HYDROGEN INFRASTRUCTURE FOR A SUSTAINABLE MOBILITY - A ROADMAP FOR THE GERMAN FEDERAL STATE BADEN-WUERTTEMBERG UNTIL 2030

F-cell / Session B1: Hydrogen Infrastructure

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Agenda

- Introduction
  - Motivation and goals
  - Approach of this study
- Current state in the development of hydrogen refuelling stations (HRS)
- Hydrogen roadmap for Baden-Wuerttemberg
  - Three phase approach
  - Hydrogen demand for road traffic
  - Number of required HRS
- Conclusion and recommend actions
Sustainable Mobility
Something we must achieve in the next decades.

- Challenges for our mobility
  - Limited resources in fossil energy carriers
  - Reducing GHG emissions
  - Pollutant emissions in urban centres

- Expected benefits
  - Local: zero emissions
  - Global: reduced emission by usage of renewable energy sources (RES)
  - Domestic value-added chain

- Technical solution for road traffic
  - Battery electric vehicle (BEV)
  - Fuel cell electric vehicle (FCEV)

- Tasks and objectives of this study
  - Survey on current state of hydrogen refuelling stations in BW/Germany/world-wide
  - Discussion of required demand
  - Development of a roadmap for BW until 2030
  - Formulation of recommend actions
Methodology
How did we come to our results?

Own experience
- 700bar H2 refuelling station at Fraunhofer ISE
- 2 FCEV from Daimler
- H2 production and P2G projects
- Base data from BMU pilot study
- Vehicle forecast for Baden-Wuerttemberg
- Comparis. with other studies

Scenarios
- Literature survey
  - Current technological state
  - Stack holder analysis
  - International goals
  - International activities
  - All stack holder
  - Authorities/Users
  - Manufacturers/OEMs
  - Multi stage evaluation

Interviews with experts
Main components of the filing station:

- (Pressure) electrolyser (30 bar / 6 Nm³/h)
- Mechanical compressor
- Storage tanks
- Dispenser units (200/350/700bar)
- Filling according to SAE J2600
- Integrated container solution
- Publicly accessible filling station
- Located at premises of Fraunhofer ISE
- Coupled with renewable energies:
  - Photovoltaic modules (roof)
  - Certified green electricity
700bar Hydrogen Refueling Stations in Germany
15 out of 50 until 2015 are built already …

Publicly Accessible Hydrogen Refueling Stations in Germany (CGH2, 700 bar)

Under construction

Berlin, Airport BER
Total/Enertrag

Berlin, Holzmarktstraße
Linde/Total

Berlin, Sachsendamm
Shell

Frankfurt
facility Höchst
AGIP

Munich,
Detmoldstraße
Total (only LH2)

Updated chart based on
O. Ehret – NOW, 2012
Selected Typical System Layout of HRS (1/2)

CGH$_2$ delivery by trailer
Selected Typical System Layout of HRS (2/2)

On-site hydrogen production by water electrolysis

onsite-System: Elektrolyse / Reformer (1 – 50 bar)

Mitteldruckkompressor

Hochdruckkompressor

Mitteldruckspeicher (200 – 450 bar)

Rückschlagventil

Mitteldruckspeicher (800 – 1000 bar)

Booster-Kompressor
Status Quo 700bar hydrogen refueling stations
What needs to be done?

- Technology
  - Increasing reliability and availability
  - Further development of components
  - Standardisation of technical concepts
  - Enhancements in codes and standards
- Beyond technical issues
  - Development of business models
  - Creation of real competition in the supply chain and under manufacturers
  - Higher public acceptance and visibility
  - Set up an infrastructure roadmap
### General Hydrogen Roadmap

**Development in three phases**

#### Phase 1: Research, development and demonstration (until 2015)
- Further technical development, testing of whole systems
- Development of codes and standards, larger public visibility

#### Phase 2: Market preparation (until 2020/21)
- Increased number of standardised HRS → high reliability (learning curve)
- Chicken-egg dilemma solved (cluster and corridors) → High user acceptance
- Establishment of business models and legal regulations

#### Phase 3: Market introduction and commercialisation (until 2030)
- Cost reduction through economy of scale
- Inclusion of rural areas in the infrastructure → 100% coverage with HRS
- Commercial HRS operation → government funding decreases
Hydrogen Roadmap
FCEV forecast derived from different studies

- Increasing numbers of hydrogen passenger cars in Baden Wuerttemberg
  - BMU: Pilot study 2011
  - ZSW: e-mobil study
  - H2M: "coalition study"
- Forecast is calculated from data about market penetration

ZSW: Centre for Solar Energy and Hydrogen Research Baden-Wuerttemberg
H2M: H2 Mobility (an European industrial initiative)
Hydrogen Roadmap
FCEV forecast derived from different studies

- Increasing numbers of hydrogen based light and heavy duty vehicles and busses in Baden Wuerttemberg
  - BMU: Pilot study 2011
  - ZSW: e-mobil study
- Again: Forecast is calculated from data about market penetration
Hydrogen Roadmap
How many HRS do we need in Baden Wuerttemberg?

- Refuelling stations of type S, M and L according to H2 Mobility
- Typ S ist mobile
- Operation time: 20 years
- Av. utilisation climbs up to 80% until 2025

<table>
<thead>
<tr>
<th>Typ</th>
<th>1 dispenser</th>
<th>2 dispensers</th>
<th>4 dispensers</th>
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<tr>
<td>Max.</td>
<td>Max.</td>
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<td>H2 kg/d</td>
<td>212</td>
<td>420</td>
<td>1.000</td>
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![Graph showing the number of H2 stations per year](image)
Hydrogen Roadmap

HRS infrastructure close to general CEP strategy

Phase 1 - until 2015

- Main goals
  - Strengthen cluster
  - Build up corridors
- Cluster Stuttgart with extension to area Karlsruhe
- Connection of cluster Frankfurt with Rhein - Neckar - area
- Corridor A8: Connection to cluster München
- Corridor A5: Connection to Switzerland and France
Wasserstoff-Roadmap
Achieving user's acceptance

Phase 2 - until 2020/21

- Market preparation to overcome the chicken - egg - problem
- Acceptance similar to CNG
- Focus on urban areas:
  - Stuttgart - Karlsruhe
  - Rhein-Neckar area
  - Donau-Iller area
  - Bodensee area
- Redundancy at the corridors
  - Highways A5, A6, A8, A81
  - National roads B10-14-29-30-31-290-311
Hydrogen Roadmap
Complete coverage only with commercialisation

Phase 3 - Commercialisation
- Ramp up beginning 2020/21
- Extension to the rural areas (mean utilisation):
  - 2020: 70 HRS (25 %)
  - 2025: 195 HRS (70 %)
  - 2030: 330 HRS (80 %)
- Limit of CGH2 and LH2 trailer in delivery capacity after ~ 2030
- Possible further options > 2030:
  - H2 pipeline
  - On-site H2 production
Hydrogen and Urban Public Transport
Large opportunity for market preparation in 2\textsuperscript{nd} phase ?

- According to studies:
  No large impact of busses for German's goal in climate protection

- But: hydrogen and urban busses fit together well:
  - FC busses best option for "zero emission" public road transport
  - Support "fine dust protection" policy
  - Large and continuous H2 demand enables early commercial operation of HRS
  - Large publicity and higher user acceptance
Hydrogen and Urban Public Transport
Large opportunity for market preparation in 2nd phase?

- BUT high requirements for HRS in public transport sector
  - Reliability of stations and uninterrupted availability of h2-supply
  - HRS capacity has to grow with FC bus fleet → modularity
  - H2 delivery and large footprint
- Differences to HRS for passenger cars
  - Larger storage tanks
  - Larger compressors
  - separate dispenser unit and nozzle for busses
  - No pre-cooling, lower filling pressures
Conclusions
What have we learnt from this work?

Possible development of a hydrogen infrastructure:

- Build up of a basic HRS infrastructure with the help by the public body
- Deployment of small mobile HRS which can be relocated and replaced once higher demand is established
- In urban centres installation of medium and large HRS with LH2 delivery
- Once the H2 production capacity of current sources is exceeded: Construction of new H2-production sites close to highways and urban centres (with large HRS) which supply HRS in cities
- At a certain point (~ 2030) LH2 delivery in urban/industrial centres might be replaced by H2 pipeline
- 2030+: Pipeline delivery allows HRS with smaller footprint, reduced HRS capital costs and higher refuelling capacity
Conclusions
Recommend actions (only short extract)

- Public funding and support should depend on delivery of "green" hydrogen
- H2 infrastructure should adapt to expansion of RES concerning timeline and local distribution → closer investigation
- Further development of funding schemes for phase 2 und 3 required → Tax incentives? Government aid for HRS?
- Increased visibility could be reached by selected "light house projects" → including municipal utilities and urban transport companies
- Manufactures and suppliers should agree on standardised concepts for HRS → e.g. functional description according to H2M
Thanks a lot for your kind attention!

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