Implementation of Hydrogen into the German Energy System

Dr. Johannes Töpler; Reinhold Wurster

This document appeared in

Detlef Stolten, Bernd Emonts (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Speeches and Plenary Talks
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78
Institute of Energy and Climate Research - Fuel Cells (IEK-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: $978_3 - 89336 - 658 - 3$

Implementation of Hydrogen into the German Energy System

Dr. Johannes Töpler, German Hydrogen and Fuel Cells Association, DWV, Berlin, Germany
Reinhold Wurster, DWV and Ludwig-Bölkow-Systemtechnik, LBST, Munich, Germany

Abstract

The paper combines a study of German Hydrogen and Fuel Cell Association (DWV) with respect to the future energy situation with the perspectives of the use of renewable primary energies together with hydrogen as secondary energy carrier in Germany.

As a result of the study a reduction of fossil primary energy supply and increasing contributions by renewable energies within the next decades is to be expected. The potential of renewable energies to cover the energy demand is described as well as cost reductions of wind and photovoltaic energy in Germany and Europe. The increasing use of renewable vehicle fuels is investigated with special focus on hydrogen in short and long term considerations.

As a result the study will show an energy supply gap between decreasing fossil energies and increasing renewable energies which can only be bridged by a more efficient general use of energy.

As a result of an overall consideration of different secondary energies with respect to energy density, efficiency and environmental aspects, hydrogen has the best perspectives.

As an introduction strategy for the implementation of hydrogen in Germany a concentration of research and demonstration projects in a national program (NIP) is started and the industrial process for a market penetration of fuel cell vehicles with corresponding infrastructure is prepared by MoU's of the OEM's and related companies for building up of the infrastructure.

1 Introduction

Hydrogen as a universal energy carrier can be produced as secondary energy from a wide variety of primary energy sources. Considering the whole energy chain from production to end-use, hydrogen, used in fuel cells to power transport and stationary applications, can provide significant benefits in terms of greenhouse gas emissions and local pollutants through increased efficiency and/or lower rate of emission per end-use energy unit.

As the EU Strategic Energy Technology Plan is pointing out in its Technology Map[1] "The possible competition for primary energy sources for hydrogen production and other sectors of activities indicates a need for synergies and coordination between policies and industrial sector strategies". From today's observations, there also will be a mix of different solutions suited to individual mobility needs. This will include shifts in the modal split.

There is a broad consensus that the future powertrain is electric. Battery vehicles would be the most energy efficient solution. However, by evaluating different secondary energies (e.g. electricity, hydrogen) with respect to energy density, efficiency, environmental aspects and subject to customer performance expectations and infrastructure development (both electricity grid and hydrogen infrastructure), hydrogen in combination with fuel cell vehicles have excellent perspectives in the medium as well as in the long term.

2 Future Energy Supply

The aggregate supply of fossil and nuclear energy is expected to peak by around 2015.

After the peaking of the oil supply (today) [2], the global supply of natural gas and coal [3] is expected to reach a combined maximum by around 2020 – at the latest. This will have significant impacts on the total energy supply. With peak oil we are entering into a transition phase towards a post-fossil energy area.

The limitation in the availability of fossil energy resources as well as the threat of climate change to biosphere have led to the formulation of political goals with regard to security of energy supply and especially reduction of greenhouse gas emissions. All the underlying issues can be addressed in an efficient and sustainable way by energy conservation, by the increased use of renewable energy sources and by the use of hydrogen and fuel cells.

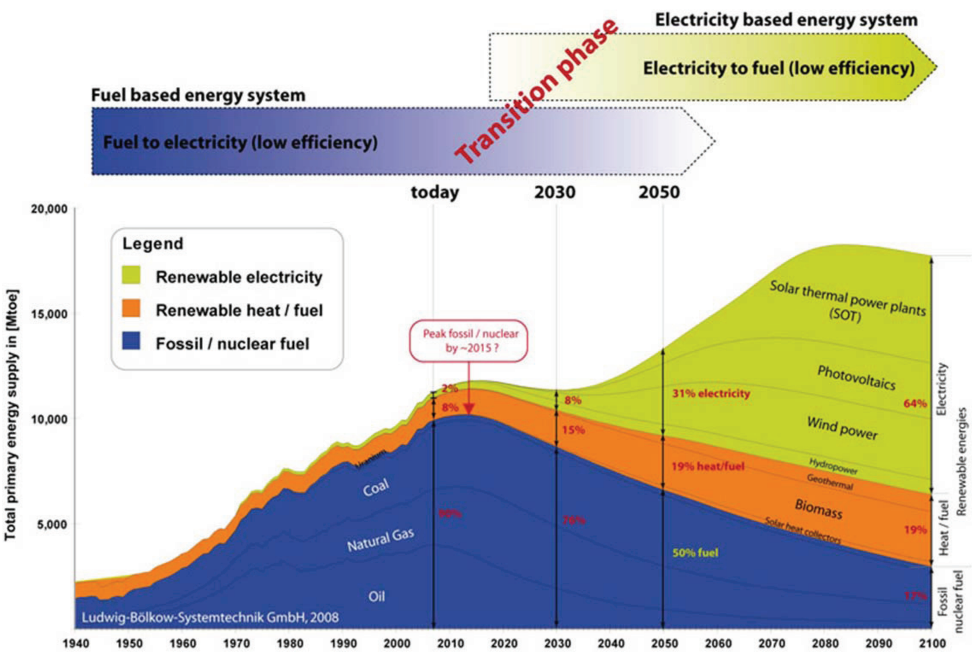

Figure 1: Future primary energy supply.

In the long term, renewable energies will be able to provide more energy than all fossil and nuclear fuels will have been able to supply at their aggregate peak. On a global level, solar energy and wind power can become the major pillars of our energy system.

The transition from fossil fuels to renewable energies is a transition from primary energy fuels (i.e. crude oil, natural gas, coal) to electricity (e.g. from photovoltaics, solarthermal power plants, wind or hydropower). This will offer new options and opportunities but also new challenges for the future energy system.

To a large extent, the transport sector will be electrified. Soon, road vehicles will start to switch to renewable electricity as a “primary energy source”. Hydrogen will become a very essential partner for the future transport sector. As electricity from wind and solar energy is difficult to store, hydrogen will serve as electricity storage and as a transport fuel for future vehicles. Vehicles with longer operating ranges, higher payloads and fast refuelling capabilities very likely will have to be hydrogen fuel cell vehicles in the foreseeable future.

3 First Markets – the Role of By-product Hydrogen

Today, large quantities of excess hydrogen are already available in some regions in Europe. In most cases hydrogen is produced as by-product in chemical processes. Hydrogen from these sources offers an interesting option for first applications in transport and stationary uses.

The major by-product producers in Europe are Germany (~850 m Nm^3/yr), Norway (~650 m Nm^3/yr), France (~300 m Nm^3/yr) and the Netherlands (~100 m Nm^3/yr)

In case hydrogen can be used near the production site, it can constitute an early but also economic source for first large-scale vehicle demonstrations and commercialisations. Also the use in efficient stationary fuel cell CHP units is feasible and economic.

As these sources are not available everywhere, they will have to be complemented by other hydrogen supply sources as time progresses. Nevertheless, these by-product sources can assist in providing low cost hydrogen efficiently, as they save the energetic losses and associated CO_2 emissions of at least 20% incurred by natural gas reforming or other conversion processes.

In order to give an estimate, if it is assumed that 850 million Nm^3 of by-product hydrogen can be made available as vehicular fuel in Germany, some 680,000 efficient fuel cell passenger cars could be operated [assuming an energy consumption of 0.3 kWh/vehicle-km and an annual operating range of 12,500 km/yr]. In a ramp-up strategy to ½ million FCVs towards 2020, these H_2 sources may well be sufficient until the end of the present decade.

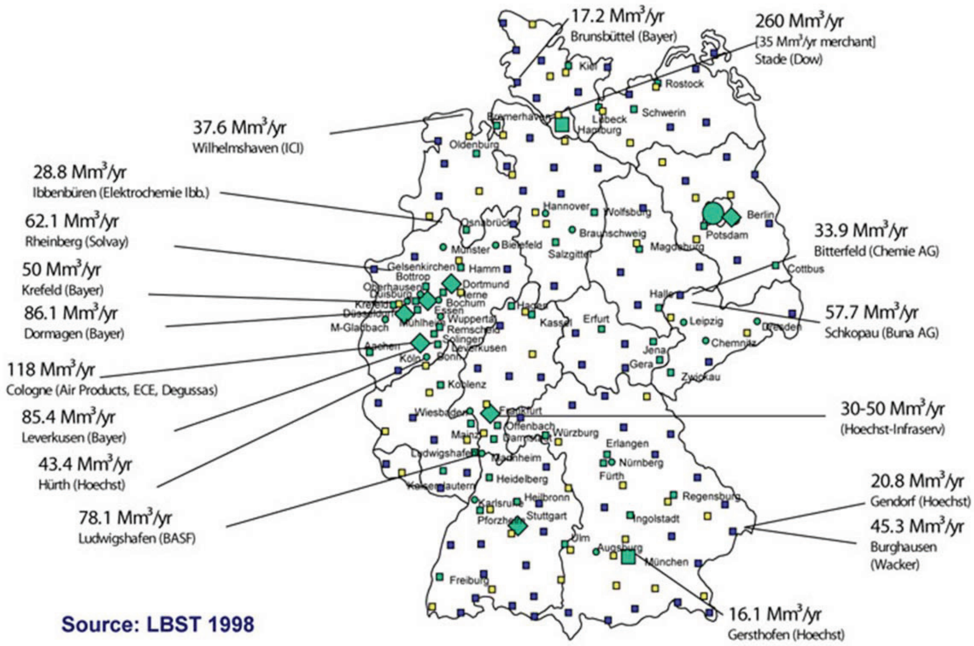

Figure 2: Potential for chemical by-product hydrogen in Germany.

In Germany, at various locations there is a surplus of hydrogen which today can only be burnt for thermal uses. This hydrogen, if substituted 1:1 by natural gas for its thermal uses, could be made available for other energetic uses with higher value, like e.g. vehicle fuel. In most cases purification and additional compression is required. In Germany the potential amounts to between 800 million and 1 billion Nm³/ year or 2.5-3 TWh (9-10.8 PJ).

4 Technical Potential of Renewable Energy

Renewable energy will become the most important energy of the world. [4]

For the EU the largest technical potentials for renewable electricity generation are identified for wind and solar energy. The technical potential in Europe 27 is estimated at 3,500 to 4,000 TWh/yr for wind energy and at 1500 to 2,000 TWh/yr for electricity from solarthermal power stations (SOT) and more than 1,000 TWh/yr for electricity from photovoltaic plants. In Germany the largest potentials are identified for wind and offshore and photovoltaics. (Figure 3)

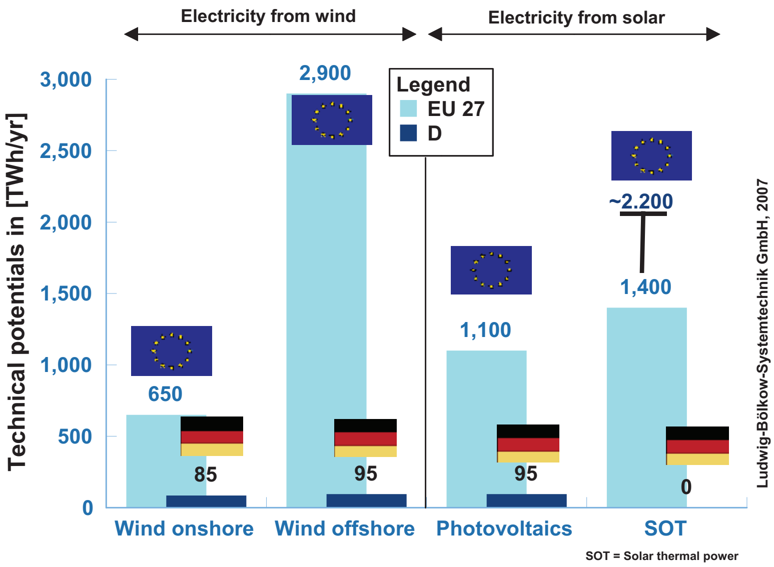

Figure 3: **Technical potential of wind and solar electricity in Europe and Germany.**

4.1 Biomass energy potentials

The potential of biomass for transport fuel production is limited and in direct competition with food production and other usages. The worldwide potential of solid biomass is estimated at about 95 EJ per year [5]. The EU potential lies in the order of 7-8 EJ per year.

Therefore it is not possible to substitute today's EU transport fuel consumption (approx. 15 EJ/ yr) or even a reduced demand of transportation fuel in the future completely by biomass from within the EU. A further increase of biofuel use requires the import of biofuels or biomass. But also on a worldwide level the potentials are limited and there are serious conflicts with the stationary sector for the energetic use of biomass and the food production chain worldwide.

As a result it can be concluded that biomass can only meet a relatively small fraction of the overall energy demand and only in some regions as negative environmental and social impacts should be avoided. The highest fraction of the future energy demand will be met by wind power and the direct use of solar energy.

5 Renewable Electricity Generation

The share of renewable electricity is expected to increase significantly since the largest potentials for renewable energies in Europe and Germany are identified as wind, hydropower, solar and geothermal electricity. In 2007, the German Federal Ministry for the

Environment, Nature Conservation and Nuclear Safety has published the Guiding Study 2007 “Development Strategy Renewable Energies”[6]. This study predicts that the electricity production from renewable resources will increase from 74 TWh in 2006 to 156 TWh in 2020. With regard to the current and presumably also the future electricity production this represents more than 25% of the overall production. This scenario also reflects the already enacted and binding goals of the European Union.

As can be seen in figure 4 the share of fluctuating and non-dispatchable renewable resources (onshore wind, offshore wind, solar) is increasing steadily reaching 59% of all renewable electricity in 2020 where offshore wind energy will be the main contributor to this growth. The proportion of this fluctuating and non-dispatchable resources will amount to 90 TWh in 2020, about 3 times the value of 2006.

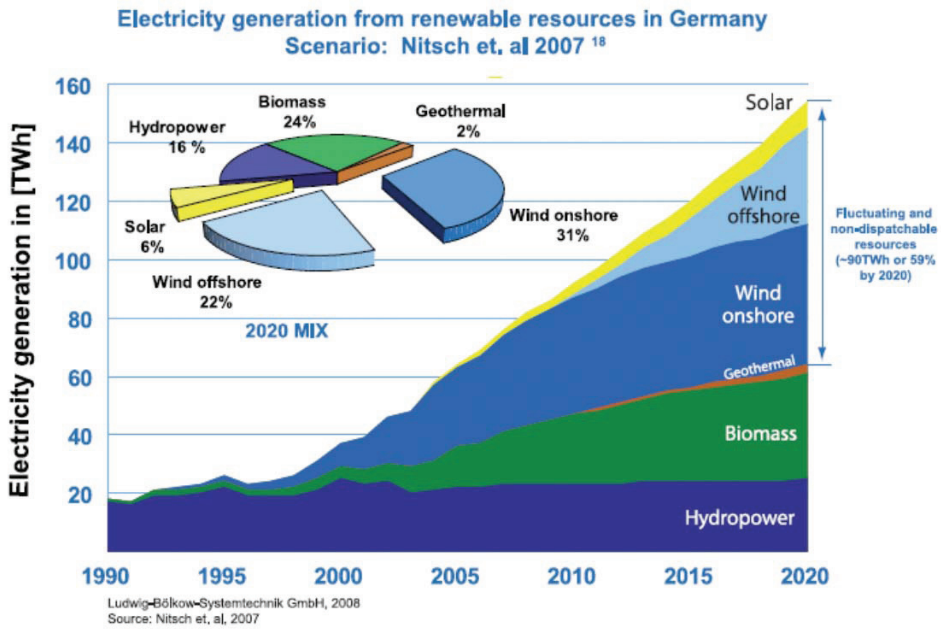

Figure 4: Scenario – renewable electricity in Germany until 2020.

5.1 Renewable electricity storage

With increasing share of renewable electricity our future energy system will require large scale storage systems for electricity. Today, pumped hydro power stations are the only widely used means to store electricity at industrial scale. But the potential for further extension and new installations is very limited. The only technology at present knowledge which has the potential for single storage systems in the 100 GWh range is the storage of hydrogen in underground salt caverns [7].

5.2 Hydrogen as storage for electricity

Hydrogen can be produced from electric power by high pressure electrolysers (≈ 3MPa). For efficient storage hydrogen has to be further compressed before stored in underground salt caverns at a pressure up to 30 MPa. For high power levels the most efficient conversion back to electricity can be achieved in combined cycle power plants. In the lower power range fuels cells can be applied. Round-trip efficiencies are expected to be in the range of 35- 40 %. The achievable storage capacity of compressed hydrogen is more than one order of magnitude higher than the one of compressed air. The storage of compressed hydrogen in salt caverns being relatively cheap, this technology qualifies especially for long-term storage of bulk energy to be reused during long-lasting unavailability of wind energy.

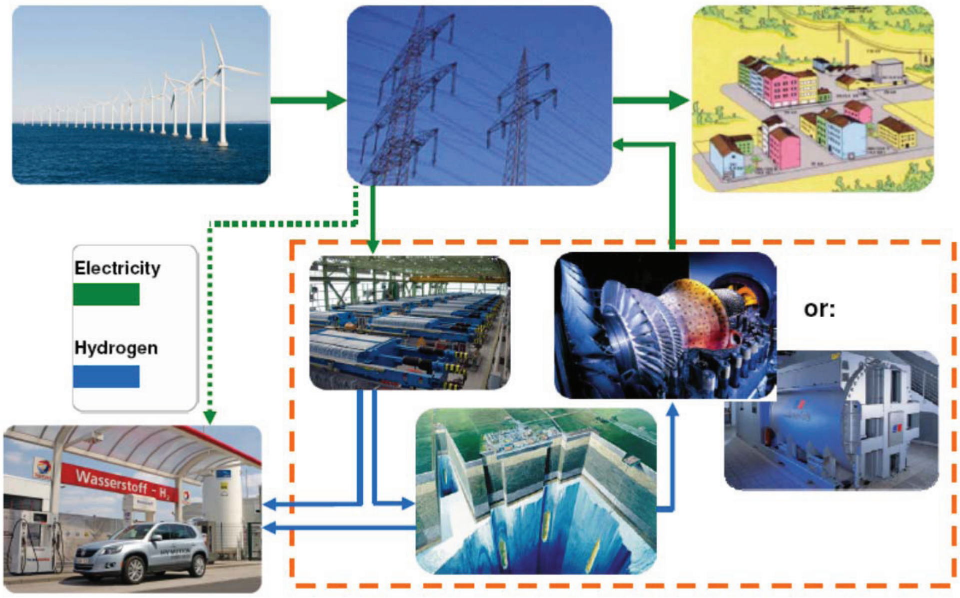

Figure 5: Ways of hydrogen storage.

5.3 Hydrogen as transport fuel

A further pathway for the utilisation of sustainably produced hydrogen will be its use in the transportation sector. The current discussions on CO_2 reduction and the availability of fossil fuels show, that car industry is speeding up with their efforts to develop hydrogen powered vehicles and that first significant vehicle sales can be expected around 2015 followed by a broad market entry towards 2020 (see Capter 6).

Furthermore, it can be observed that hydrogen propulsion in passenger cars is a twice as efficient end-use technology than today's direct injection engines and thus displaces conventional fuels and powertrains more efficiently than using hydrogen in stationary conversion units (combined cycle power plants or fuel cell systems) where it competes for the time being with almost as efficient natural gas-based end-use technologies.

Finally it should be mentioned, that these topics – large-scale storage of hydrogen, utilisation of hydrogen as a storage medium for electrical energy and the utilisation of surplus energy in the transportation sector – only played a sub-ordinate role in RD&D activities in the past.

5.4 Production costs of energies

Energy costs are expected to increase during the next decades due to the depletion of fossil and nuclear energy sources and rising investments in new power plants and infrastructure.

The graph in figure 6 shows rising costs for fossil energy sources and decreasing costs for renewable energies depending on the assumption that the break-even point between fossil and renewable electricity production will occur sometime between 2020 and 2030. Up to this date, the introduction of renewable energies will lead to higher average energy costs whereas after passing the break-even point, the growing contribution of renewable energy sources will reduce electricity costs compared to a purely fossil scenario.

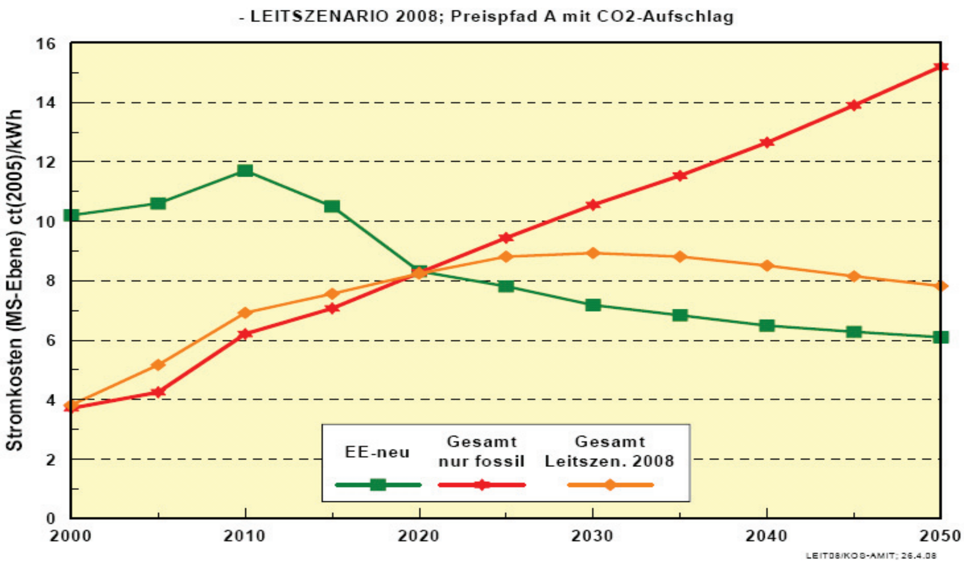

Figure 6: Average electricity cost scenario for renewable and fossil plants [8].

5.5 Infrastructure cost

For a fully functioning hydrogen road transport system in 2035, the HyWays project [www.hyways.de] assumed a scenario covering 6 European countries for which could be shown that more than 60% of the total investment costs have to be brought up for the conventional part of the vehicle.

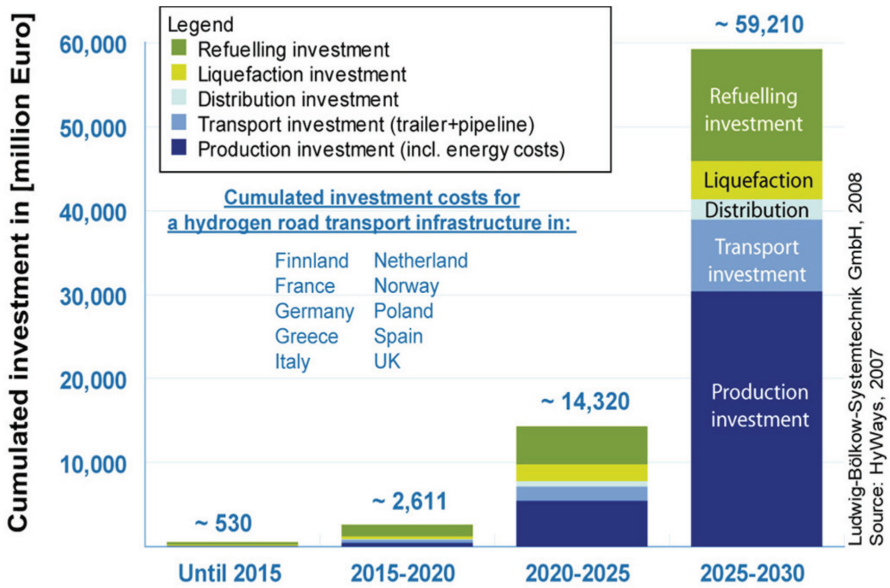

Figure 7: Cumulative investment costs for a hydrogen road transport system in six European countries.

Related to the total investment costs, the H_2 infrastructure part amounts to only 15-20 % of the total investment (i.e. H_2 production, transport, distribution and dispensing). About 60 % of the investment costs have to be brought up for the conventional part of the vehicle. The H_2-specific onboard part of the vehicle (e. g. FC and storage) amounts to about 20 % of the total investment costs.

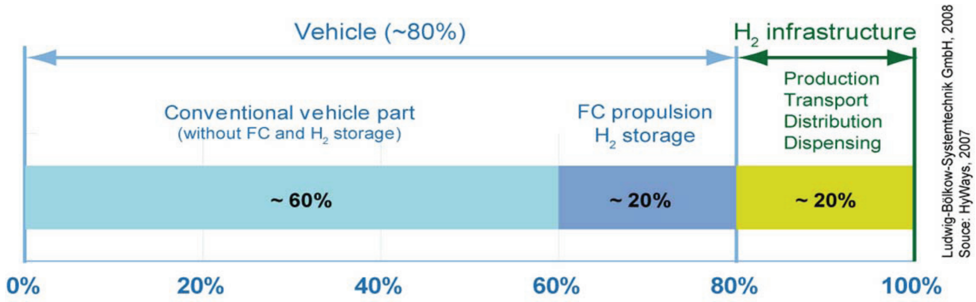

Figure 8: H_2 infrastructure versus H_2 vehicle investment.

Also hydrogen infrastructure costs are not the bottleneck for a fully functioning hydrogen road vehicle system in Europe.

6 Political Consequences and Perspectives

In recognition of the scientific and technical perspectives of the availabilities of renewable primary energies and hydrogen as secondary energy carrier different projects with significant support and financing by policy in Germany (incl. federal states) and Europe were initiated with respect to special topics of hydrogen applications [9].

One of the most important activities was the “Clean Energy Partnership (CEP) with the demonstration of hydrogen-fuelled vehicles with combustion engines and liquid hydrogen (BMW) as well as fuel cells and compressed hydrogen (DaimlerChrysler, VW, Opel, Ford) [10].

In the roadmap study “GermanHy” [11] a comparison of the political goals for the transport sector in Germany and the potentials of hydrogen was executed. (Figure 9)

with significant corresponces.

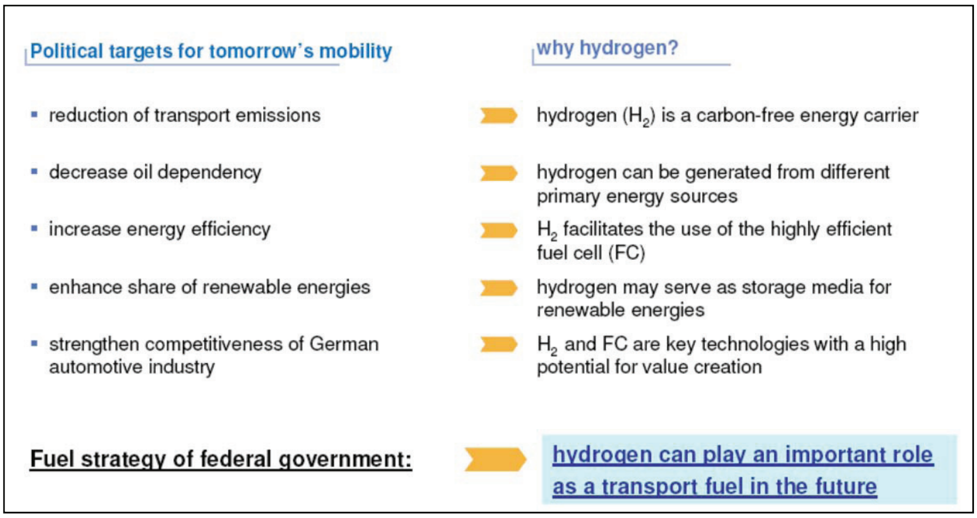

Figure 9: Comparison of political targets of transport sector in Germany and potentials of hydrogen in "GermanHy"[11].

Since 2008, all national activities in the field of hydrogen technology have been consolidated within the National Innovation Programme (NIP), which is administered by the "Nationale Organisation Wasserstoff" (National Hydrogen Organization, NOW). Under this programme, which is funded through equal contributions from the Federal Government and the industry totalling 1.4 billion EUR for a period of ten years, preparations are being made for the launch of hydrogen technologies in the market through research and demonstration projects. The programme focuses on both mobile applications (CEP II) and building energy supply (Callux) (Ill.) [11].

In cooperation of GermanHy and NIP the roadmap for hydrogen was elaborated. This includes a summary of perspectives of car numbers (passenger cars and trucks), H_2-demand and – cost, renewable energy sources and H_2-Infrastructure for the next 40 years as shown in figure 10.

In addition to this scientific study the realisation started in September 2009 by signing two Letters of Understanding by automotive and Infrastructure industry:

1) Daimler, Ford, GM/Opel, Honda, Hyundai, KIA Renault-Nissan and TOYOTA globally anticipate together *"…that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised. This number is aimed at a few hundred thousand (100.000) units over life cycle on a worldwide basis."*
2) Daimler, EnBW, Linde , NOW, OMV, Shell, Total and Vattenfall agree on a German build-up plan for hydrogen-infrastructure, flanking expected serial-production of FC-vehicles starting 2015 by standardization of hydrogen fuelling stations and a joint business plan for area-wide roll-out in Germany (Phase I, till 2011) and a implementation of respective action plan (Phase 2).

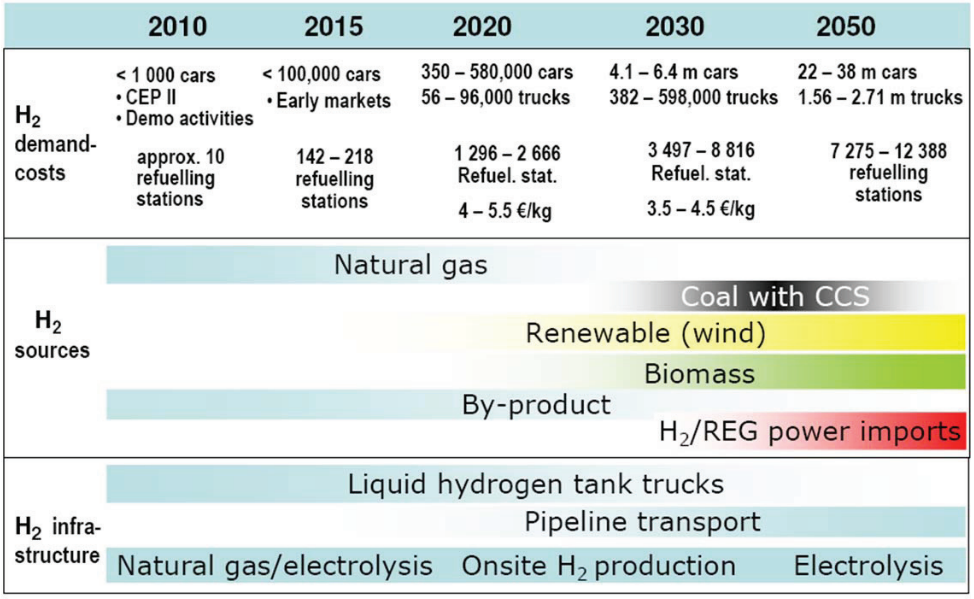

Figure 10: H2-Roadmap for Germany [11].

Additionally to the plans of mobile application the NIP-Programme includes lighthouse projects for fuel cells for domestic energy supply (Callux) and a project for stationary industrial energy supply (NEEDS).

For special markets first applications represent initial steps towards market penetration:

- fuel cell-applications in leisure and tourism markets (boat, light vehicles, caravans, etc.) and small utility and materials handling vehicles
- safe energy supply: public safety communication systems, uninterruptible power supply.

This paper has shown the important role hydrogen can play in a cleaner and more renewable energy and transport system in the future. It furthermore shows how renewable electricity can be phased into the energy system more successfully with hydrogen a crucially important long-term storage component and how the transport system will benefit from the largest potential of renewable energy, electricity, in a much wider scale than could be achieved with battery-electric vehicles only.

References

[1] Communication from the EU Comm.: A European Strategic Energy Technology Plan (SET-Plan), Technology Map, SEC(2007) 1510, sub-chapter “16.6. Synergies with other sectors”, page 48

[2] Energy Watch Group, Crude Oil – The Supply Outlook, Oct. 2007, EWG-Series No 3/2007, http://www.energywatchgroup.org

[3] Energy Watch Group, Coal: Resources and Future Prod., March 2007, EWG-Series No 1/2007,

[4] J. Schindler et.al. "Hydrogen and Fuel Cells as strong Partners of Renewable Energy Systems", Study of EHA and DWV, 2008, www.h2-info.de

[5] M.Kaltschmitt et al., Energie aus Biomasse ,Springer, (2001), ISBN 3-540-64853-4

[6] J. Nitsch, "Lead Study 2007", DLR Institute for Technical Thermodynamics, Feb. 2007

[7] W.Leonhard et.al. "Energiespeicher in Stromversorgungssystemen mit hohem Anteil erneuerbarer Energien, Study of VDE/ETG, Dec.2008

[8] J. Nitsch, "Lead Study 2008", DLR Institute for Technical Thermodynamics, October 2008

[9] J.Töpler, R. Wurster, "National strategies for hydrogen and fuel-cell technology" in BWK , Bd.62, Nr 4, (2010), S2-S3

[10] www.cleanenergypartnership.de

[11] www.germanhy.de