- Railway to take on larger share of the transport demand

Objectives

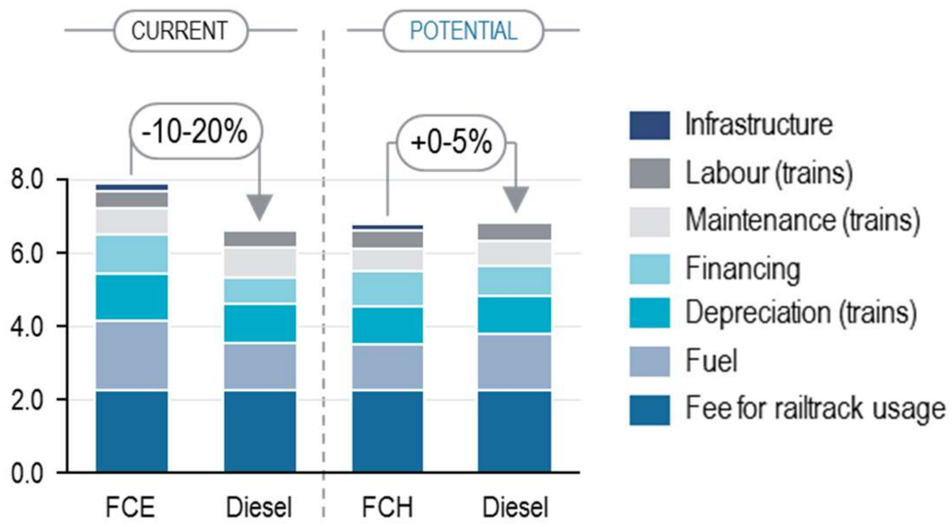
- Cutting the life-cycle cost of railway transport (i.e. costs of building, operating, maintaining, renewing and dismantling infrastructure and rolling stock) by as much as 50 %;
- Doubling railway capacity;
- Increase reliability and punctuality by as much as 50%

1€ = 135 ¥

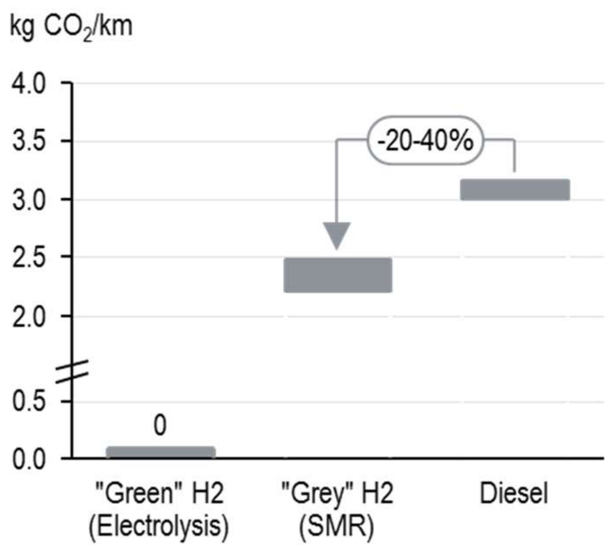
Cost-wise, H2 Trains are competitive against diesel…

…while decreasing drastically harmful emissions

Estimated annualised Total Cost of Ownership (TCO) [€/km], 2017 prices



Estimated tailpipe emissions of pollutants [CO2/NOx)



1€ = 135 ¥

H2 Trains: not only environmental benefits…

Use case characteristics

Stakeholders involved

- Regional train operators, regional transport authorities
- Rolling stock OEMs as well as operation and maintenance providers, fuel cell suppliers
- Hydrogen suppliers and infrastructure providers
- Permitting and licensing authorities

Demand and user profile

- Typically non-electrified routes (e.g. 40-50% of infra.in Germany) as part of regional networks (i.e. 100-200 km per route, several cycles per day and train with total required range of up to 1,000 km, speed of 140 km/h)
- Differing topographic profiles (e.g. tunnels of 5-10 km each) and large number of stops/stations (15-50)

Deployment requirements

- Supply infrastructure able to supply large quantities of hydrogen per day, e.g. through local production
- Hydrogen storage, regional/ local distribution networks
- Network of hydrogen refuelling stations along relevant train routes, i.e. in train depots

Key other aspects

- Elimination of need for engine idling at train stations due to fuel cell auxiliary power units (contrary to diesel units)

Benefit potential for regions and cities

Environmental

- Zero tailpipe emissions of pollutants (esp. NO_x) and greenhouse gases (esp. CO_2)
- Lower noise pollution (depending on speed and track conditions reduction of overall noise emissions)

Social

- Increased passenger comfort through reduced noise and vibration, fewer adverse impact on neighbouring communities
- Public health benefits (esp. urban areas near tracks/station), reduced social security expenses, higher standard of living

Economic

- Avoiding cost of future electrification of several million EUR investment per km (i.e. power generation, transformers and transmission lines as well as service disruption caused by overhead wire installation)
- Maintenance and other OPEX savings vis-à-vis operations with diesel-locomotive, long-term savings potential in TCO[1]

Other

- Flexibility to move into service areas not covered by electrification (for industry-stakeholders involved)
- Significant innovation and high visibility potential as flagship/lighthouse projects

Source: FCH2 JU; Roland Berger

1) Total Cost of Ownership

Germany, already testing H_2 trains

A precursor in the deployment of H_2 trains

Situation

- 43% of the network is not-electrified (17.000km)
- Costs of 1M€ per km to electrify
- Potential for H2 trains in area densely populated
- 4 pilots in different regions

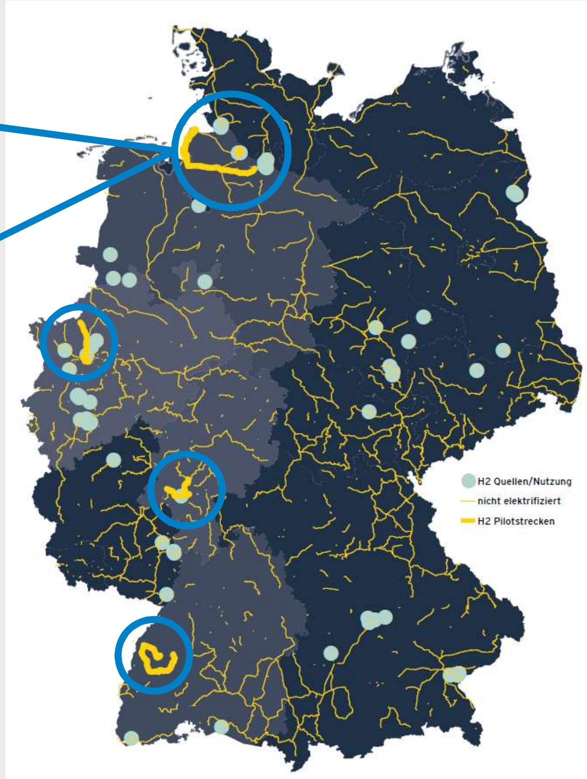
Testing

Testing of 2 fuel cell powered iLINT trains manufactured by Alstom on the route Cuxhaven-Buxtehude (**220 km return**) in northern Germany, first operation as part of the regional network to start early 2018 – then for two years

Projects and announcements

Schleswig-Holstein
60 Hydrail cars

Lower Saxony
47 Hydrail cars

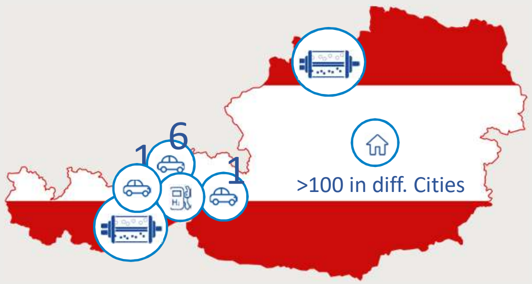


1€ = 135 ¥

Austria, Norway, UK are next in line

Strong local political and economical support

Austria



Norway

- 32km line in the Alps “Zittertal trains to main ski resorts
- Train consumption = 800,000 litres of diesel annually
- A 156M€ plan for electrification is opposed by municipalities, as catenary are visually intrusive
- H2 trains are the option under a 80M€ plan
- Hydro produced H2
- A prototype is under construction.
- After tests, serie production to start, first delivery by 2022

1€ = 135 ¥

United Kingdom

- Less than 50% of network is electrified
- State Secretary of Transport expressing intention to schift for cleaner trains, including H2 trains (Dec. 2017)
- Welsh valleys and Great Western network

FCH support on H_2 trains

No projects, but looking into the best business cases

2016 – budget for 1 project

- Develop an emission-free fuel cell based powertrain system, suitable for rail applications, and to validate it in a rail vehicle for 6 months
- TRL 4 – 7
- Power range at least 200kW
- 4M€

2 applications, none successful

2018 – study

European business cases for FCH trains (regional trains, shunting locomotives, freights/last mile)

Workshop in May 2017

- Hybridisation strategy is key, FC + batteries
- CAPEX >> OPEX
- Fixed fuel cost for the locomotive lifetime (30 years), hydrogen fuel cells will need to be replaced every 6-8 years.
- Business focus: The industry is first investing in regional trains and shunting locomotives. Freight and mainline will follow if there is a business case

1€ = 135 ¥

How to best deploy hydrogen trains

Regional and urban interest

- **German initiative** has stimulated a great deal of interest especially in neighboring areas (Austria, Denmark and Netherlands)
- Up to now, the electrification of lines has been the only alternative to diesel trains
- Many rail routes and lines do not generate **enough traffic to justify rail electrification**
- **Hydrogen offers an attractive alternative** especially when it is not **cost effective** to electrify lines
- **Environmental sustainability**, well-to-wheel emissions largely depend on hydrogen production
- **Cities and Regions** that have introduced hydrogen fuel cell technology in buses or cars/vans are keen to **diversify into other forms of transport**
- Support of Cities and Regions – **both financial and political** – could be crucial

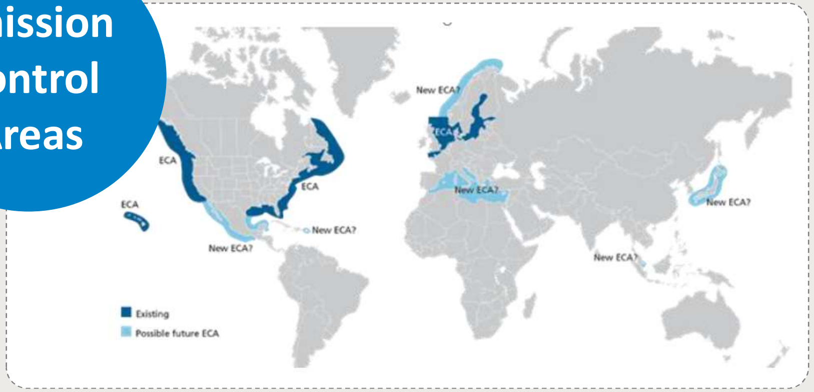
MARITIME APPLICATIONS

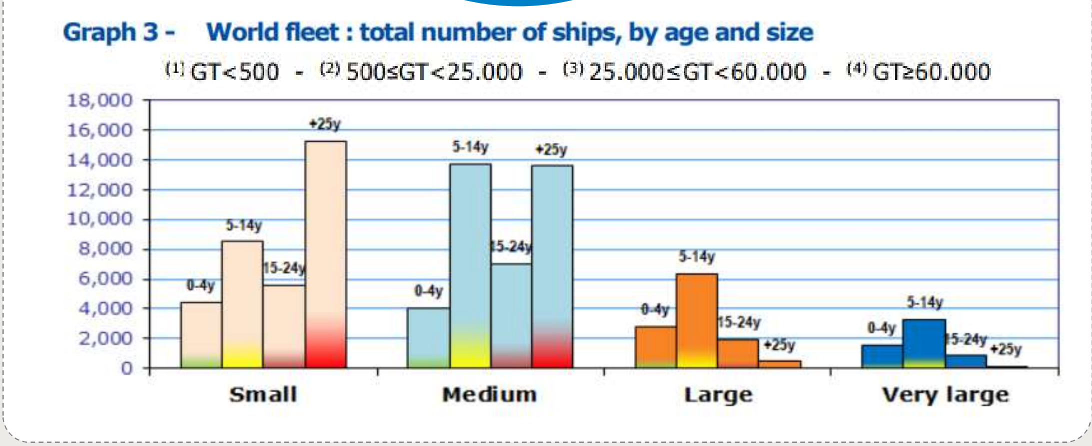
Ageing fleet, tighter emissions control, long range...

Many opportunities for hydrogen!

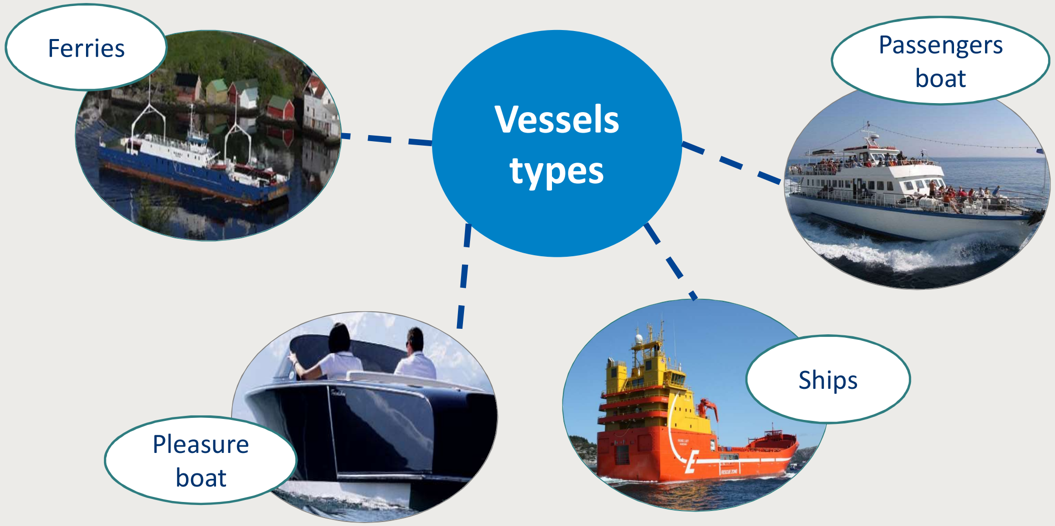
½ of world Ships' fleets are at least 15 years old

Emission Control Areas





Source: Equasis



EU policies for clean maritime industry

Future competitiveness goes hand-in-hand with greater environmental sustainability

Importance of the EU maritime sector

- EU controls 36% of the world fleet (in dwt)
- Gross added value of ~500G€/year and some 5.4million jobs
- New orders ~18G€ of for European shipbuilding in 2016

But…

- Maritime transport is responsible for ~2.5% of global GHG
- Shipping emissions predicted to increase by 50-250% by 2050
- Air quality issues at ports

So what is the EU doing about it?

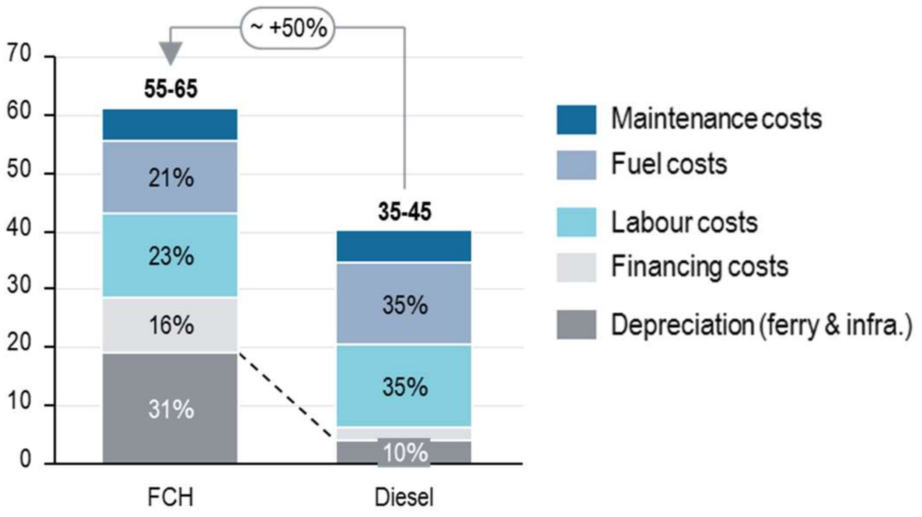
- **Regulations** on reduction of sulphur emissions (directive 2012/33/EU), deployment of alternative fuels infrastructure (directive 2014/94/EU)
- **Target to reduce EU's CO2 emissions** from maritime transport by at least 40% from 2005 levels by 2050, and if feasible by 50%
- **Policy**: Valetta declaration in March 2017
  - Decarbonisation
  - Digitalisation and automation
  - A world-class, competitive maritime cluster

1€ = 135 ¥

FCH ferries still with a ~50% premium price comparing with diesel

…while decreasing drastically harmful emissions

Estimated annualised Total Cost of Ownership (TCO) [€/nm]



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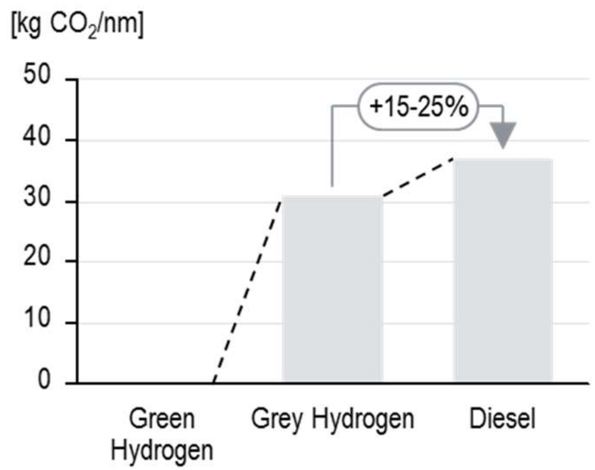


1€ = 135 ¥

FCH ferries, potentials and use case characteristics

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

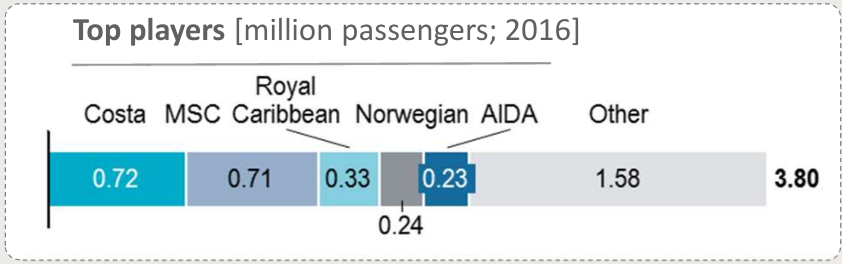
- Eventually reduced cost in harbors of countries with high electricity prices where vessels are not allowed to use diesel for electricity production and instead have to rely on external electricity
- Depending on the development of oil prices, lower TCO in the long run

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

Cruise ships is a strong sector in EU

Yet cities with inner-city cruise ship terminals are heavily affected by pollution



Impact of a large cruise ship (>3.000 passengers)

"Hotel load" for one stay of 10 hours is equivalent to:

- 60-120 MWh of energy supply
- 50-60 t of CO_2
- 25-30 compact cars in 1 year

Alternatives exist

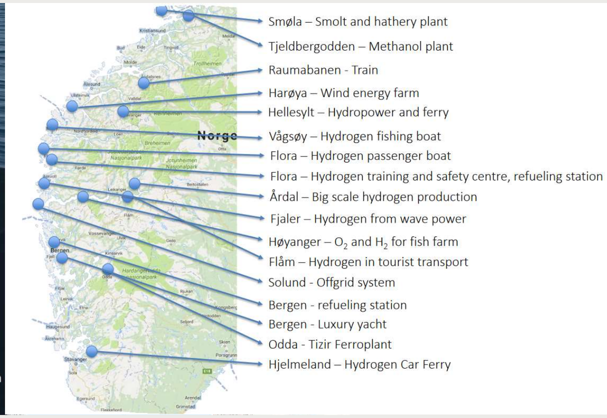
- On-shore energy via the port: sufficient supply and grid infrastructure must be in place
- Separate on-board engines for in-port hotel services: small additional diesel/MGO powered engines and FCH applications

Norway – Green H_2 and linkage with local food industry

Cross-connecting the value chains

40% emission reduction by 2030

2015 Norwegian Environment Agency report
- *"Ferries and boats must be battery driven. Large ships, like cruise liners, must have capability for electricity charging at docks and run on hydrogen fuel or gas (LNG)"*



Strenghts

- Surplus or curtailed renewable energy (wind and hydropower)
- Industry sector is using, producing or have H2 as a by product
- Maritime public transport is the worst polluters in the transport sector on the West Coast
- Strong clusters with world leading companies
- Possibilities for public and private H2 consumers

Hydrogen maritime ecosystems

- Fisheries and aquaculture are strong export industries
- Great demand for O2 and heat in salmon production
- Often located near a fresh water source/hydro power plant

Delivering O2 and heat for salmon production, and H2 to the service vessels

Germany – methanol, as preferred fuel

Focus in studying the diversity of fuels and FC types for both on-board power and propulsion

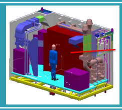
e4-Ships Phase I

- Cooperation between German yards, ship operators, manufacturers of fuel cells, equipment suppliers and classification societies
- 39M€ during 2009-2016
- Technology, Safety, codes and standards

Conclusions - e4-Ships Phase I

- Fuel cells in ships work, results are promising
- Next step is to look at market, infrastructure and costs
- All 4 projects are continuing for Phase II
- **Regulations, Codes & Standards** need continuous work
- Interets in FC for maritime application is rising

e4-Ships Phase II is starting

	SchIBZ	*PA-X-ell*	*RicerCell*	*ELEKTRA*
Project Management	*ThyssenKrupp Marine*	*Meyer Werft*	*Meyer Werft*	*BEHALA*
Application Area	*Sea*	*Sea*	*Inland*	*Inland*
Application	*Multi purpose vessels, yachts*	*Passenger ships, cruise ships*	*Passenger ships, river cruiser*	*Tug boat*
Type of Use	*On-board power supply*	*On-board power supply*	*On-board power supply & propulsion*	*Propulsion*
Fuel	*Diesel, optional methanol, LNG*	*Methanol, optional LNG*	*Methanol, optional LNG*	*Hydrogen*
Fuel Cell Type	*SOFC*	*HT-PEM*	*HT-PEM*	*Still open*
Ships				

EU support – H2020 invests in maritime applications

PURE aims at developing auxiliary power units (APUs) for recreational yachts

DURATION: 2013-2016
FCH Funding: ~1.6M€

MARANDA: emission-free hydrogen fuelled PEMFC based hybrid powertrain system developed for marine applications and validated on board the research vessel Aranda

DURATION: 2017-2021
FCH Funding: ~3M€

BIG HIT

A hydrogen territory in the Islands of Scotland by implementing an ecosystem of hydrogen production, storage, transportation and utilization for heat, power and mobility.

DURATION: 2016-2021
FCH Funding: ~5M€

\+

2018

- Mid-size passenger ships of inland freight
- FC for port/harbor ecosystems

- 5M€
- 4M€

2019

- Next Generation Propulsion for Waterborne Transport >5MW on-board power

- 3-5M€

PURE

Development of auxiliary power unit for recreational yachts

Objectives and specifications

- Demonstrate the market readiness of the technology
- Develop a integrated system
- Create a **0.5kW HT-PEMFC stack and an integrated LPG/propane reformer**

Achievements

- An integrated 0.5kW, light weight (17.5 kg) and small (25 L) system
  - 60% size reduction
  - 37% weight reduction
- **Tested over 800 hours**

pure
auxiliary power unit for recreational yachts

FCH JU Project - MARANDA

Prove the technical performance, demonstrate the economic feasibility

Highlights

- **PEMFC 165 kW (2 x 82.5 kW AC)** fuel cell powertrain (hybridized with a battery) with a **mobile hydrogen storage container** (80 kg CH2) on board the research vessel Aranda
- Emphasis: **air filtration, hydrogen ejector solutions**, **full scale freeze start testing of the system**.

KPIs

Fuel to electric efficiency
50%

freeze start capabilities
from -35°C

operating temperature
[-32°;+50°]

system cost
< 1000€/kW*

Fuel cell stack life
15 000h

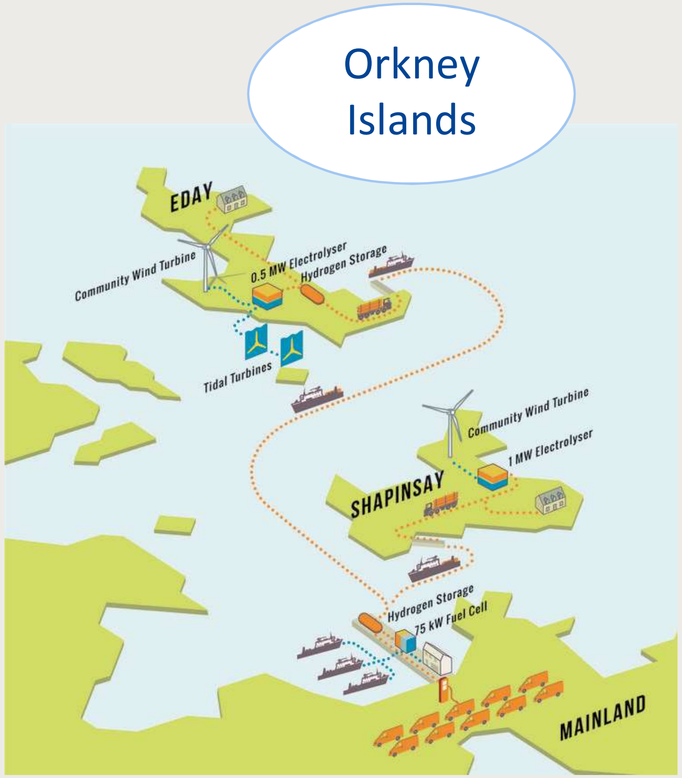
Fuel cell systems conditions
able to withstand the shocks, vibrations, saline environment and ship motions

Aranda vessel test platform

- Ice-going vessel, year-round operation
- Extensive marine-environment testing on-board
- Put into class (DNV-GL) as part of vessel overhaul
- Video: https://adobe.ly/2xCHLqC

BIG-HIT Project - “Hydrogen Territory”

Building Innovative Green Hydrogen Systems in Isolated Territories



Use of renewable energy curtailment

In 2016 renewable electricity generation **produced 120% of the islands annual electricity demand**

Hydrogen from wind and wave

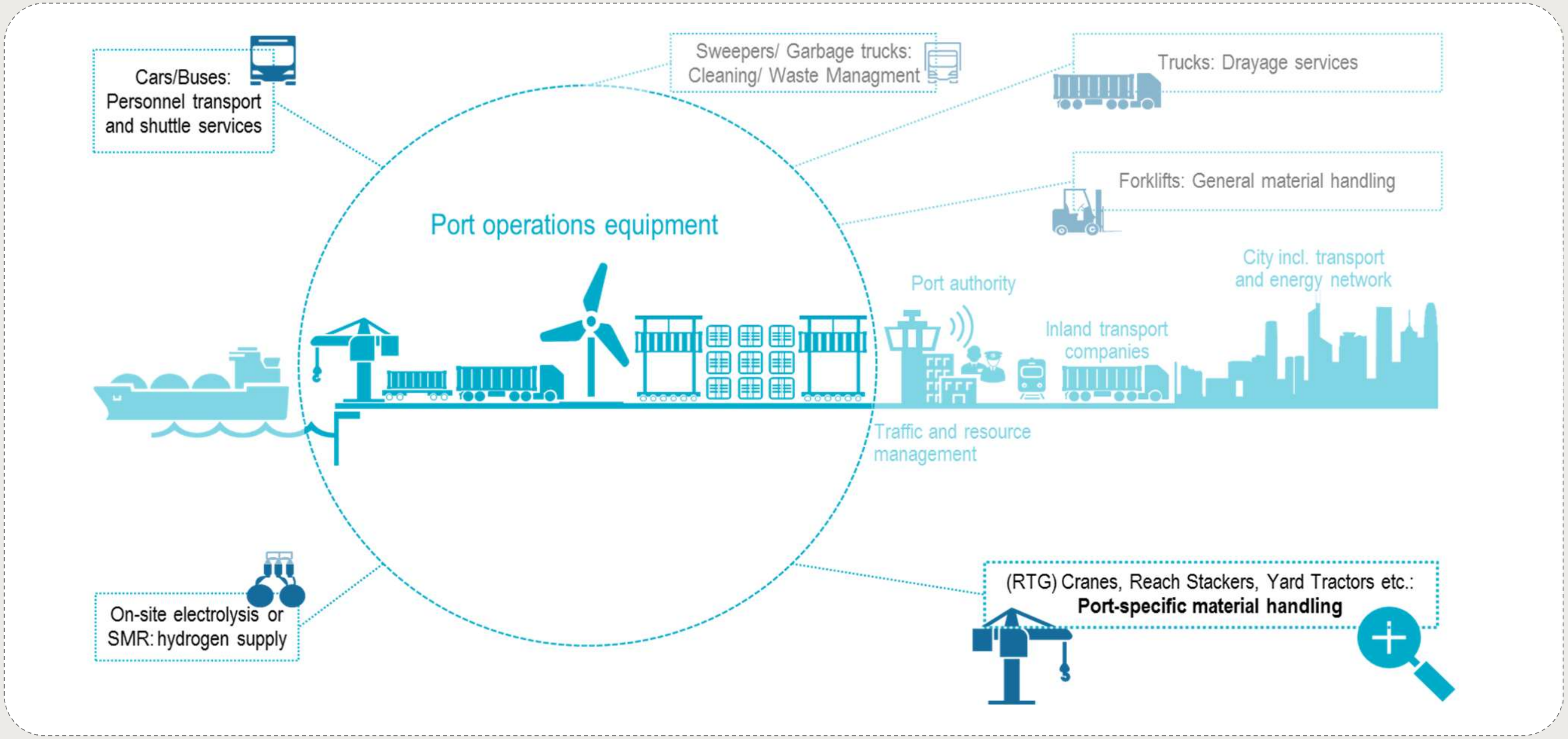
- Integration with wind and tidal turbines
- 2 PEM electrolysers (**1MW & 0.5MW capacity**) producing **~50T/year of H**2.

Port ecosystem

- 75kW PEM for cold ironing (3 ferries) and CHP at harbours offices and marina
- CHP for 2 schools, a HRS for 10FCEvs

Future project on port terminal ecosystems

Linking mobile equipments (on sea and land) with infrastructure



Workshop, and Regulation, Codes and Standards

International cooperation is key to foster introduction of H_2 ships

Workshop FC and H_2 in maritime applications

- Awareness raising on FC and H_2, technical State-of-the-Art
- Work needed on standards, protocols, permission framework for hydrogen handling in harbours or in boats

Regulation, Codes and Standards

- Projects having specific tasks on RCS gaps for FC and H_2 in maritime applications
- Creation of a RCS Group
- **There is a crucial need to adress RCS at IMO level**

International Cooperation

- Member of IEA – HIA – Task 39 Hydrogen in Maritime Transport
- FCH projects are open to cooperation

How to best deploy hydrogen and fuel cells in maritime ?

International cooperation

- Continue technological development on **multiples fuels and FC types aiming at decarbonisation**
- **Technology** should **focus on** both CAPEX **costs**, and indirect costs
- **Share knowledge across heavy duty sectors** (buses, trains, trucks, etc.) notably on refuelling infrastructures and FC behaviour
- Consider **harbours as « ecosystems »**, individual solutions exist, it is the combination of all which must be proven
- Investigate synergies by **sector coupling**: ships, terminal logistics, trains, public transport
- Global cooperation is needed at IMO for **crucial development of the RCS for H_2 ships**
- **Customer awareness, acceptance issue and safety** are unavoidable

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