Making Hydrogen and Fuel Cells an everyday reality

Lionel Boillot
Tokyo, 21st February 2018
Human responsibility to address climate change

CO₂ emissions and pollution are a common problem

A) CO₂ problem, utilize renewables and improve efficiency
- Transport CO₂ evolution on yearly basis vs 2030/2050 decarbonisation targets
- EC energy outlook – Transport CO₂ 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**
  - CO₂ 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 H₂ infrastructure targets (optional) by 31 December 2025
The EU vision

The overall target is 60% cut in transport CO₂ emissions by 2050

Specific targets are:

- Conventionally-fuelled cars in cities: -50% (By 2030 - 2050)
- Aviation uptake of low-carbon sustainable fuels in aviation: 40% (By 2050)
- EU CO₂ maritime bunkers: -40% (or 50%) (By 2050)
- 50% freight on rail (2050)

* EU transport White Paper 2011
Strong public-private partnership with a focused objective

EU Institutional Public-Private Partnership (IPPP)

Fuel Cells & Hydrogen Joint Undertaking (FCH 2 JU)

Industry grouping
More than 130 members
50% SME

Research grouping
over 68 members

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 ...

226 projects supported for 841 M€

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/id/?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$_2$eq
- Strong industry and public/private operators
- About 900,000 direct jobs (operators only)

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

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

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%
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**

<table>
<thead>
<tr>
<th>Stakeholders involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional train operators, regional transport authorities</td>
</tr>
<tr>
<td>Rolling stock OEMs as well as operation and maintenance providers, fuel cell suppliers</td>
</tr>
<tr>
<td>Hydrogen suppliers and infrastructure providers</td>
</tr>
<tr>
<td>Permitting and licensing authorities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand and user profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>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)</td>
</tr>
<tr>
<td>Differing topographic profiles (e.g. tunnels of 5-10 km each) and large number of stops/stations (15-50)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deployment requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply infrastructure able to supply large quantities of hydrogen per day, e.g. through local production</td>
</tr>
<tr>
<td>Hydrogen storage, regional/local distribution networks</td>
</tr>
<tr>
<td>Network of hydrogen refuelling stations along relevant train routes, i.e. in train depots</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key other aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elimination of need for engine idling at train stations due to fuel cell auxiliary power units (contrary to diesel units)</td>
</tr>
</tbody>
</table>

**Benefit potential for regions and cities**

**Environmental**

| > Zero tailpipe emissions of pollutants (esp. \( NO_2 \)) 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 |

**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
Germany, already testing H₂ trains
A precursor in the deployment of H₂ 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

- 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 ¥

Norway

United Kingdom

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

No projects, but looking into the best business cases

### 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

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

Many opportunities for hydrogen!

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

Source: Equasis

Graph 3 - World fleet: total number of ships, by age and size

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
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, CO₂)
  - 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 CO₂
- 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 H₂ 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)”

Strengths

- 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
- Interests in FC for maritime application is rising

---

e4-Ships Phase II is starting
EU support – H2020 invests in maritime applications

**PURE**
- Aim: Developing auxiliary power units (APUs) for recreational yachts
- Duration: 2013-2016
- FCH Funding: ~1.6M€

**MARANDA**
- Description: 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 H2IT**
- Aim: 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€

**Big HIT +**
- 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€
Objectives and specifications

- Demonstrate the market readiness of the technology
- Develop an 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
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°C;+50°C]
- 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 H2.

**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 H₂ ships

Workshop FC and H₂ in maritime applications

- Awareness raising on FC and H₂, 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 H₂ in maritime applications
- Creation of a RCS Group
- There is a crucial need to address 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 H₂ ships**
- **Customer awareness, acceptance issue and safety** are unavoidable