“Technologies for hydrogen fueled trains”

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DRIVERS THAT MAKE ALTERNATIVE TECHNOLOGIES NECESSARY

- Political strategy: more and more support for the environment
- Increase in diesel and medium / long-term traction prices
- Rules for the protection of noise pollution. Emissions and noise are socially less tolerated
- Technological development supports sustainable public transport

- Reduction of CO₂ emission
- Alternative fuel
- Noise pollution
- Urban transport without emissions
THE FCH JU PROGRAMME STRUCTURE

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, …)

FCH 2 JU:
Total Budget: 1,3 bn €
EC contribution: 646 m €

Source: FCH JU 2018
Energy
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- Road vehicles
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Cross-cutting
- E.g. standards, safety, education, consumer awareness ...

227 projects supported for 844 m€

Source: FCH JU 2018

Similar leverage of other sources of funding: 886 m€
HYDROGEN: ESSENTIAL TO DECARBONIZE EUROPE

Enable large-scale renewables integration and power generation

Enable the renewable energy system → Decarbonize end uses

Distribute energy across sectors and regions

Act as a buffer to increase system resilience

Help decarbonize transportation

Help decarbonize industrial energy use

Help decarbonize building heat and power

Serve as renewable feedstock: steel, refineries, chemicals

SOURCE: Hydrogen Council
Rail and Maritime are discovering Hydrogen and Fuel Cells
The first business models are appearing

42% of the European railway is not yet electrified, Hydrogen Trains needs half of the investment vs full electrical train with catenary.

Maritime and ports are looking, now more and more towards Hydrogen, the first demo projects are appearing.

Source: FCH JU 2018
DEMOS AND PRECOMMERCIAL PRODUCTS EXIST IN SEVERAL SEGMENTS, INITIAL STEPS TOWARDS THE COMMERCIALIZATION

Source: « UPSCALING » Hydrogen Council 2017
Example of integration layout

- Innovative solutions
- System and dynamic modelling
- Advanced controls, FDIR, predictive tools
AFC - Concept

- For the electrolyte, it is utilized an alkaline solution mixed with a porous matrix acting as a support, usually KOH.
- Concentration of the electrolyte depends on the working temperature of the cell.
- Electrodes usually made of nickle or silver.
- Catalyst layers usually made of Cobalt.

Source: https://lepa.epfl.ch/page-139282-en.html
• **30 bar** high pressure production
• **Reduced foot print** : 44 m² / MW
• **BOP optimization**
• **High purity of H₂** : 99.9%
• **Cosφ > 0.9** from 15% to 110% of load range
• **High efficiency with High current density** @ 9.000 A/m²
• **Fast dynamic response enabling Service System**
  
  Nominal Load : 0% to 100% < 30 sec.
  Off Peak : 100% to 0% < 5 sec.

• **Mature and industrialized product**
• **Optimized CAPEX and OPEX**

**An innovative solution combining the reliability of ALKALINE and the flexibility of PEM**

**Key Learnings:**
ALKALINE brings robustness
30 bar is a must
Efficiency is key
Flexibility brings value
Modularity is important
MCPHY WILL HAVE INSTALLED

13.5 MW
OF HIGH CAPACITY ELECTROLYZERS
= 6 TONS OF CLEAN HYDROGEN PRODUCED PER DAY

Focus on Alkaline Pressurized Technology

INSTALLED ELECTROLYSERS’ CAPACITY WITH MCPHY TECHNOLOGIES

- Audi | 6 MW | 2013
- Prenzlau | 0.5 MW | 2013
- H2Ber | 0.5 MW | 2014
- Hebei | 4 MW | 2017
- EnergieDienst | 1 MW | 2017
- Jupiter 1000 | 1 MW | 2018
- RAG | 0.5 MW | 2018

- Alc, ATM
- Alc, ATM
- Alc, 30 b
- Alc, 30 b
- Alc, 30 b
- Alc, 30 b + PEM
- Alc, 30 b
CH2P project
(Cogeneration of Hydrogen, Heat and Power)
has the objective to realize a new technology
at high efficiency and limited impact on carbon emissions,
able to generate hydrogen and power
for use in refueling stations of the next future
impacting the sustainability of the transport sector

The research leading to these results has received funding from the European Union’s H2020 Programme (H2020/2014-2020) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant agreement nr. 735692.
AT THE CORE OF CH2P – reforming + fuel cell

- CORE OF THE CELL WORKING AT 850°C
- INPUT AIR AT THE CATHODE AT 650°C
- CERAMIC MATERIALS
- HIGH EFFICIENCY WITH WASTE HEAT RECOVERY

CH2P combined hydrogen, heat and power generation

- REFORMER
- CONTROLLED FUEL UTILIZATION
- HYDROGEN COMPRESSION AND PURIFICATION (PSA)

www.ch2p.eu
<table>
<thead>
<tr>
<th>KPIs</th>
<th>unit</th>
<th>SMR</th>
<th>Electrolysers (ALK, PEM)</th>
<th>CH2P (project targets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>%</td>
<td>50 - 52</td>
<td>50 - 74</td>
<td>75 (up to 90 in case of waste heat availability)</td>
</tr>
<tr>
<td>Lifetime</td>
<td>years</td>
<td>15</td>
<td>20</td>
<td>10 (system)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 (stack)</td>
</tr>
<tr>
<td>CAPEX</td>
<td>EUR/kW</td>
<td>2.500 – 4.200</td>
<td>ALK: 630 (max 900) PEM: 1000 (max 1300)</td>
<td>5.000</td>
</tr>
<tr>
<td>Output pressure</td>
<td>Bar</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Hydrogen purity</td>
<td>%</td>
<td>99,999</td>
<td>99,5 – 99,999</td>
<td>&gt;99,999</td>
</tr>
<tr>
<td>TRL</td>
<td></td>
<td>Demo / Pre-Commercial TRL6 – TRL8</td>
<td>Ready / Market introduction TRL8</td>
<td>Engineering / Prototypal TRL6</td>
</tr>
</tbody>
</table>
Smart Ways for Intermittency Tolerance by multisource Continuous generation of Hydrogen

- **H2 Storage / Solid state**
- **Grid Balancing Power**
  - Power reserve
- **Green H2 Production**
- **(NG, biogas, P2G)**
- **GAS GRID**
  - Low cost production

- **ch2p**
  - NEAR ZERO EMISSION
  - HIGH EFFICIENCY
  - HIGH DYNAMICS
  - SECURITY OF SUPPLY

- **Reliable HYDROGEN**
  - From 0% to 100%

- **Reliable Power**
  - From 100% to 0%

- **HEAT**
  - Internally recycled
(i) GREEN HYDROGEN from LOW CARBON SOURCES

(ii) LOCAL HYDROGEN STORAGE for direct use of hydrogen or conversion to electric power (SOFC mode) for districts (small scale) or grid services (big scale)

(iii) OVERALL TECHNOLOGY COSTS, limited with ALL OPTIONS IN ONE CORE MODULE

(iv) SECURITY OF SUPPLY
Solid Oxide cells can have several options providing the technology with a very high flexibility:
- Can be run with several mixtures: methane, natural gas, syngas, biogas, biomethane
- Can be operated off-grid
- Can be hybridized with systems in need of both hydrogen (fuel cells) and power (batteries)
HYDROGEN REFUELING STATION

ALTERNATIVE FUELS REFUELLING STATIONS

THE CH2P MODEL CAN ALLOW A SINGLE TECHNOLOGY EMBEDDED IN A REFUELLING STATION FOR MOST OF ALTERNATIVE FUELS
Coradia iLint: the zero emission train

DEVELOPED THROUGH THE NATIONAL FUNDING PROGRAMME
“Nationales Innovationprogramm Wasserstoff und Brennstoffzellentechnologies (NIP)”
SUPPORTED BY THE GERMAN MINISTRY OF TRANSPORT
Coradia iLint: A TRAIN POWERED BY FUEL CELLS

- An alternative to diesel
- A cheaper option than rail line electrification
- Emissions: only steam and condensed water
- Up to 300 seated / 150 seated passengers
- 140 km/h

Connect to YouTube: https://www.youtube.com/watch?v=O3bUE9uHkgM

An important technological breakthrough for the future of rail transport
Coradia iLint: THE 1ST HYDROGEN TRAIN

- Based on the consolidate LINT platform
- Hydrogen Fuel cells technology (240 KW each) and electric drive
- Li-Ion batteries with innovative "energy management"
- Increased power during acceleration phases
- Energy recovery during braking
- Auxiliary converters
- Autonomy up to 1000 km

ZERO EMISSIONS – ZERO NOISE – SUSTAINABILITY
## Coradia iLint: TECHNICAL DATA ALONG THE FIRST REGIONAL LINES IN GERMANY

<table>
<thead>
<tr>
<th></th>
<th>Hannover – Bad Harzburg</th>
<th>Köln – Marienheide</th>
<th>Hamburg – Neumünster</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length / nr. of stations</strong></td>
<td>195 km / 16</td>
<td>133 km / 28</td>
<td>129 km / 52</td>
</tr>
<tr>
<td><strong>Running time</strong></td>
<td>2 h 38 min</td>
<td>2 h 48 min</td>
<td>2 h 54 min</td>
</tr>
<tr>
<td><strong>Energy consumption, net kWh</strong></td>
<td>584,2 kWh</td>
<td>479,5 kWh</td>
<td>482,3 kWh</td>
</tr>
<tr>
<td><strong>H₂ consumption, Along the line</strong></td>
<td>40,2 kg</td>
<td>32,9 kg</td>
<td>32,4 kg</td>
</tr>
<tr>
<td><strong>H₂ consumption, km</strong></td>
<td>0,21 kg/km</td>
<td>0,25 kg/km</td>
<td>0,25 kg/km</td>
</tr>
<tr>
<td><strong>Full tank range, km</strong></td>
<td>821 km</td>
<td>685 km</td>
<td>674 km</td>
</tr>
</tbody>
</table>

- Rapid fueling: 7,2 kg/min, 15 – 20 minutes for full fueling
- Class 4 Hydrogen tanks: 99,99% purity level
- 350 Bars pressurization without cooling

**ALSTOM**

*Designing fluidity*
Coradia iLint: development program

- Phase 1: Development and testing of the H2 traction system completed 03/2016
- Phase 2: Testing of hydrogen iLINT trains 2016 - 2018
  - Design, production, commissioning & validation of 2 iLINT 54
  - Certification for commercial service in Germany
  - Start of tests in Lower Saxony (LNVG partner)
- Phase 3: Commercial service - Passenger transport 2018 - 2019
  - 2 trains in daily commercial service in North Germany

A mature product: commercial service from 2019 in Germany with fleets of 10 to 20 trains
Coradia iLint: development program already in Phase 2

2 completed trains / 1st train presented at Innotrans 2016
HYDROGEN TRAINS: THE BUSINESS MODEL

Implementation and management of the hydrogen infrastructure (partners)

Alstom Maintenance Full Service (25-30 years)

Supply of the Alstom train fleets

We provide availability

The operator manages rolling stock we guarantee maintenance
Electrolysis – management modes

Model 1  
**Power intensive**
- Power scale at production
- Compressors size
- Storage tanks size (hh – dd)
- Hybrid Connection with natural gas grid
- Availability for high power
- High CAPEX and OPEX
- Limited CAPEX and OPEX

Model 2  
**Energy intensive**
- Power scale at production
- Compressors size
- Storage tank size (dd – ww)
- Hybrid Connection with natural gas grid
- Limited availability of power generation
- Limited CAPEX and OPEX
- Higher CAPEX and OPEX
Conclusions

Hydrogen trains cover a **wide sector in EUROPE**, mostly covering the Regional lines operated by DIESEL

In the market are yet available technology solutions with **competitive performances and costs**

Several **EU countries have started** to install, commission, plan hydrogen fueled trains

Several **new options will be developed** in the next future improving hydrogen production, storage and distribution solutions, at a full market readiness. This is expected in the next 5 – 7 years

Considering the novel technologies, they would benefit of **a policy support** and incentives (defiscalization measures, indirect measures) to open the markets
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