Workshop
Fuel Cells and Hydrogen
In the Railway Environment
Technology Status prior to railway developments

Hydrogenics HD Power Modules provide a robust and flexible platform for zero-emission heavy mobility applications.

- Proven track record for superior performance, durability and reliability in bus, truck, and other heavy and light mobility since 2002
- Robust stack architecture: low pressure, dry/dry features (no humidifiers since 2009)
- High durability high cycle life components, ruggedized,
- > 10,000+ hour stack lifetime since 2009 with unlimited start/stop cycles since 2005
- Modularity enables wide and flexible kW range
Current Technology Status for Passenger Rail

The Alstom Coradia iLint has received Certification Approval by the EBA and has started regular Regional Bahn service.

- 2014/2015 Technical Specifications defined
- 2014/2015 Applicable Codes and Standards identified
- 2015/2016 Prototype hybrid system run in the test bench (fuel cell, power electronics, battery, electric drive and controls)
- 2017 Fuel cell systems integrated into two Pre-Series Trains for test track and testing on the public rails
- 2018 Certification by the German Railway Authority (EBA) Awarded ~ TRL Level 8
- Two trains in regular Regional Bahn service – Weser Elbe Netz (RB33: Cuxhaven - Bremerhaven - Bremervörde - Buxtehude)
Challenges for Rail Applications

- The Rail Application is one of the most demanding in terms of Reliability, Availability, Maintainability and Safety
- Demanding Duty cycle. Vehicle operation for 30+ years
- Railway Codes, Standards, etc., extremely demanding (EMC, Shock & Vibe, Ingress Protection, Welding, QA Requirements …)
- Key Constraints: Reliability, Durability, Fuel Efficiency, Weight, Compactness and Noise
Gen 3.0 Enhancement examples

- External coolant strainer no longer required
- Advanced cold start routine
- High isolation resistance
- Long life H2 recirculation unit
- Simplified H2 supply system
- New H2 purge architecture

<table>
<thead>
<tr>
<th>G2.0</th>
<th>2011</th>
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</thead>
<tbody>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>G3.0</th>
<th>2019</th>
</tr>
</thead>
</table>
Released 2019-03… HD50

Rated Power: 50 kW

- Increased power in a monolithic stack module
- Increased power density

And for modular combinations:
- Reduced weight
- Less interconnection
- Increased simplicity
- Integration space gains
Ongoing & Future

Continuous improvement:

- Technical
- RAMS
- Production
- Costs
- TRL 9
Thank you for your engagement

The human factor

Leadership / Experience / Technology

We’re Ready.
Linde Hydrogen FuelTech
Competences, technologies & products
Brussels, May 17th 2019

Making our world more productive
Hydrogen: a game changer in industry
H2 plays a central role as energy carrier

H2 emerging as **energy carrier**... ...with **mobility applications** as first commercial users

- De-carbonization transforms the energy industry; H2 expected to play an important role as energy carrier
- Applications going to transform to H2 at different paces; with H2 mobility / transportation being the frontrunner

* Source of graph: H2 Council, units: Exa Joule, 1 EJ = 7 m tons H2 = 80 Bn Nm³ H2 ** Source of graph: H2 Council
# Hydrogen: a game changer in mobility

## Linde Gas – operational models

### Network

**Network of H2 refueling stations** for seamless mobility for Fuel Cell Electric Vehicle (FCEV) passenger cars

- In case of technology break-through (successful customer value proposition), high growth potential
  - High upfront investment in infrastructure necessary, with low utilization rates initially (business case challenge)
  - Strong & continuous buy-in from multiple players required (OEMs, infrastructure & utility providers, authorities)

### Back-to-base

Buses, urban delivery trucks, intralogistics vehicles, taxis, car fleets with regular routes & **H2 refueling at a fix depot** (base)

- Upfront investment in infrastructure limited to one (few) H2 station(s) at central depot
- High utilization and predictable H2 demand allowing for economically attractive business cases
- Strongly positive impact on urban environment (local emission free, noise reduction) already with first project
  - Vehicle availability and costs
Linde technology along the hydrogen value chain. Linde Hydrogen FuelTech is the leader in hydrogen fueling infrastructure.
Linde technology along the hydrogen value chain.
Linde Hydrogen FuelTech is the leader in hydrogen fueling infrastructure.

Distribution & storage

Trailer & Tanks
(Trailer: 300 bar GH2 or LH2 or 500 bar GH2, tanks for GH2/LH2, stationary & mobile)

or

Pipeline
(e.g. from producer)

5/28/2019
Linde technology along the hydrogen value chain.
Linde Hydrogen FuelTech is the leader in hydrogen fueling infrastructure.

---

**Fueling**

**Compression**
(e.g. ionic compressor station)

or

**Pumping**
(e.g. cryopump station)

---

Core competence of Linde Hydrogen FuelTech
First to world
Linde Hydrogen FuelTech is building the first station for hydrogen passenger trains

Alstom, Bremervörde/Lower Saxony, Germany

- H2 source
- H2 distribution
- Trailer
- Electricity
- Electrolysis
- HRS
- Compressor
- Storage
- Dispenser (e.g. 350 bar)
Thank you for your attention.

Linde AG
Dr. Peter Haider
Peter.s.haider@linde.com

Making our world more productive
Coradia iLint
- Hydrogen train

17-05-2019
Coradia iLint

Coradia iLint and the technological challenges

Homologation and market introduction

Next steps
Coradia Lint: Diesel platform from which FC train was developed.

LINT 27: 47 trains
LINT 41: 688 trains
LINT 54: 203 trains
LINT 81: 72 trains

More than 1000 Coradia Lint Diesel Trains sold

... a reliable and service proven base for the first hydrogen FCMU
Coradia iLint : Design criteria

- Use proven reliable product as base
- Retain the same train dimensions
- No significant changes in weight/center of gravity
- Re-use of architecture and main components
- Maintain performance (acceleration, range, etc)
- Avoid technical equipment in passenger areas
- No adverse impact on passenger experience and comfort
- High energy efficiency

The goal: The FCMU can operate the same services as the DMU
Fuel Cell Trains: The Technology – transformation from Diesel to FCMU

Removal of diesel propulsion system

Integration of electrical propulsion system

Diesel powerpack

Diesel tank

Hydrogen tank

Fuel cell pack

Battery pack

Converter system

Electrical traction motor
Agenda

1. Coradia iLint
2. Coradia iLint and the technological challenges
3. Homologation and market introduction
4. Next steps
Coradia iLint
Coradia iLint: Diesel replaced with hydrogen and fuel cell technology

- Replacing diesel traction by electrical traction system
- Primary energy supply by hydrogen fuel cells
- Intermediate energy storage by Li-Ion batteries
  - to boost during acceleration
  - to recover kinetic energy during braking
- All electrical auxiliary supply

Modern energy supply and storage system combined with intelligent energy management
Coradia iLint - the components: -> fuel cell composition, -> hydrogen storage, -> lithium-ion battery composition.

Fuel cell composition

Hydrogen storage

Storage at 350 bar (at 15°C)

Lithium-ion battery composition
Agenda

1. Coradia iLint
2. Coradia iLint and the technological challenges
3. Homologation and market introduction
4. Next steps
Coradia iLint: Validation and certification process
(as completed in Germany)

Core subjects
- Running dynamics
- Crash
- Brake
- Wheelsets
- Train radio / Train protection

Technical Specification for Interoperability (TSI)
- LOC & PAS
- SRT
- PRM
- NOI

Notified National Technical Rules
- Running dynamics
- Fire Safety
- EMC
- Functional Safety
- Labeling
- and some others

Safety assessment on Common Safety Methods (CSM)
Coradia iLint: From certification to regular passenger service

- **Certification** for passenger service in Germany received on **11.07.2018**

- **Daily passenger service** according to regular time table since **17.09.2018**
Two pre-series vehicles in passenger service since 17.09.2018

- Daily passenger operation
- Mixed operation with DMU and H2 trains
- Line length 119 km
- One mobile refueling station in Bremervörde
Interims H2 fuelling station installed in Bremervörde during operation of the Coradia iLint pre-series trains

Interims solution for train trial operation only
Agenda

1. Coradia iLint
2. Coradia iLint and the technological challenges
3. Homologation and market introduction
4. Next steps
Coradia iLint - Timetable

Development

07/2014
Start iLint Project

Pre-series vehicles / First trains

2016
Production of two pre-series vehicles

2018
Homologation in Germany

Orders

2018-2020
Pre-series vehicles in passenger Service

2014 - 2015

2016

2017

2018

2019 - 2021

2021/2022
Start of fleet operations

2014 - 2015

2016

2017

2018

2019 - 2021

2021/2022
Start of fleet operations
Coradia iLint – next steps

- Passenger service mileage with pre-serial trains
- Development of the hydrogen infrastructure
- 2021/2022 Start of operation of fleet operations
- Homologation in other European countries
Questions?

www.Sli.Do: #HydrogenTrain
The Mireo Plus –
One platform for two hybrid technologies

Mireo Plus
All advantages of the Mireo platform

Mireo Plus B
A modular battery drive system

Mireo Plus H
A modular battery and fuel cell drive system
Our hybrid Traction kit – Overview of innovations

**HD8 next gen. fuel cell**
- 50% higher power density
- Higher lifetime
- Low LCCs
- 5% improved efficiency rate

**H₂ storage**
- Modular concept
- +10% H₂ storage capacity

**Hybrid control SW**
- Optimized operation by predictive E-Management
- ~ 5-15% energy saving

**Powerful battery family**
- LTO safe battery cell chemistry
- High-power charging
- 15 years life time

**DC – DC chopper**
- SiC Technology (compact, light @ low losses)
Development overview of fuel cell system

**Phase 1**
*Test & system optimization*
- Modeling of key components and investigation of vehicle operation strategies
- System behavior investigation on a real system test set up (Co-operation)
- Deep dive view on improvement potentials

**Phase 2**
*Modular traction system*
- Definition of a vehicle concept based onto the improvement of the key components
- Development of a FC system of next generation
- Development and detail specification of the sub components

**Phase 3**
*Vehicle integration & safety*
- Development of mechanical designs & interfaces
- Development of a mission management vehicle control system
- Safety management & certification preparation
- Support by ext. studies

**Funding project**

2017

2020
H2 Traction System Development
Fuel Cell System Design and Optimization Siemens - Ballard

- System design and preparation
- Concept design and system test
- Integration and commissioning

Hardware design
Concept device for system test
Prototype fuel cell for first train
Mireo Plus H –
our solution for large scale networks

- H₂ fuel cells HD 8 next gen with storages of Type IV cylinders
- Optimized for large scale networks (> ~120 km) one time refilling per day
- Two configurations for different ranges and applications
  - up to 800 km range: 2-car train with 120 seats
  - 800 up to 1,000 km range: 3-car train with 165 seats
Katrin Seeger
Project manager business development alt. drive systems for regional trains

Werner von Siemens Strasse 67
91052 Erlangen, Germany

Cell: +49 173 793 5641
E-mail: katrin.seeger@siemens.com

siemens.com
Hydrogen Train Project

May, 17th 2019

Samuel DESHAYS
samuel.deshays@sncf.fr
France rail network electrification

15 500 km
of electrified lines
(50% of network)

80 %
of SNCF rail operation is done
by electric trains

SNCF Réseau 2017

SNCF - Hydrogen Train Project
Improvement potential rolling stock

0.4% CO₂ of carbon emissions in transport is done through rail
(for shares: 11.2% of passenger.km and 10.5% of tons.km)*

20% of national traffic is operated by diesel

Regional train fleet
2300 trains

- 50% of TER train fleet is equipped with diesel engines, representing 40% of kilometres operated, mono mode and bi-mode
- Long rolling stock lifetime over 40 years: investment for rail decarbonisation is needed today in order to remain competitive against road transport and be ready for large fleet renewal

600,000 tons of CO₂ emission per year (2017)

0.4% CO₂ of carbon emissions in transport is done through rail
(for shares: 11.2% of passenger.km and 10.5% of tons.km)*

*Source: Stratégie Nationale Bas Carbone 2015
SNCF objectives toward decarbonisation

2015 – 2025

- Improve energy efficiency by 25%
- Improve carbon performance by 20%

2035

End of diesel train operations
Our portfolio is built to value the complementarity of solutions.
Innovation in the France $H_2$ train initiative

**Operation flexibility & market size**
- Bi-mode train $\rightarrow$ ability to operate on the whole rail network
- More capacity $\rightarrow$ suitable for medium traffic

**Integration on an existing train platform**
The demonstrator project involves the development of a new FCH train on an existing platform with the ability of retrofit in mind

**Remaining challenges**
- Available volumes $\rightarrow$ Limited $H_2$ autonomy
- Regulation/safety of catenary and $H_2$ in confined spaces
- New partnership model for refueling infrastructure, considering synergies without other usage
- Securing the financial roundtable to kick-off FCH train demo
## Hydrogen deployment roadmap

### French objective
**First train in 2022**

### 2022 - Demonstration and feedback
- **SNCF support the French regions in deploying a first mini fleet**
- **Generate feedback on operational conditions and economic performance**

### 2028 - Potential
- **Sustainability and replicable business model**
- **Adapted regulation**

### 2035
- **Large scale deployment**

- **French transport minister to develop a FCH train by 2022**
- **Specification of the train and conception of infrastructures**
#HydrogenTrain
Starting Point: Austrian Climate & Energy Strategy #mission 2030

- ÖBB CO2 Neutrality in the Mobility Sector in 2030
- ÖBB CO2 Neutrality in total in 2050
- Traffic Relocation Road2Rail (Capacity through Innovation & Technology)

- 4864 km Network (2/3 Electric)
- 10 HydroElectric PowerPlants
- 8+8 Terminals + Shunting Yards
- 80 Single Wagon Hubs

Production
- 6660 Trains daily / 800 Diesel
- 100 Diesel Locos Mainline
- 150 Diesel Shunters (80 E)
- 300 Diesel OTMs

Infrastructure
### SWOT: From 100% Green Electric to 100% Green Power with H2

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
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<tbody>
<tr>
<td>- Green Power</td>
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<td>- Reduced Maintenance</td>
<td></td>
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<td>- New Design &amp; Retrofitting</td>
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<td>- Packaging &amp; MGU</td>
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<tr>
<td>- Change of System</td>
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<td>- Increased Complexity (short term)</td>
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<tr>
<td>- Cost level</td>
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<td>- Green Hydrogen availability</td>
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<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
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</thead>
<tbody>
<tr>
<td>- Innovation Path</td>
<td></td>
</tr>
<tr>
<td>- 100% Green Power</td>
<td></td>
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<tr>
<td>- Integrated Hybrid System</td>
<td></td>
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<tr>
<td>- Sector Coupling Enabler</td>
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<tr>
<td>- New Business Models</td>
<td></td>
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<tr>
<td>- Stranded Investments</td>
<td></td>
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<tr>
<td>- Legal &amp; Safety hurdles</td>
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<tr>
<td>- Infrastructure restrictions</td>
<td></td>
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<tr>
<td>- Life Cycle</td>
<td></td>
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<tr>
<td>- (Overhead Electrification)</td>
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</tbody>
</table>
Timeline: From 100% Green Electric to 100% Green Power with H2

 Entwicklung  Construction  Demonstration  Testing

2019  2020  2021  2022

15 kW

Development  Construction  Demonstration  Testing

300 kW

Development  Construction  Demonstration  Testing

4-6 MW

H2 Storage 1,1 t  FC/Batt Hybrid  4-6 MW  1,5 kV DC
Thanks for Your Attention!
BEMU/hydrogen initiative for railways
Workshop FCH JU in Brussels 17 May 2019

Julian Mohr
Initiative on BEMU/hydrogen project for railways

- Motivation DB / SNCF (main promoters)
  - Fossil energy free operation on existing infrastructure (e.g. non or partially electrified)
  - Focus at first on regional traffic
  - With only new trains, it will take more than 30 years until all running diesel trains are substituted by new BEMUs / HMUs.
  - A large portion of the European Diesel fleet (appr. 4.000 Diesel trains) was identified to be suitable for a retrofit
  - Need for a component demonstrator for the use in battery trains, hybrid trains and hydrogen trains

- A separate working group was established, lead by DB / SNCF

- Participating Industry

ALSTOM | BOMBARDIER | CAF | SIEMENS | KNORR-BREMSE
The working group identified significant R&D-potential to be investigated

- Additional R&D-potential identified in the following clusters (in **bold**)

<table>
<thead>
<tr>
<th>R&amp;D-Cluster</th>
<th>Major Topics</th>
<th>Benefit / Effort</th>
</tr>
</thead>
</table>
| Use cases globally | • Market for storage systems  
• target costs / LCC-reduction  
• new services / increased availability  
• Migration strategy for rollout | to improve the knowledge of different solutions and use cases                   |
| Infrastructure * | • **Battery charging solutions for different applications**  
• Standardization of loading and refilling systems | to come to standardized and cost efficient solutions                            |
| Rolling Stock * | • **Battery technology for rail application**  
• weight and energy management  
• **technical roadmap on batteries and fuel cells** | to make the new technologies cheaper and more available                        |
| Operation      | • Adoption of time table with recharging requirements  
• **Performance and system optimization**  
• safety aspects                          | to optimize the operational integration of the new technologies                |
| Homologation   | • Simplification and standardization of homologation  
• Scope enlargement to trains and infrastructure | to make the homologation of new technologies faster, cheaper and more flexible |

* In coordination with EuroSpec-WG „Alternative traction“
The working group identified significant R&D-potential to be investigated

- **Use cases globally**
  - Reduction of System LCC expectations
  - Different new services offered by using battery / hydrogen trains
  - New “NEXT generation” battery / hydrogen trains or / and refurbishment of existing trains
  - Business models
  - Benchmarking with other transport modes
  - Adaption of rules for operation / train / infrastructure

- **Infrastructure**
  - Electricity: catenary and connector/plug; integration into national and European electric network
  - On-site hydrogen production from surplus power (wind or solar) incl. electrical grid stabilization
  - Hydrogen: filling stations integration into hydrogen “network”/supply
  - Ownership of loading facilities / investment / …
  - Standardization of loading and refilling systems/facilities
  - Safety (hydrogen filling)
  - Infrastructure/charging aspects
The working group identified significant R&D-potential to be investigated

- **Operation**
  - Driver training
  - Timetable optimisation
  - Performance (long distances/high speed/acceleration) vs. Costs (total and in comparison to today's DMU or...?)
  - Recharging time
  - Operation conditions (speed, disruptions, timetable, ...)
  - Definition of "range" (under which condition)
  - Safety (passengers, battery hazard, rescue of train)
  - System optimisation (i.e. battery on board or on ground)

- **Rolling Stock**
  - Train system level (e.g. system architecture, weight management)
  - Battery technology (e.g. increased availability, standardized interfaces)
  - Fuel cell and hydrogen technology (e.g. improvement of hydrogen storage system)

- **Homologation**
  - Standardisation
  - Reduction of costs and duration
  - Safety (e.g. hydrogen filling)
Possible future collaboration between S2R / FCH – Open to railway stakeholders

- **Motivation:** Identification and exploitation of possible synergies and avoidance of double-funding by the EC

- **Possibility to either make use of existing project results at FCH JU or to define topics for future collaboration involving**
  - Technology providers
  - Railway stakeholders
  - Policy makers

- **Results of the Roland Berger H2-study (presented today) may path the way for the future collaboration**
Many thanks for your attention
Workshop on the use of fuel cells and hydrogen in the railway environment

Brussels, 17th May 2019

D. C. Javier Navarro Espada
Technical Advisor Government of Aragón
Board Trustee of the Aragon Hydrogen Foundation

www.aragon.es
WHY HYDROGEN IN ARAGON?

• First Wind Farm in Spain installed near Zaragoza
• 2003: Great energy change approaching
• Reasons to support new hydrogen technologies:
  1. To take advantage of the renewable energy potential
  2. To take advantage of the region’s strategic situation
  3. A consolidated industry with sectors that could apply and develop new products
  4. Existence of a high level of involvement in research groups
• 2003: Workshop organized by Government of Aragon
  • Objectives:
    • To learn and to discuss about hydrogen as energy vector
  • Results:
    • **Strategy to develop Hydrogen technologies in Aragon**
    • **Foundation for the Development of New Hydrogen Technologies in Aragon**
WHY HYDROGEN IN ARAGON?

• The initiative to develop hydrogen technologies in Aragon was included as key strategic line:
  
  • 2\textsuperscript{nd} Research, Development and Knowledge Transfer Regional Plan of Aragon 2005-2008
  • **Aragon Research And Innovation Strategies For Smart Specialization (RIS3)**
  • **Aragon spatial planning strategies**
Introduction

Hydrogen Master Plans in Aragon

AIMS OF THE PLAN:

• GENERALS
  • To have a tool for the identification of opportunities in the new hydrogen technologies
  • To identify strategic lines for the region and to establish a timeline and actions plans

• SPECIFICS
  • To review the state of technology and define opportunities.
  • To identify specific projects for Aragon's SMEs.
  • To set across-the-board and general support actions
  • To carry out a survey with longer temporary horizons 2020-2050, defining the continuity of the strategic actions

TO PREPARE SME’S AND PROFESSIONALS FOR THE FUTURE

**GENERAL AIMS OF THE PLAN**

- To have a tool for the identification of opportunities of the new hydrogen technologies detected in Aragon, which will allow decisions to be taken on an institutional, business and academic level.
- To identify the strategic lines for the region and establish a time scale and actions plans for the deployment of these lines.
- To involve the Aragonese economy in the adoption of new technologies as a differentiating competitive positioning factor in the medium and long term.

**SPECIFIC AIMS OF THE PLAN**

- To review the state of the art of technology, current development, projects, reference companies in the sector, potential of the region in the matter, incipient markets and to define opportunities.
- To identify strategic lines of work for the coming years and opportunities for specific development for the Aragonese business sector.
- To set cross-cutting and general support actions: training, awareness-raising, technology transfer, protection and impact needed to guarantee the success of the deployment of the rest of the work lines (production, storage, transportation, distribution and applications.)
- To define actions oriented to achieve specific results through the establishment of monitoring indicators that allow monitoring effectively the objectives proposed.
- To carry out a survey with longer temporary timeframes 2020-2050, defining the continuity of the strategic lines drawn and setting the bases to reach these.

A. Production.

B. Storage, transport and distribution.

C. Applications.

D. Transfer of technology, protection and economic impact.

E. Training and awareness.
## Line of Work: Production

<table>
<thead>
<tr>
<th>ACTIONS</th>
<th>PROCEEDINGS</th>
<th>PRIORITY</th>
<th>INDICATOR 2018</th>
<th>INDICATOR 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Electrolysis</td>
<td>Optimization at the technical and cost level, through simulation and improved design of components and subsystems</td>
<td>HIGH</td>
<td>5 to 7</td>
<td>Systems developed and tested aligned with the European indicators for 2020 (TRL 7; CAPEX (M€/ton/day))</td>
</tr>
</tbody>
</table>

**ELYGRID**
- Improvements to integrate High Pressure Alkaline Electrolyzers for Hydrogen production from Renewable Energy

**ELYINTEGRATION**
- Grid integrated MHI Magnitude High Pressure Alkaline Electrolyzers for Energy Applications

**DEMO4GRID**
- Demonstration of AMR Protonic Alkaline Electrolyzer for Grid Balancing Services

**QualyGridS**
- Standardized qualifying tests of electrolysers for grid services

**ELY4OFF**
- PEM Membrane Electrolysis Fuel Cells for operation with ELY4OFF renewable installations
Line of Work: Storage, Transport and Distribution

<table>
<thead>
<tr>
<th>ACTIONS</th>
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<th>PRIORITY</th>
<th>INDICATOR 2018</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Study of development of storage systems for the market standards</td>
<td>Study on high pressure container development</td>
<td>MEDIUM</td>
<td>9 Completed studies and conclusions</td>
<td>To be determined</td>
</tr>
</tbody>
</table>
## Line of Work: Applications

<table>
<thead>
<tr>
<th>ACTIONS</th>
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<th>INDICATOR</th>
<th>2018</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Hydrogen integration in isolated grids</td>
<td>Design, development and implementation of projects with hydrogen technologies in isolated networks fed by RES</td>
<td>HIGH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design and optimisation of power electronics and communications and control systems for the production of hydrogen in isolated networks from RES</td>
<td>HIGH</td>
<td></td>
<td>Start of a demonstrator in Aragon</td>
<td>Know-how established in the industrial fabric of Aragon</td>
</tr>
<tr>
<td></td>
<td>Seek opportunities of demonstrators in isolated networks where hydrogen can be somehow integrated, preferably in rural areas. Identification of possible locations/end users</td>
<td>HIGH</td>
<td>6 to 7</td>
<td></td>
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</tbody>
</table>
About the railway

• We believe that the possibilities of application of hydrogen technologies find in the railway one of the niches of application more feasible and closer to the market.

• In Aragon we have a developed sector of bodybuilders.

• In Zaragoza there is an important railway construction company, CAF.

• The industrial subsector of transport equipment is the most important in our region.

• Among the shareholders of the Foundation are several companies from the industrial and services sectors related to the railway.

• The Foundation worked on the planning of mobility concepts for the Zaragoza tramway with the aim of eliminating the catenary at some point. And it already has some experience in the sector.

• The Aragones logistics sector, due to its geographical location, is one of the strongest in southern Europe.

• We have the technological capacity and the will to promote the application of hydrogen technologies in the railway sector.
## Line of Work: Transfers of technology, protection and economic impact

<table>
<thead>
<tr>
<th>ACTIONS</th>
<th>PROCEEDINGS</th>
<th>PRIORITY</th>
<th>INDICATOR</th>
<th>2018</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Impetus to standardisation systems</td>
<td>Participation in AENOR committees</td>
<td>MEDIUM</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Participation in European and international level initiatives (For example: CENELEC)</td>
<td>MEDIUM</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
# Line of Work: Training and Awareness

<table>
<thead>
<tr>
<th>ACTIONS</th>
<th>PROCEEDINGS</th>
<th>PRIORITY</th>
<th>INDICATOR</th>
<th>2018</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Studies on social perception and technology dissemination effectiveness</td>
<td>HIGH</td>
<td>Degree of acceptance</td>
<td>Hydrogen technologies are known by at least 50% of SMES in the region</td>
<td>Hydrogen technologies are known and accepted by at least 70% of SMES in the region</td>
</tr>
<tr>
<td></td>
<td>Perception and social acceptance study for companies</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Perception and social acceptance studies for society in general</td>
<td>HIGH</td>
<td>Degree of acceptance</td>
<td>Hydrogen technologies are known by at least 20% of the population of the region</td>
<td>Hydrogen technologies are known and accepted by at least 40% of the population of the region</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTIONS</th>
<th>PROCEEDINGS</th>
<th>PRIORITY</th>
<th>INDICATOR</th>
<th>2018</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Actions within the WHEC 2016</td>
<td>MEDIUM</td>
<td>No. of participants</td>
<td>5</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Competition of ideas on hydrogen and fuel cells technology innovation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Development of activities in the framework of the “Emprender en la Escuela” Programme</td>
<td>MEDIUM</td>
<td>No. of participants</td>
<td>5</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Demonstration of practical applications close to society presented in the WHEC 2016</td>
<td>MEDIUM</td>
<td>No. of participants</td>
<td>5</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Development of technical visits to projects and entities related with hydrogen in the region</td>
<td>MEDIUM</td>
<td>No. of participants</td>
<td>3</td>
<td>NA</td>
</tr>
</tbody>
</table>
CONCLUSIONES

El proceso de evaluación intermedia del Plan Director del Hidrógeno en Aragón 2016-2020 constituye uno de los compromisos adquiridos en su redacción y un elemento de impulso de las actividades previstas en un momento especialmente relevante en el que el sector hidrógeno afronta nuevos retos tecnológicos. La evaluación realizada se ha dividido en tres bloques principales:

- Resultados por línea de trabajo, estructurado en los cinco lineamientos definidos en su redacción.
- Resultados en términos globales.
- Actualización del Plan Director a mitad de periodo que incluye una propuesta de línea a trabajar para la fase final del Plan.

Para ello, el presente informe ha empleado la combinación de un análisis documental de la información disponible y generado en el periodo de vigencia del Plan Director junto con el desarrollo de un intenso proceso de participación a través de reuniones de trabajo y entrevistas con responsables de la FPA y organismos representativos en su ejecución.

Las metas de trabajo contaron con la participación de 30 organismos y empresas que realizaron una labor de análisis de las acciones estratégicas a la vista de los últimos avances tecnológicos y legales. Estando destacable por tanto la buena respuesta y alta participación de las empresas y organismos aragoneses que fueron invitados a tomar parte del proceso participativo.

RESULTADOS POR LÍNEAS DE TRABAJO

El análisis y evaluación del desarrollo de las líneas de trabajo, y del cumplimiento de las acciones y objetivos establecidos en los mismos, permite extraer las siguientes conclusiones:

- La línea de producción de hidrógeno cuenta con un alto grado de cumplimiento de las actuaciones propuestas. El desarrollo de tecnología de electrocrísis y la electrónica de potencia asociada sigue siendo una de las principales líneas de trabajo del Mir y varias empresas de la región. Actualmente existen 5 proyectos en marcha con actuaciones en este campo.
- Otros procesos de producción de hidrógeno, como la producción a partir de residuos, aún con menor actividad en la región, siguen considerándose de interés y se mantienen como acción estratégica.
- La línea de trabajo de almacenamiento transporte y distribución es la que menor grado de actividad y cumplimiento ha tenido en la revisión realizada. Es una línea que engloba acciones de desarrollo de tecnología que han sido modificadas para adecuarse a la realidad del estado de la tecnología en este campo.
- De manera especial, la distribución de hidrógeno sigue considerándose una línea de prioridad alta debido a que Aragón tiene una ventaja competitiva y además se mantiene el interés de lograr el objetivo de poder incluir en la red de correderas del hidrógeno a nivel europeo. Aunque los objetivos marcados para este periodo no se han cumplido, debido sobre todo a incertidumbres en la puesta en marcha del proyecto más importante al respecto, H2PÁR, se mantiene con toda su vigencia para la fase final del Plan Director.
- En la línea de actuaciones del hidrógeno destacan el desarrollo de tecnologías de plazas de combustible que en Aragón están establecidos por el CISC y la Universidad de Zaragoza. Las acciones y actuaciones propuestas se han cumplido casi en su totalidad en el periodo.
- Finalmente, la quinta línea de formación y sensibilización se considera de importancia capital y se han realizado muchos avances durante el periodo con buenos resultados destacando las realizadas en el Congreso Mundial del Hidrógeno 2016 en Zaragoza. No obstante, en el marco de la presente evaluación ha sido relevante para confiar a futuro toda clase de actividades que puedan realizarse. Mientras que en el desarrollo de las mismas se concluyó que, a tenor de lo mencionado anteriormente, la sensibilización y concienciación de la ciudadanía es de alta importancia, sobre todo ante los cambios de los modelos de transporte y las alertas a que lo hacen combustibles y nuevas tecnologías. Para ello, en su redacción se ha tenido en cuenta un papel primordial para lograr los objetivos globales del Plan.
Hydrogen Master Plan in Aragon 2016 - 2020

Med-Term Review 2018

RESULTADOS EN TERMINOS GLOBALES
El Plan Director del Hidrógeno 2016-2020 cuenta con un sistema de seguimiento global que ha sido analizado también en la presente evaluación y cuenta con un conjunto de indicadores que permiten valorar su nivel de avance divididos en tres tipologías:

- Indicadores de seguimiento globales y por línea de trabajo.
- Indicadores de resultado.
- Indicadores de gestión.

El análisis de los indicadores de seguimiento propuestos en el Plan refleja una evaluación intermedia muy positiva del cumplimiento de los objetivos propuestos. Así, durante este periodo, aunque el número de proyectos financiados ha disminuido levemente ha aumentado considerablemente la inversión global y la financiación recibida en total, siendo resultado este hecho de la participación en proyectos de mayor emergencia y con más participación aragonesa. Además, el número de empresas que tienen en marcha proyectos con tecnologías del hidrógeno es mayor que en periodos anteriores, y la financiación obtenida por las empresas, con transformación, ya ha superado los 40 millones.

- El hidrógeno constituye un elemento que cada vez suscita un mayor interés. Este factor se refleja en el interés de empresas y organismos aragoneses en el desarrollo de proyectos de hidrógeno, consolidando además de los integrantes del Patronato de la Fha, 15 organismos que realizan actividades en este campo.
- La composición del Patronato de la Fha ha sido creciendo también paulatinamente, situándose en 70 organismos en el periodo analizado por encima de la media de 65 en el periodo anterior.
- Los profesionales dedicados a las tecnologías del hidrógeno también han crecido de una forma considerable. La planta flota de la Fha ha aumentado un 16 % respecto al periodo anterior y la participación en personas/por parte de las empresas y otros organismos está actualmente en cifras cercanas a los 40.
- Respecto a los indicadores de resultado la cifra de inversión global, cercana a los 10 millones ha superado ampliamente el del periodo anterior, que se encontraba en 0 millones. La financiación recibida en convocatorias públicas se situaba en casi 7 millones destacando además el éxito obtenido por las empresas con algo más de 2 millones de euros en proyectos de hidrógeno y pilas de combustible.
- Finalmente, respecto a los indicadores de gestión el cumplimiento ha sido muy positivo. El Plan Director cuenta con 2.1 acciones y 64 actuaciones concretas en las cinco líneas de trabajo establecidas. El porcentaje de actuaciones en marcha en total asciende al 62 % y del 36 % de actuaciones que ya han alcanzado los objetivos fijados es del 36 %. Además los indicadores relativos a reuniones de seguimiento, presentación de propuestas y convocatorias han seguido la senda marcada en su definición.

En definitiva, los indicadores del sistema de seguimiento globales, así como los de resultado y gestión son adecuados para la correcta monitorización de los objetivos del Plan y por tanto no se han propuesto modificaciones en el mismo en esta etapa intermedia.

ACTUALIZACIÓN DEL PLAN DIRECTOR 2016-2020

Dentro del proceso de evaluación se ha constatado que el cumplimiento de los objetivos del Plan por línea de trabajo no ha sido uniforme por lo que se ha propuesto en el marco de la presente evaluación una reflexión sobre las causas de esta disparidad y la validación de las acciones y actuaciones propuestas así como de los objetivos fijados.

Para ello, además del análisis documental, el desarrollo de las mesas de trabajo y entretelas realizadas ha constituido una valiosa fuente de información para esta revisión.

La realización del proceso de participación a través de las mesas permite concluir que existe un consenso con los participantes para afrontar las modificaciones incluidas en el Plan Director, la repackificación de algunas líneas de acción y el mantenimiento o modificación de los objetivos.

Además, aunque algunos objetivos propuestos se consideran exigentes a la vista de las actuaciones ejecutadas, en la mayoría de los casos se ha optado por mantenerlos en su postura, como se ha optimizado para mantenerlos en la ejecución de los participantes en continuar con los desarrollos planteados y a la espera de la mejora del marco económico actual.
Las modificaciones más significativas realizadas sobre la revisión del Plan incluyen las siguientes menciónes:

- En la línea de producción de hidrógeno, se ha incluido una diferenciación de tecnología de electrolitos entre pH y alcalinas.
- Respecto a la línea de almacenamiento, transporta y distribución, se incluye de forma específica el seguimiento de diferentes tipologías de almacenamiento quitando la prioridad al almacenamiento mediante hidrógeno.
- En cuanto a la línea de aplicaciones del hidrógeno se mantienen las acciones generalizadas propuestas.
- Respecto a la transversalidad de tecnología, protección e impacto económico, la revisión se ha dirigido en la línea de seguir fortaleciendo este ámbito incrementando la implicación de empresas aragonesas que puedan aprovechar las oportunidades del hidrógeno, se mantienen las acciones globales propuestas como objetivo, pero se definen actuaciones de manera más amplia para recoger la enorme diversidad de actuaciones que pueden hacerse en este campo.
- En cuanto a la línea de formación y concienciación al igual que en el caso anterior se mantienen las acciones y se incluyen actuaciones menos concretas para incluir la diversidad de las mismas.

Finalmente, en el marco del presente Plan se establecen algunas recomendaciones operativas surgidas del proceso de evaluación que se corredera de interés de aplicación de cara a la fase final de la programación 2016-2020:

- Los cambios normativos constituyen un elemento básico en el ámbito de hidrógeno de cara al futuro. Por ello, resulta de interés el establecimiento de elementos de vigilancia en materia normativa y social para que puedan ser incorporados a la estrategia futura de actuación de cada organismo.
- Los mecanismos de trabajo han permitido evidenciar líneas futuras de trabajo que si bien puede ser prematura su inclusión en este momento es necesario el establecimiento de un protocolo de seguimiento que permita no perder las oportunidades que ofrece el sector para su inclusión en el próximo Plan. Además esta metodología participativa, que ha resultado muy provechosa por parte de los participantes, puede dar lugar a construir un foco de encuentros de los organismos más representativos que trabajan e buscan trabajar con el hidrógeno y establecer nuevos mecanismos de trabajo conjunto.
- En materia de seguimiento se considera de interés ampliar el seguimiento de los indicadores de resultado para lograr una verdadera cuantificación del impacto que supone la inversión en hidrógeno así como los resultados de la financiación obtenida en diferentes convocatorias europeas sobre la materia.
International Participation (HyER)

Representing the interests of European regions and cities active in the field of hydrogen, fuel cells and electro mobility

- Membership based network / political organisation
- 16 members in 10 countries (02.2018)
- **Aim**: help our members to develop their hydrogen and electro-mobility activities

- Enabling the share of knowledge
- Bridging the gap

Regions and cities

EU institutions

FCH-JU

Industry
FCH JU Cities & Regions Initiative

New initiative:
>50 Cities & Regions signed an MOU with the FCH - JU

Opportunity to participate in a large study:

- Defines business cases for Hydrogen & Fuel Cell based products the Cities & Regions are seeking for.
- Put Cities & Regions in direct contact with the Industry
- Help to find best financing schemes

At no cost to the Cities & Regions
(Other than their own time and travel costs)

Signing ceremony 23rd Nov. 2016
European Hydrogen Initiative

The Hydrogen Initiative
The Foundation for the Development of New Hydrogen Technologies in Aragon is a private, not-for-profit entity, created to promote the use of hydrogen as an energy vector.

Key instrument for the promotion of strategic projects around the hydrogen, renewable energy, electric vehicles, energy efficiency. With the purpose of generating, storing and transporting hydrogen, for its use in fuel cells, in transport applications or for the generation of distributed energy. In this way it aims to foment research, technological development, cogeneration and industrial adaptation, contributing to industrial modernization and improved competitiveness.
Who we are?
Projects and Collaborations

Industrial Development Level

Agreements / Collaborations

Projects (Among Others)
Thank you very much for your attention

C. Javier Navarro Espada
jnavarro@aragon.es

www.aragon.org www.hidrogenoaragon.org
ENTREE100

Project initiative for multi-MW-Applications in Hydrogen und Flexibilities

17.05.2019: Potential of hydrogen by railways in SH - S2R/FCH - Brussels
Development agency Region Heide

City of Heide
Supervisory board
Department KLG Heider Umland

Promotion of economic development
CEO / director
City-surrounding-cooperation

Public authority
Non profit
10 employees
Founded 2013

Real Estate Westküste
Real Estate
Lohe-Rickelshof, Wöhrden, u.a.
Settlements and Start-ups
Existing enterprises and expansion
Networking, R&D-Projects
Living
Retail and trade
Schools and social infrastructure
Traffic & Mobility
Landscape and Erholung
Space- and vacancy-management

Funding and project development
Region Heide - Facts

- City of Heide
  + Department KLG
  Heider Umland
- 37,000 inhabitants
- Motorway to Hamburg (approx. 45 min)
- 15 km to north sea
Region Heide - Impressions

Europe’s largest region for cabbage

Germany’s largest market place

WE’VE GOT ENERGY!
NordLink
1.4 GW

Offshore
1.2 GW

Westcoast SH - Windpower Onshore 2016 *
* Ministerium für Energiewende SH

<table>
<thead>
<tr>
<th>Region</th>
<th>In operation</th>
<th>Under construction</th>
<th>Applied</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Husum</td>
<td>1,8 GW</td>
<td>0,4 GW</td>
<td>0,8 GW</td>
<td>3,0 GW</td>
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<tr>
<td>Heide</td>
<td>0,9 GW</td>
<td>0,1 GW</td>
<td>0,1 GW</td>
<td>1,1 GW</td>
</tr>
<tr>
<td>Süderdonn</td>
<td>0,8 GW</td>
<td>0,1 GW</td>
<td>0,1 GW</td>
<td>1,0 GW</td>
</tr>
<tr>
<td>Total</td>
<td>3,5 GW</td>
<td>0,6 GW</td>
<td>1,0 GW</td>
<td>5,1 GW</td>
</tr>
</tbody>
</table>

For comparison:
Electrical gross power Nuclear Power Plant Brunsbüttel 0.8 GW
Region Heide – infrastructure today

Present project assembly

Project Initiative
Energy System Transformation towards 100% Renewable Energy

Project (2017 – 2022)
System-beneficial urban energy supply systems for full integration of renewable energies

Project (2017 – 2021)
R&D to produce green, synthetic jet fuel by hydrogen and CO₂ via methanol

Research
Institute for transformation of the energy system
Application Reallabor
(submitted 05 April 2019, decision July 2019)

- Application in the call “Reallabor” of the 7th Energy Research Program (BMWI, German Federal Ministry for Economic Affairs and Energy)
- 9 partners (7 enterprises, 1 university, 1 municipal entity)
- 30 MW electrolysis
- Complete value-added chain from RES to Syn-Fuel
- First integration of the cement industry as unavoidable source of CO2
- Option for scale-up to 700 MW electrolysis

Current application BMWI

„Reallabor Westküste 100“
Supply-Chain oriented Energy Transition process meets Decarbonisation of Industry

Reallabor Westküste 100 – a complete value-added chain
H4Valley
PROPOSAL TO THE CALL H2020-FCH-03-1-2019 (Horizon2020)

• H2 integrated hydrogen economy from RES to diverse end-user application portfolio

• H2-Application with 5t/d (1.500 t/a) H2 demand

• H2-Application in transport sector (trucks, busses, cars, garbage trucks)

• H2-Application in energy sector (cooperation with QUARREE100)

• H2-Application in industry sector (Production of synthetic fuels)
Schleswig-Holstein
fuel cells and hydrogen
in the railway environment
Track overview from NAH.SH

Current Work – H2-to-Rail
Hydrogen train option in Schleswig-Holstein

The H2-Consortium Westküste (from left to right): Dr. Uffe Borup (NEL), Frederic Pfeffer (Entwicklungsagentur Region Heide), Jean-Marc Bazenet (EDF Deutschland), Dirk Burmeister (Entwicklungsagentur Region Heide), Harro Possel (IPP Projects); Source: Entwicklungsagentur Region Heide
Electrification of tracks

376 km out of 1,275 km electrified (29%)
Electrification vs non-electrified tracks (idea)

Current Work – H2-to-Rail

Dr. Holger Busche
Expert for economic affairs, energy transition, transport and innovation; Fraktion Bündnis 90/Die Grünen
Track lines recently in tender process

**Verkehrsleistung**

**Netz Ost**
- Größtes Netz in SH: ca. 7,1 von 25,5 Mio. Zug-km
- 2 – 3 Lose denkbar (Betreiber)
- DB Regio RB SH als Altbetreiber aller Strecken

**Netz Nord**
- Dieselnetz mit 5,6 Mio. Zug-km
- 2 Lose denkbar (Betreiber)
- Derzeit NBE und DB Regio RB SH als Altbetreiber
Preliminary Site Layout (example)

Final siting in process (incl. detailed site drawings)

Dispensers planning (35 MPa)
- each dispenser: 0.6x0.6m

mobile swap-storage
- 12.2 x 2.4 m (40ft.)
- 50 MPa

On-site storage
- 12.2 x 2.4 m (40ft.)
- 35 MPa

H2 Station®
- Cooling and controls
- Compressors (redundant)
## Phases in the associated EU Siting process

<table>
<thead>
<tr>
<th>Phase</th>
<th>Task</th>
<th>Content</th>
<th>Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>Preliminary Site Layout</td>
<td>Site visit, lite risk study, pre dialogue with AHJ</td>
<td>1) Site check list/accessories, 2) Site Sketch, 3) Site budget estimate, 4) Draft time schedule, 5) Stakeholder paper &amp; 6) Protocol signing</td>
</tr>
<tr>
<td>Phase 2</td>
<td>Site Quantitative Risk Assessment</td>
<td>Site Risk Assessment</td>
<td>1) Site risk mitigation list, 2) Input to AHJ &amp; 3) Protocol signing</td>
</tr>
<tr>
<td>Phase 3</td>
<td>Site Layout</td>
<td>CAD 3D work, site construction and module placement (Customer to deliver present site drawing in DWG)</td>
<td>1) Draft DWG Site Layout, 2) One review + Adjustment, 3) HRS installation budget, 4) 3D EX Zone drawings, 5) Placement of Grounding, 6) Fundaments Specification, 7) Sign-off Site drawing, 8) Updated time schedule &amp; 9) Protocol signing</td>
</tr>
<tr>
<td>Phase 4</td>
<td>Building Application</td>
<td>4a) Nel management of building application</td>
<td>4a) Subcontracting architect and AHJ. Nel will secure Building and Operation Permit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4b) Send documentation on HRS modules – No support included</td>
<td>4b) Hand over HRS Module documentation</td>
</tr>
<tr>
<td>Phase 5</td>
<td>Installation Planning</td>
<td>If 4a) ➔ Tender &amp; Programming management</td>
<td>1) Site specific Bill of Material from Site Layout &amp; 2) Protocol signing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If 4b) ➔ Align time schedule and sign Site PO</td>
<td></td>
</tr>
<tr>
<td>Phase 6</td>
<td>Installation &amp; Commissioning</td>
<td>Transport, Cranes and Installation</td>
<td>1) Module G certificate, 2) Ready for SAT &amp; 3) Protocol signing</td>
</tr>
<tr>
<td>SAT</td>
<td>Site Acceptance Test</td>
<td>SAT test on site with customer</td>
<td>1) Signed SAT document &amp; 2) Protocol closure</td>
</tr>
</tbody>
</table>
When to act
/ local specifics
/ regional added value
/ more than providing transportation

AND in SH
/ 100% green and regional energy for H2-to-Rail
Perspective on Fuel Cell Trains in East Germany

FCH JU, „Fuel cells and hydrogen in the railway environment“, 17 May 2019
Hydrogen in East Germany

**Middle Germany:** Saxony, Saxony-Anhalt, Thuringia

- hydrogen-related:
  - Middle German Chemical Triangle with large hydrogen demand: 3.6 bn m³/a
  - dedicated hydrogen Pipeline: 200 km
  - large-scale storage in salt cavern
  - **Green Hydrogen activities since 2013!**

- train-related:
  - several regional commissioner
  - remaining nonelectric routes
  - first test drive of FC-train in February
Feasibility Study on FC-Trains in Middle Germany

**Background & Target**
- future tender with new modalities concerning technology and infrastructure
- possible routes:
  - Leipzig – Grimma – Döbeln
  - Leipzig – Zeitz – Gera
- evaluation concerning:
  - technology in context
  - refuelling infrastructure
  - drive through Citytunnel Leipzig
  - railway installations

Source: HYPOS 2017
Feasibility Study on FC-Trains in Middle Germany

Approach
- determination of possible rotation schedules
- consideration of route profile
- determination of fuel demand

- Leipzig – Döbeln: 725 kg H2/d
- Leipzig – Gera: 580 kg H2/d
- ➢ 1300 kg H2/d
Feasibility Study on FC-Trains in Middle Germany

Specific Fuel Costs, €/kg H₂
- largest expense are hydrogen production cost
- path 1+2:
  - possible hydrogen cost of 5-6 €/kg H₂
  - via onsite electrolysis, pipelines, compressed transportation
- cheapest opportunity remains: SMR+pipeline (path 3), SMR+trailer (path 4)

Commissioner: 
Contractor: 

Quelle: HYPOS 2017
Feasibility Study on FC-Trains in Middle Germany

**Cost per Kilometre, €/km**
- **Diesel:**
  - 1,3-1,6 €/km
  - at diesel cost of 1,1-1,3 €/l
- **hydrogen cost:**
  - 1,5-2,7 €/km
  - competitive at high diesel price of 1,3 €/l

- consumption optimisation,
  - technology progress,
  - carbon pricing

---

*Zum gemeinsamen Tankstellenstandort beider Strecken in Leipzig; Ergebnis nicht auf die Tankstellenstandorte Grimma und Gera übertragbar*

*Quelle: HYPOS 2017*
Funding Opportunities

**Middle Germany is facing a structural transformation!**

- phase-out of lignite mining
- phase-in of new technologies and value chains
- participation process including basically all local/regional parties

- **in this context hydrogen is one of the major topics in Middle Germany**
  - supplier: large electrolyser projects
  - storage: salt cavern to be realised as large-scale hydrogen storage
  - distributor: utilisation of hydrogen grid and gas grid
  - consumer: refinery, chemical industry, households and mobility

- opportunity to fund FC-trains projects with structural transformation
Future Projects

Targets of Local Commissioner ZVNL

- several routes are in consideration:
  - Leipzig – Grimma – Döbeln: gradual implementation of FC-trains, regular operation planned with tender in 2025, implementation in local-traffic grid
  - Leipzig – Zeitz – Gera: consideration of freight traffic, tender in 2024
  - Glauchau – Rochlitz – Colditz – Großbothen: reactivation of decommissioned route, restoration of all infrastructure

- year 2019: in-depth study on future routes, hydrogen supply chain, legal aspects
- year 2020-2021: building of refueling infrastructure
- year > 2021: procurement of trains
THANK YOU FOR YOUR ATTENTION
HYPOS – The Region

- Second longest H2 pipeline in Germany
  - 150 km, spreading between Zeitz and Bitterfeld
  - connecting H2 production with consumption

- Salt Caverns for large-scale storage
  - high storage potential in underground storage units
  - caverns just 20 km away from H2 pipeline

- Existing high hydrogen demand
  - 3.6 bn. m³/a in the Middle German Chemical Triangle
  - 1.25 bn. m³/a substitutable

- High potential for Renewables
  - 105 TWh/a onshore wind power
  - 33 TWh/a photovoltaic
HYPOS – The Idea

Vision
Constitution of a widespread Green Hydrogen Economy.

Mission
HYPOS is connecting the power, natural gas and chemical grid in East Germany via Green Hydrogen. Through systemic innovation and research Green Hydrogen applications will reach economic efficiency.

Mission statement
HYPOS is a long-term network of small, medium and major sized companies as well as research institutions working on the entire hydrogen supply chain of production, transportation, storage and utilisation.
HYPOS – The Value Chain

GREEN POWER

- Hydrogen electrolysis
- Further conversion procedures (e.g., methanation)

TRANSIENT

- Large-scale storage
- Decentralised storage
- Hydrogen pipelines
- Truck transport

STORAGE

UTILIZATION & DISTRIBUTION (centralised/decentralised)

- Mobility
- Energy supply
- Chemical industry
- Refinery
## HYPOS – The Projects

### Chemical Conversion
- **PEM-Elektrolysis**
  - MegaLyseur: Development of 2 MW Stacks
  - ElyKon: Assessment of degradation in dynamic operation
- **Alkaline Electrolysis**
  - LocalHy: Development of a decentral high pressure electrolysis
  - ELKE: continuous process of coating for electrodes
- **Reversible Electrolysis**
  - rSOC: Demonstration of reversible high temperature electrolysis
  - REVAL: Development of reversible alkaline electrolysis
- **Other Systems**
  - COLYSSY: Process development of CO-electrolysis
  - H2-Flex: Flexibilisation of chloralkali process
  - RW-Trockner: Drying of hydrogen based on radio waves

### Transport & Storage
- **Grid**
  - H2-PIMS: Conversion of natural gas infrastructure for hydrogen
  - H2-MEM: Development of a carbon based membrane to separate natural gas and hydrogen
  - H2-Netz: Demonstration of hydrogen distribution grid based on synthetic materials
  - HyProS: Development of sensor technology for hydrogen in natural gas grids
- **Storage**
  - H2-UGS: Standardisation for assessment of cavern storage units
  - H2-Forschungskavernen: Construction and demonstration of hydrogen storage within a salt cavern
- **Storage Technology**
  - MMH2P: Mobile storage solution including energy management system
  - H2-HD: Development of 1000 bar storage as a trailer

### Utilization & Distribution
- **Energy Supply**
  - H2-Horne: Development of a FC-cogeneration unit based on PEM
  - LocallyHy: Development of hydrogen combustion engine
- **Mobility**
  - LocalHy: Development of decentral hydrogen tank station concept
  - ImplaN: Design of an optimal extension schedule for hydrogen tank stations in Germany
- **Chemicals and Refinery**
  - FRAGRANCES: decentral production of CO with reverse water-gas shift reaction
  - COOMet: Development of an one step process for methanol production
  - HYTHANOL: Development of a double membrane reactor for methanol production
  - eKeroSyn: Conceptual study on renewable kerosine production

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*INES: multidisciplinary safety analysis*

*H2-Index: multidisciplinary economic efficiency analysis*
HYPOS – H2-Forschungskaverne

Development and construction of a large-scale underground storage for Green Hydrogen

- Conversion of a salt-cavern in Bad Lauchstädt/Saxony Anhalt
- Conjunction with on-shore wind farm and multi-MW electrolysis
- Connection to natural gas grid and hydrogen grid
- Realisation within three project phases
- First filling scheduled for 2023/24
Living Lab – GreenHydroChem

Electrolysis Leuna

Carbontrans Leuna

H2 Cavern Bad Lauchstädt

2t carbon/h from waste, biogenous residues and lignite

pretreatment

H2 Pipeline

Refinery

H2 Pipeline

Chemical industry

Methanol Synthesis
Synfuels
Mobility
**HYPOS – The Roadmap**

### SHORT TERM (2017 – 2021)
- HYPOS PROJECTS
  - H2-UGS, HyProS, H2-PIMS, H2-MEM
  - Mega-Lyseur, REVAL, ELKE, rSOC
  - INES, H2-Safety-Re-Design
  - RW/Trockner
- ...

### MEDIUM TERM (2022 – 2030)
- CONTINUATION OF THE HYPOS RESULTS
  - Conversion of the natural gas infrastructure
    - H2-Forschungskaverne
  - Implementation of various electrolysis technologies according to the field of application

### LONG TERM (FROM 2030)
- WIDESPREAD USE OF HYPOS AND OTHER TECHNOLOGIES ALONG THE HYPOS VALUE CHAIN
  - Hydrogen production
  - Transport and storage
  - Utilization and distribution

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- Efficient green hydrogen applications (decentralized / niche markets)
- Initial substitution of grey hydrogen in the chemical industry
- Preparation of infrastructures (networks and storage)

- Implementation of green hydrogen value chains in energy supply using natural gas networks as well as in the mobility sector
- Entry into the refinery market and fuel production
- Increasing substitution of grey hydrogen in chemistry

- Widespread use of electricity-based H2-technologies in the sectors of chemistry, refinery, mobility and urban energy supply
HYPOS – The Services

Services
- Extensive networking for hydrogen activities
- Increasing Visibility for model region Middle Germany
- Presence at fairs, events and conferences
- Support for search of project partners
- Presentation of research results
- Monitoring of relevant research and funding programs
- Contributions and publication in journals and periodicals
- Regular newsletters and press releases

Website
- HYPOS-Blog with news, dates, calls and studies
- English version available
- scheduled H2-project-, stakeholder- and expert catalogue with integrated search and filter functionality
HYPOS – The Structure

DIE HYPOS-INITIATIVE

HYPOS e.V.

GREMIEN
- Vorstand
- Mitgliederversammlung
- erweiterter Lenkungskreis

GESELLSCHAFTSSTELLE/VEREINSMANAGEMENT

ARBEITSGRUPPEN

HYPOS-PROJEKTE
Entlang der H₂-Wertschöpfungskette

BEIRAT

BMBF
„Zwanzig20 – Partnerschaft für Innovation“
HYPOS – The Members

102 Members
- 24 major enterprises
- 40 SME
- 38 research institutions, non-profit organisations and associations
- 78 members from East Germany
- 24 members from West Germany
- 3 honorary member

- Ventures with \( \geq 10 \text{ Mio } \) € yearly turnover
- Ventures with \( < 10 \text{ Mio } \) € yearly turnover
- Research institutions, non-profits, associations
HYPOS – The Board

Dr. Joachim Wicke
Siemens AG
Chairman

Prof. Dr. Ralf Wehrspohn
Fraunhofer IMWS
1st Deputy Chairman

Axel Klug
Ehrenmitglied
2nd Deputy Chairman

Dr. Christoph Mühlhaus
Cluster Chemie
Honorary Member

Dr. Kathrin Goldammer
Reiner Lemoine Institut

Thomas von der Heide
Terrawatt
Planungsgesellschaft mbH

Stefan Kauerauf
Nouryon
Akzo Nobel Industrial Chemicals Bitterfeld

Kay Okon
VNG Gasspeicher GmbH
Co-opted Boardmember
HYPOS – The Office

Juliane Renno
Association and Network Management

Stefan Bergander
Project and Knowledge Management

Florian Thamm
Marketing and Public Relations
Germanys Perspective on Hydrogen Trains

- Political Perspective & Policy Landscape -

FCH JU Workshop on the use of hydrogen in the railway environment
SHAPING SUSTAINABLE MOBILITY

Integrated implementation of German national funding programs

**Battery Electric Mobility**
Research and development, market activation, concepts

**Charging Infrastructure**
Nationwide buildup, normal and fast charging

**NIP**
Research and development, market activation

**Export Initiative Environmental Technology**
German-Japanese cooperation for PtG, development cooperation for H2/FC technologies, cooperation with the GIZ

**Mobility and Fuels Strategy**
Pilot projects, alternative fuels, LNG as a marine fuel

* National Innovation Programme Hydrogen and Fuel Cell Technology
R&D PROJECTS
Fuel cell and battery electric trains

**X-EMU**
Siemens, RWTH Aachen – Fuel cell drive for hybrid EMU trains

**iLint**
Alstom, DLR – development & validation of a fuel cell electric train

**TALENT 3**
Bombardier, TU Berlin, NVBW, SWEG – development of a battery electric train

**EcoTrain**
DB RegioNetz, TU Chemnitz, TU Dresden – modular battery drive and storage technology
NIP – VEHICLE AND INFRASTRUCTURE ACQUISITION

5 calls

241 Mio. € requested funding of which

191 Mio. € are requested funding for trains

85 Mio. € granted

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ACQUISITION OF HYDROGEN TRAINS IN GERMANY

Defined projects

**LNVG, LOWER SAXONY**

Cuxhaven – Bremerhaven – Bremervörde – Buxtehude

14 trains + HRS in Bremervörde, acquisition until the end of 2021, operation starting in early 2022

**RMV/FAHMA, HESSE**

RMV lines 11, 12, 15 & 16

28 trains + HRS in Frankfurt-Höchst, acquisition and start of operation in 2022
FOR RAIL TRANSPORT WE INTEND TO ESTABLISH A COMPREHENSIVE FUNDING PROGRAM, WHICH COVERS BOTH THE ELECTRIFICATION OF TRACKS AND THE ACQUISITION OF VEHICLES AND THE RESPECTIVE CHARGING/REFUELING INFRASTRUCTURE. FURTHERMORE, REGIONAL RAIL TRANSPORT IS INTENDED TO BE SUPPORTED THROUGH INVESTMENT GRANTS FOR FUEL-CELL-HYBRID-RAILCARS INCLUDING FACILITIES & DEPOT MODIFICATIONS AS WELL AS THE CONSTRUCTION AND OPERATION OF HYDROGEN REFUELING STATIONS.

– TRANSLATED FROM THE COALITION AGREEMENT BETWEEN CDU, CSU & SPD, 2018

NEW FUNDING GUIDELINE

→ Applications for 164 fuel cell trains, 11 HRS and 4 onsite electrolysers

→ Expressions of interest for more than 300 battery and fuel cell electric trains until 2024

New funding programme for the acquisition of trains with alternative drives

→ Announced budget 2019: 13.9 Mio € + 38.8 Mio € until 2024
→ Funding guideline in preparation
Electrification through catenaries → feasible for tracks with a high level of traffic

Battery electric trains → lucrative for tracks with already existing catenaries in some parts

Fuel cell electric trains → lucrative for longer tracks (up to 1,000 km range) without catenaries and with availability of inexpensive hydrogen sources

Conclusion: SIGNIFICANT POTENTIAL FOR BOTH BATTERY AND FUEL CELL ELECTRIC TRAINS IN GERMANY
TRAFFIC FORECAST GERMANY 2030

Freight transport

- +43% 2010-2030
- +39% 2010-2030
- +23% 2010-2030

Passenger transport

- +19% 2010-2030
- +10% 2010-2030
- +65% 2010-2030

Source: https://www.bmvi.de/SharedDocs/DE/Anlage/MKS/energie-auf-neuen-wegen.pdf?__blob=publicationFile

Great potential for fuel cells in rail & heavy duty!
MARKET ANALYSIS
ALTERNATIVE DRIVES IN REGIONAL RAIL TRANSPORT

1. Comparison of European countries
2. Technology comparison
3. Status-quo of the German rail network
4. Detailed analysis of specific tracks
5. Market potential for battery and fuel cell
6. Derivations concerning funding
CHALLENGES
– CAPEX & financing (e.g. risk surcharges)
– Usually high costs for „green“ hydrogen production through electrolysis due to levies
– Responsibility for infrastructure (costs, risks)
– Access to infrastructure owned by the „DB Netz AG“
– Legal aspects of tendering procedures
– Lengthly approval procedures

POTENTIALS
– Raising hydrogen demand significantly
  ➔ economies of scale
  ➔ strengthening hydrogen as sector coupling enabler
– Raising awareness
– Proving market maturity
– Reducing overall rail grid electrification costs

Challenges & Potentials