50 HYDROGEN REFUELING STATIONS IN GERMANY

Within the frame of the National Innovation Programme Hydrogen and Fuel Cell Technology

by

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A cross country assessment of early stages of implementation"

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Abstract

To achieve the ambitious goals of the German government for CO2 reduction, for reduction of the energy consumptions and to enhance the share of renewable energies in the transportation sector a very broad approach for eclectic mobility was chosen which includes the usage of Fuel Cell Electric Vehicles (FCEV). Hydrogen, produced from renewable energies, as energy storage and as buffer for net fluctuations will play a major role in the German the *“Energiewende”.* The FCEV’s are fueled with hydrogen and are emission free, do show excellent driving ranges of several hundred kilometers and can be refueled in only a few minutes.

In order to prepare the national and international market for the relevant hydrogen technologies the federal ministry of transport, building and urban development (BVBS) does support the national innovation program for hydrogen and fuel cell technologies (NIP). The main task of the NIP is to establish FCEV’s demonstration projects and to promote the deployment of the hydrogen infrastructure.

Successful demonstration projects for fuel cell cars and busses as well as the construction of the first hydrogen refueling stations (HRS) within the Clean Energy Partnership (CEP) as part of the NIP do demonstrate the general technically feasibility of the hydrogen technology. Major car companies announced the first commercial rollout of FCEV’s for 2014/15.

The key factor for a successful commercialization of FCEV is a working HRS infrastructure. For this reason 50 HRS are required to be installed in Germany with the following objectives:

- Collaborative network planning within the CEP
- Commitment of the industry to participate
- Funding within the NIP budget, provided by the BMVBS

This circumstance gives Germany a worldwide leading position for the market of battery and fuel cell electric mobility.

1. Background/ Motivation

<u>The role of FCEV: A Portfolio for alternative driving trains and fuels for a sustainable mobility</u>

The political goals for the transportations sector of reducing the energy consumptions and the de facto decarbonisation until 2050 will not be achieved without the establishment of electric drive trains and the enhanced use of renewable energies.

Regarding the state of the art only FCEV (cars and busses) do offer the opportunity for a zero emission public transportation system which meets the current user requirements, such as vehicle size or refueling time.

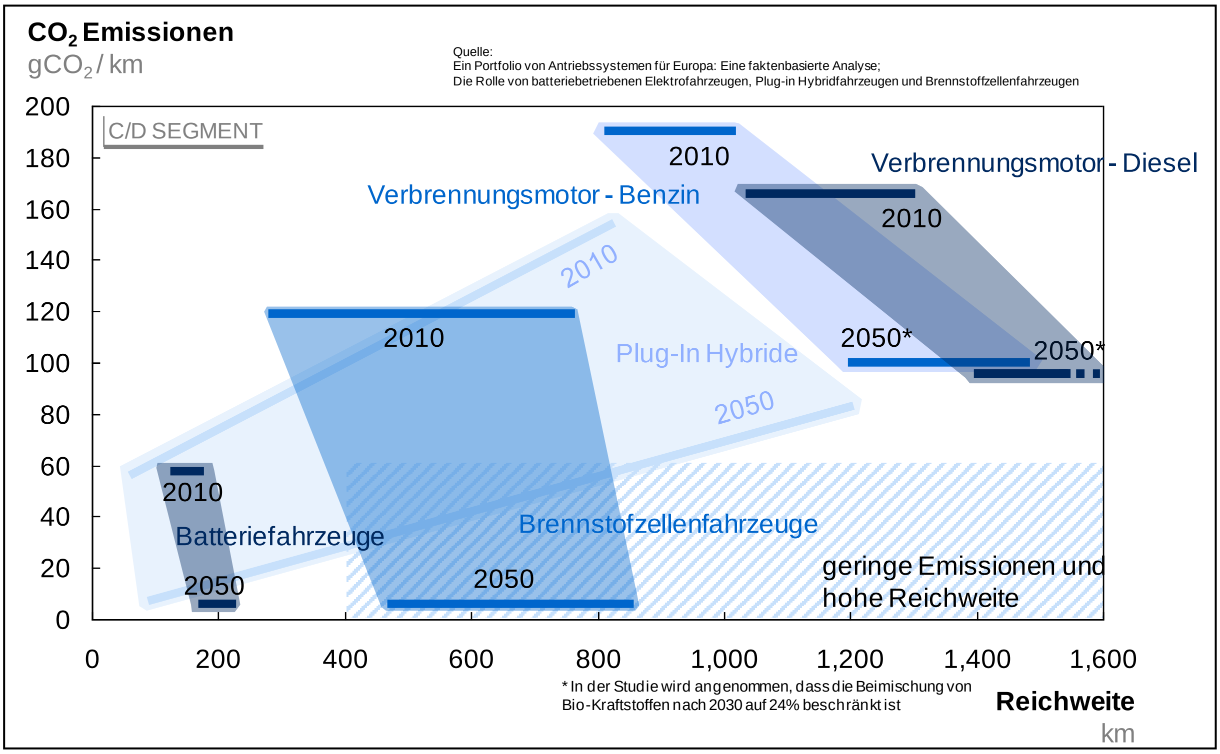

Fig. 1: Electric vehicles (Battery, Plug-In Hybrid, Fuel cells) can almost achieve the zero emission region, whereas the battery electric vehicles do have some disadvantages with the driving range.

An economical comparison of the different systems is most useful if the Total Cost of Ownership (TOC) is considered, since these costs do describe the whole Lifetime of the system.

Due to the significant scale effects of Fuel Cell Systems, BEV components and hydrogen the total operating costs do converge by 2020 for all driving systems (s. Fig. 2).

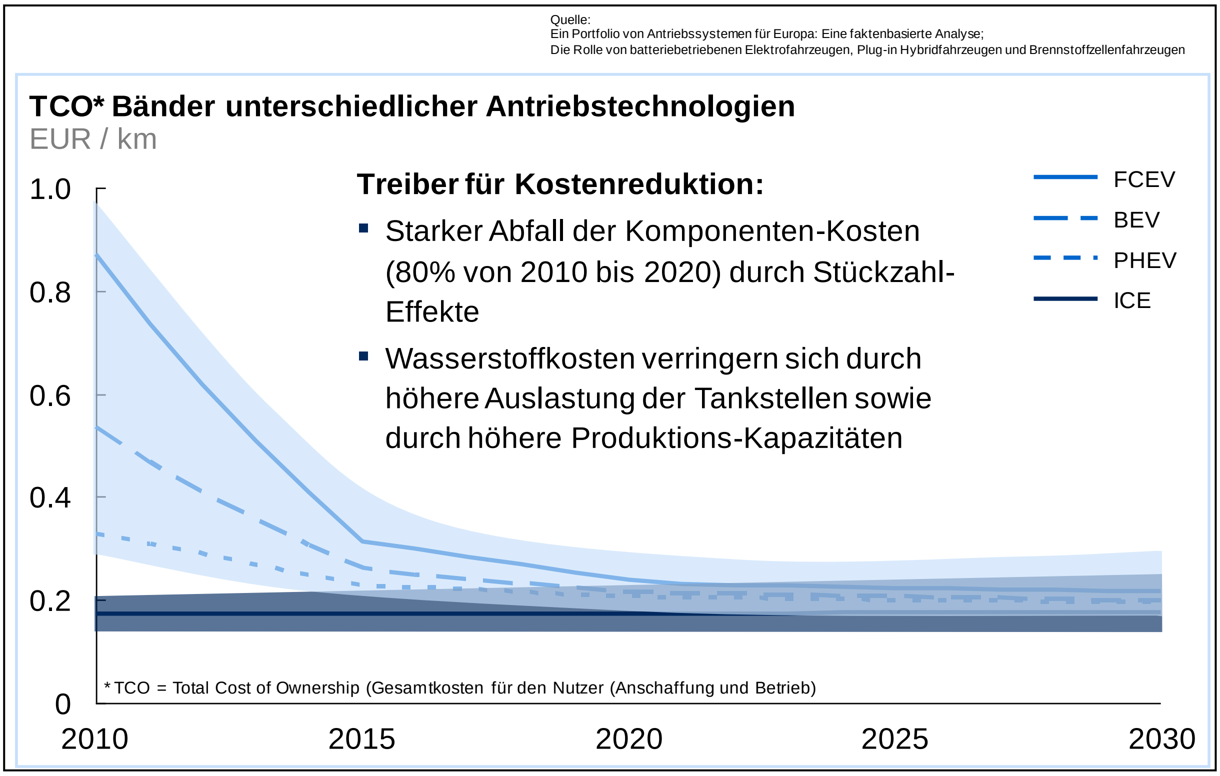

Fig. 2: *The TOC of FCEV's reaches the level of an ICE by 2020. The time can change with respect to the change of the oil prices.*

<u>Introduction of hydrogen mobility in Germany</u>

Several automobile companies, excluding the supply industry, invested already a total of about 10 bil. € into the fuel cell technology and there are no signs that this commitment will change. Some of the automobile companies announced their first commercial roll out for 2014/15 (s. Fig. 3).

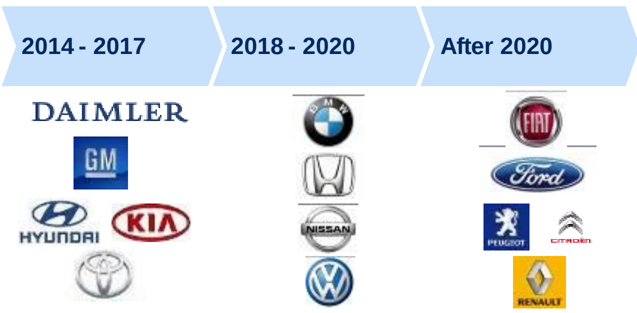

Fig. 3: Expected commercialization for FCEV's in serial production.

Regarding the market preparation for FCEV's Germany is accounted to be a flagship. Due to the industrial background as well as the political support Germany is regarded to be one of the first markets for FCEV's commercialization.

2. Current status of the market preparation

The National Innovation Programm for hydrogen and fuel cell techgnology (NIP): R&D and demonstration as a public privat partnership.

Currently 114 projects (264 granted projects) are part of the National Innovation Program (NIP) for hydrogen and fuel cell technology. The total founding is about 273 mio. €, which is provided by the BMVBS. Additional 11 projects of about 24 mio. € are currently under review.

Beside the mentioned projects, further 47 applications with a total funding of 94 mio. € are under discussion in the NOW.

The transportations department of the NIP is dealing with applications of hydrogen and fuel cell technology which can significantly contribute to the ambitious goals of increasing energy efficiency and to the CO2 reduction in the transportation sector. The transportation department concentrates on R&D and demonstrations projects for hydrogen vehicles (car and busses for private and public transportation). Besides the fuel cell driving trains the program includes systems for the auxiliary power units (APU) for trucks or even for airplanes. Applications for trains are as well a relevant sector in the transportation department.

Bridging the gap between R&D and upcoming markets is one of the major tasks of the NOW. For this reason the light house projects were developed. These projects will serve as platforms for the commercialization. The light house project of the transportation sector within the NIP is the Clean Energy Partnership (CEP).

Clean Energy Partnership (CEP):

Successful demonstration of fuel cell electric vehicles and hydrogen refueling stations.

The CEP was founded in 2002 as a joint undertaking of politics and industry, in which the federal ministry for transport, building and urban development (BMVBS) was in charge. In the meanwhile the CEP fleet collected more than one million kilometers, which is about 25 times the way around the world. This makes the CEP the greatest demonstration project for FCEV's in Europe. Due to the validation of the competitive the fuel cell technology the CEP is a successful program for the market preparation.

The first HRS was opened in 2004 at the Messedamm in Berlin. At this fueling station it was possible for the first time in Germany to refuel his car besides gasoline and diesel with hydrogen.

The second phase of the CEP started in 2008. The aim was to proof the concept of the relevant technologies for a day to day use until the end of 2010. During this time about 40 cars form six different companies and four busses in Berlin and six in Hamburg for public transportation have been driven in within the CEP fleet.

The focus of the third phase from 2011 to 2016 will be the market preparation. This includes a broader fleet of cars in the hand of end customers in order to gain more experiences at the linkage point between car, customer and infrastructure.

Fig. 4: FCEV in the Clean Energy Partnership (CEP, 2011)

Fig. 5 shows the current status of the HRS within the CEP regions (Jan. 2012): All of these HRS are public available and do meet the standards and requirements of the automobile industry with respect to fueling protocols and safety.

Some results of the previous experiences can be concluded as follows:

- The safety of the HRS could be proofed.
- The harmonization of the fueling protocols was achieved.
- The storage and compression technologies have been tested at the HRS.
- The hydrogen supply was tested for different production and distribution pathways.
- The operation management of the HRS (e. g. software) was optimized with respect to efficiency and reliability.

In the frame of accepted NIP projects the CEP fleet will increase to over 100 FCEV’s until 2013. Regarding the HRS infrastructure a broader deployment of the HRS network is the main task for the coming time. A minimum of 3 HRS will be opened until 2013; in Hamburg one additional HRS is already under construction and two more are in the planning phase. Some more HRS will be build up by the federal states and their associated partners. In an intermediate-term this aims to develop some connection corridors for the FCEV's between the hydrogen clusters, for example with HRS along some Autobahnen.

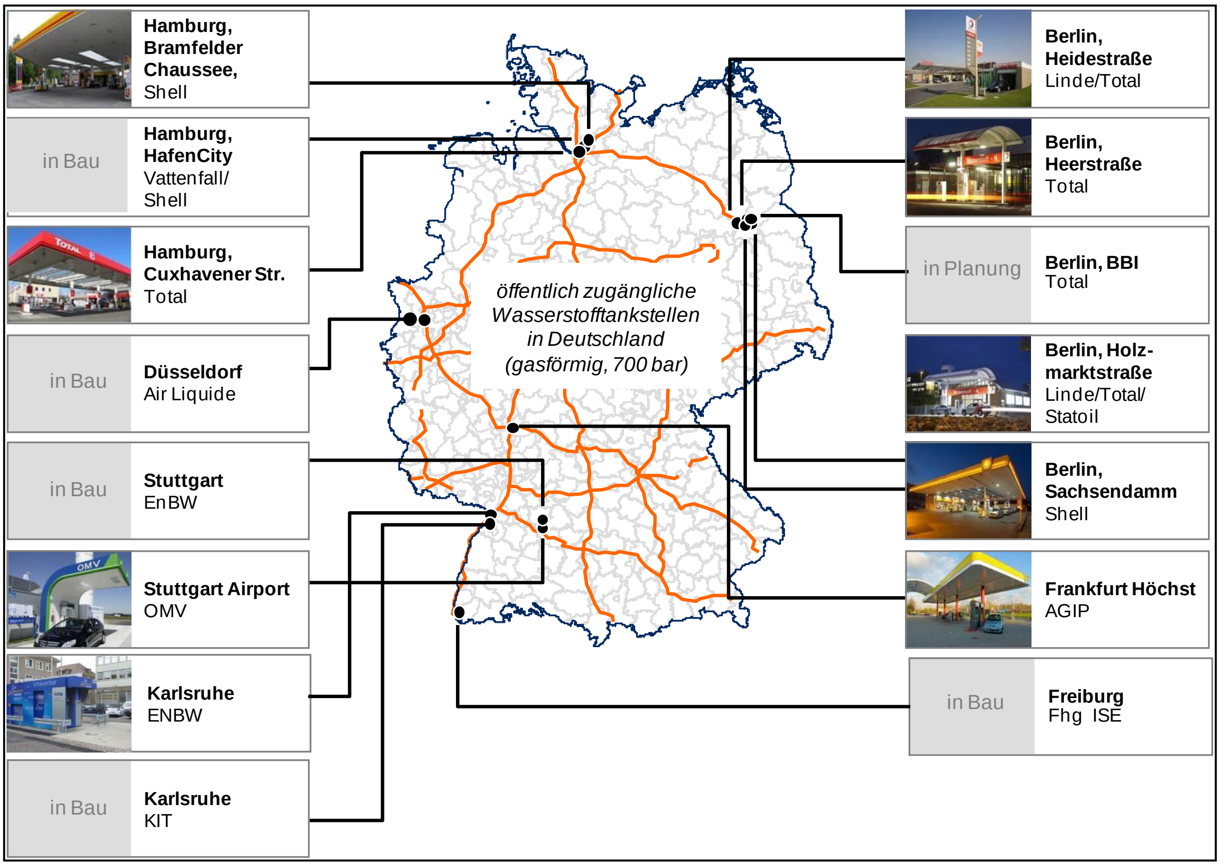

Fig. 5: Public HRS in Germany (January 2011)

Regarding the hydrogen infrastructure it is of great importance to further extend the HRS network throughout Germany. For this reason the federal minister for Transport, Building and Urban Development Dr. Ramsauer announced the deployment of 50 HRS until 2015. The joint letter of intent for the HRS deployment was signed by the German Ministry of Transport, Building and Urban Development and several industrial companies.

"To facilitate market introduction [of fuel cell vehicles] we need a hydrogen station network covering and connecting the metropolitan regions."

Dr. Ramsauer

The additional 35 HRS will be funded within the NIP with an overall investment of about 40 mio. € (US$ 51 mio.). The network of 50 HRS will allow a market-relevant testing of the filling-station technology and ensures a needs-driven supply for fuel cell vehicles. The deployment of the HRS will be coordinated by the NOW GmbH in the frame of the CEP.

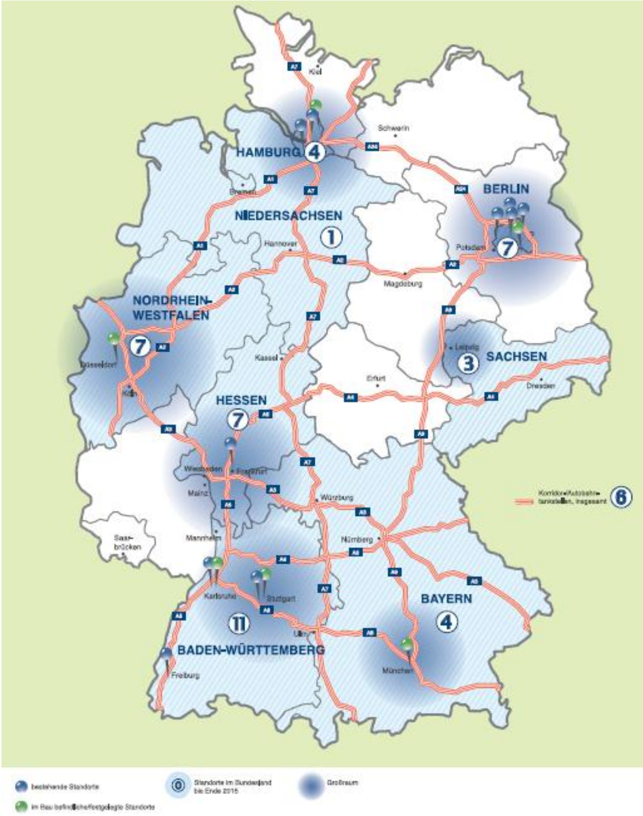

Fig. 6: The 50 hydrogen refueling station network until 2015.

The 50 stations will be positioned mainly in seven metropolitan regions with some connecting HRS in between the regions as shown in Fig. 6. This network will allow the an extended use of the FCEV's and is a crucial step on the way of a successful commercialization and ramp up of the FCEV's.

H2-Mobility:
A common approach for a nationwide HRS infrastructure in Germany

In September 2009 representatives of major industry companies founded the H2-Mobility, wherein several possibilities for the establishment of a nationwide infrastructure for hydrogen supply is analyzed. The aim is to promote the commercialization of electric vehicles and fuel cells (s. Fig. 7).

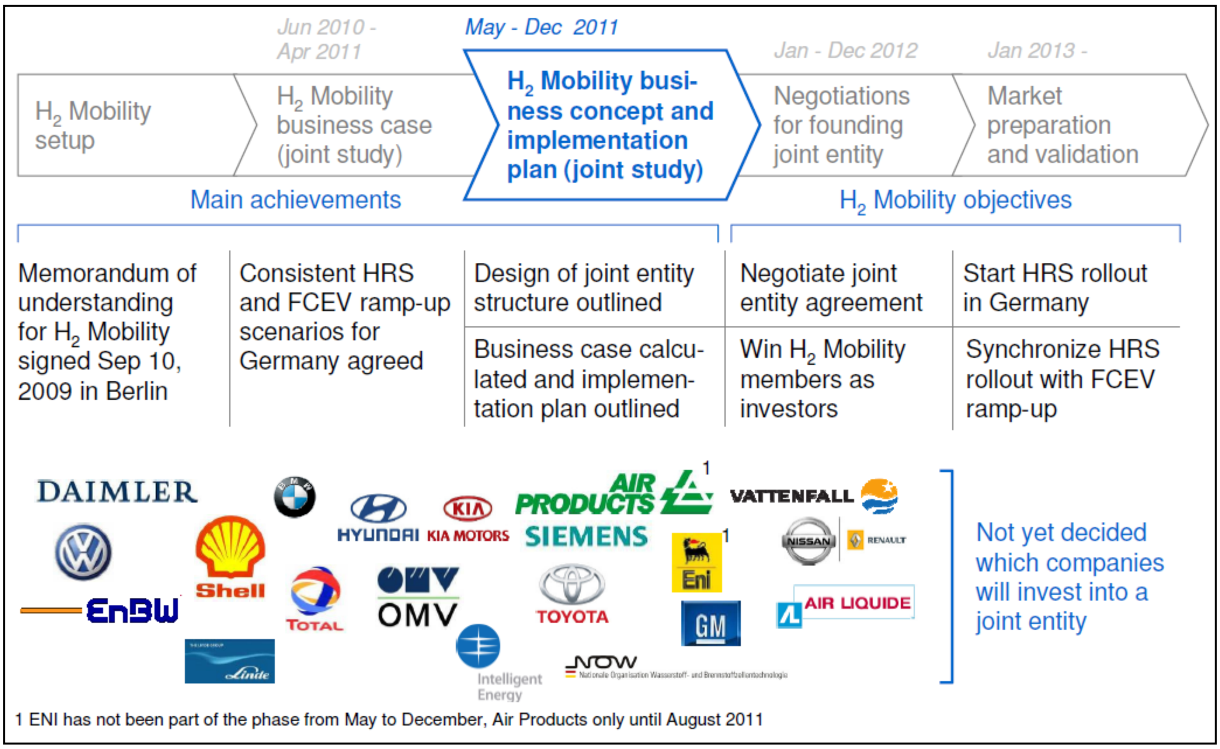

Fig. 7: H2 Mobility –a common initiative for an establishment of an nation wide HRS infrastructure.

H2-mobility concentrates on the development of a common and economical profitable business case for a hydrogen infrastructure which meets the market needs. Regarding to the results of the collaborative study, the establishment of a hydrogen infrastructure will be a profitable businesses case. The current development plan for the HRS infrastructure divides in 3 phases (s. Fig. 8).

In the first phase (Phase 0) the focus is to enhance the R&D and demonstration activities within the NIP and the CEP respectively. A total of 50 HRS are planned to be build during this phase. Theses HRS should proof the reliability of the HRS and significantly reduce the costs for the construction of the next HRS.

The hydrogen infrastructure, developed in phase 0, will improve the hydrogen supply of the metropolitan regions and it will create connection between these regions.

	Phase 0 F&E und Demonstration	**H_2 Mobility Phase I** Marktvorbereitung und -Validierung	**H_2 Mobility Phase II** kommerzieller Hochlauf
Wann?	▪ seit 2006	▪ von 2013 *bis 2018 oder bis 2022* (lfd. Diskussion der H2 Mobility Partner)	▪ nach 2018 oder 2022
Wer?	▪ Clean Energy Partnership/NIP¹	▪ H_2 Mobility (Partnerstruktur tbd) ▪ Clean Energy Partnership/NIP¹	▪ H_2 Mobility (inklusive externer Investoren) ▪ Tankstellenbetreiber
Meilen-steine	▪ Wasserstoff-tankstellen technologisch abgesichert ▪ Kosten signifikant gesenkt	▪ Nachweis der markttauglichkeit von Wasserstofftankstellen und Brennstoffzellenfahrtzeugen (jeweils inkl. der Zulieferkette) ▪ Kundenakzeptanz von Brennstoffzellenfahrzeugen ▪ Attraktives Geschäftsmodell für Phase II	▪ Flächendeckendes Wasserstoff-Tankstellen-Netzwerk ▪ Profitables Geschäft

Fig. 8: Different phases of the establishment of a hydrogen infrastructure (Source: H2 Mobility)

Phase 1 will contain the market preparation and validation. This will be implemented by a H2-Mobility Joint Venture. The hydrogen network will be expanded mainly by the industries with some public support by accepting high investment risks. The goal of this phase is to verify the economical concept of the hydrogen infrastructure.

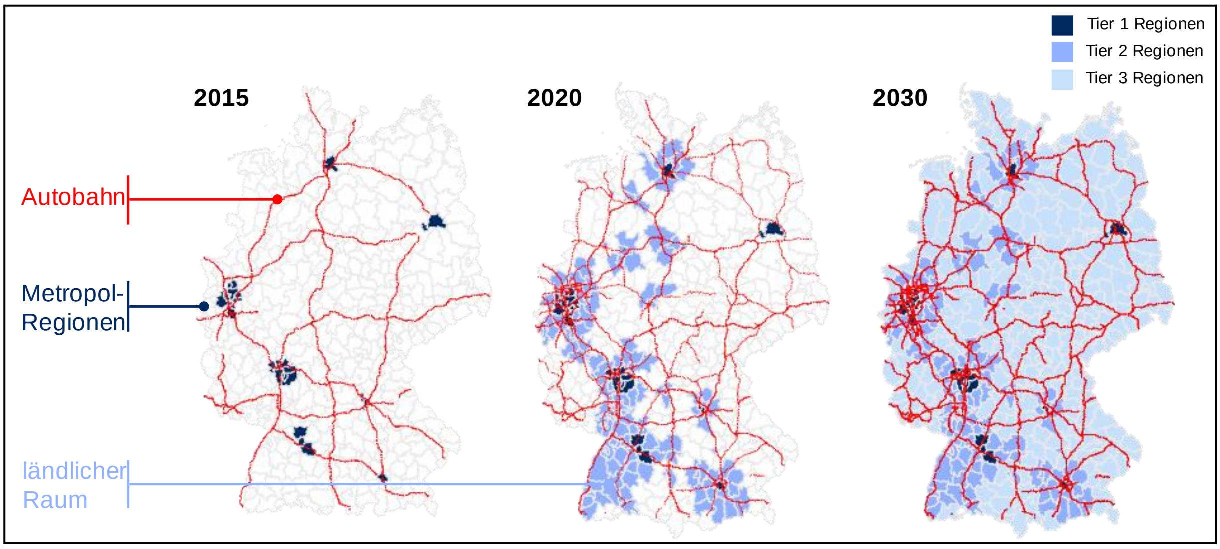

Fig. 9: Nationwide establishment of an HRS infrastructure (Source: H2 Mobility)

If the deployment of the HRS in phase 1 will meet the customer's needs the market will become attractive for external investors which would be the beginning of phase 2. An economical profitable and nationwide HRS infrastructure will then be deployed until 2030 (s.

Fig. 9). The estimated numbers of cars and HRS for the different phases of H_2-Mobility are given in the table below.

	2015	2020	2030
No. of FCVE (Thousends)	5	150	1.800
No. of HRS	100	400	1000

Tab. 1: HRS and Car deployment for the H_2-Mobility roll-out plan until 2030.

After 2020 the H_2-Mobility is supposed to attracted external investors to invest in the HRS infrastructure which will become an own and profitable business case by this time. Therefore new HRS will be deployed even beside the H_2-Mobility consortium and the numbers for 2030 given in Table 1 are a conservative projection and only reflect the minimum of HRS in Germany for the given year.

Regarding the rollout plan until 2030 an overall investment of about 2 bill. € is expected. The most crucial and risk full period is the establishment of the basic HRS network until 2020 (Phase 0 and 1). This period requires an investment of several hundred mio. € and public participation in order to minimize the investment risks. The aim is to establish a self-sustaining business for HRS. These investments do include the establishment of a hydrogen delivery infrastructure. The hydrogen infrastructure does also include the hydrogen supply which will change over the time. In the beginning the hydrogen will be mainly delivered by trucks, either with liquid or gaseous hydrogen. In long term perspective with increasing hydrogen demand and longer delivery distances a pipeline system becomes more economical and will be established.

The H2-Production portfolio in Germany covers mainly by-product from industrial plants, NG-reforming and Electrolyser. Shares of respective pathways will shift over time towards CO2-free production. Until 2020, no extra production facilities are needed; electrolyser capacity will build-up according to storage needs for the grid (increase of share of renewable) and should be sufficient until 2030. The investment in production is included in the above mentioned total investments for a hydrogen infrastructure.