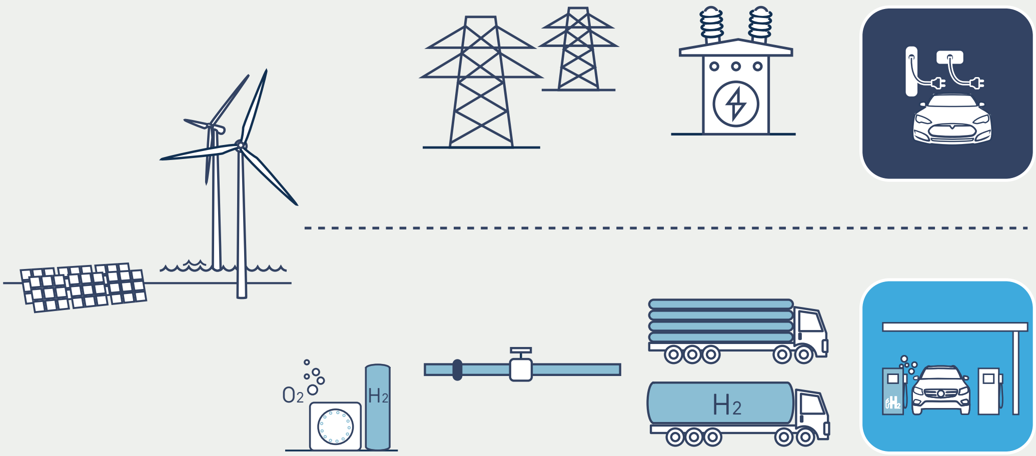

Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles

Martin Robinius, Jochen Linßen, Thomas Grube, Markus Reuß, Peter Stenzel, Konstantinos Syranidis, Patrick Kuckertz and Detlef Stolten

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Summary for Policy Makers

Electric drivetrains are key elements of low carbon energy-efficient transport based on renewable energy sources. Furthermore, a transportation system with zero local emissions will substantially improve people's quality of life, especially in urban areas currently struggling with air quality issues. Both Battery and hydrogen fuel cell electric vehicles feature these important characteristics. However, large scale integration of these vehicle technologies requires new infrastructures.

Objective and approach

The goal of the study is to perform a detailed design analysis of the required infrastructure for supplying battery and fuel cell electric vehicles in Germany at multiple scales. The underlying question concerns the investments, costs, efficiencies and emissions for an infrastructure capable of supplying between one hundred thousand to several million vehicles with hydrogen or electricity. At present, both technologies are in the initial stage of their market development and are posed to take advantage of the unavoidable surplus electricity that characterizes renewable dominated energy systems. In any case, an effective infrastructure is required to make this energy available. However, at present the design of an applicable infrastructure is unclear. To illuminate this topic, the approach of the infrastructure analysis is transparent and the results of the analysis support a facts-based discussion which can simply be adapted to the growing level of experiences.

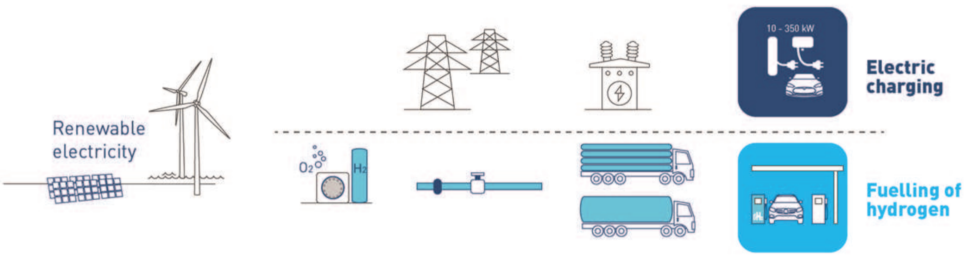

Figure 0-1: Schematic diagram of considered infrastructure set-ups.

As part of the study, an extensive meta-analysis of existing studies on infrastructure requirements for each of the technologies is performed. However, with respect to higher market penetration in particular, these studies have proven to be insufficient or contain non-transparent data. Consequently, the main body of the analysis revolves around the study's own scenario calculations for infrastructure design and techno-economic analysis.

Results

The scenario analyses demonstrate that, for low market penetration levels of a few hundred thousand vehicles, the costs of infrastructure roll-out are essentially the same for both technology pathways. Hydrogen is found out to be more expensive during the transition period to electricity-based generation via electrolysis and geological storage, both of which are needed to access renewable hydrogen from surplus electricity. In the scenario for charging battery electric vehicles no seasonal storage option is considered and grid electricity for charging is generated in part by non-renewable energy sources. If vehicle penetration increases up to 20 million vehicles in the base case scenario, a battery charging infrastructure would cost around € 51 billion, making it more expensive than hydrogen infrastructure, which comes in at around € 40 billion. Additionally, securing supply based on renewable electricity requires a consideration of seasonal storage options. For the 100 % excess electricity-based hydrogen production, seasonal storage capacity is set to bridge 60 days at low renewable electricity generation. An adequate solution is required to achieve the same level of security of supply for electric charging based on renewable energy sources.

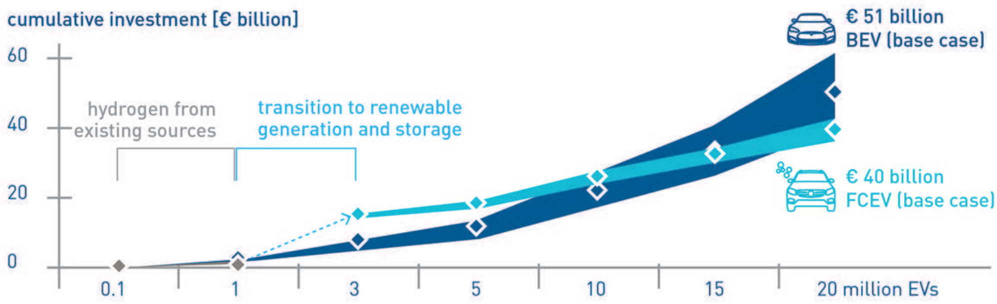

Figure 0-2: Comparison of the cumulative investment of supply infrastructures.

The mobility costs per kilometer are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km for hydrogen fueling. Because hydrogen permits the use of otherwise unusable renewable electricity by means of on-site electrolysis, the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs.

For the scenario with 20 million fuel cell electric vehicles approx. 87 TWh of surplus electricity for electrolysis and 6 TWh of grid electricity for transportation and distribution are required. On the other hand, charging 20 million battery electric vehicle accounts for an electricity demand of approx. 46 TWh out of the distribution grid.

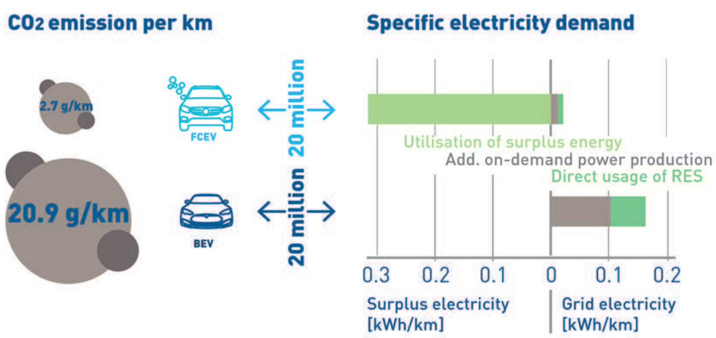

Figure 0-3: Comparison of specific energy demand and CO_2 emissions.

The efficiency of the charging infrastructure is higher, but limited to flexibility covering short-term periods. The available surplus energy in the assumed renewable dominated electricity scenario exceeds by factor of three to six the demand to supply 20 million electric vehicles.

According to the use of surplus electricity, renewable and fossil electricity out of the grid, the corresponding CO_2 balance for the high penetration scenario shows low specific emissions in comparison to the use of fossil fuels. The hydrogen infrastructure with the inherent seasonal storage option has lower CO_2 emissions because of the high use of renewable surplus electricity. The application of controlled charging can improve the use of surplus and renewable electricity, thus decrease specific CO_2 emissions of battery electric vehicles.

Conclusions

The conclusion can be drawn that electric charging and hydrogen fueling are key to realize low carbon, clean and renewable energy based transportation concepts.

A smart and complementary combination of the electric charging and the hydrogen refueling infrastructure can join the strengths of both and can avoid non-sustainable solutions with low systems relevance or efficiency. Taking advantage of low hanging fruits like overnight charging of battery electric vehicles for short distance travel and meeting the challenges in long distance and heavy duty transport by fuel cell electric vehicle and hydrogen refueling can be beneficial with regard to systems solutions. Insofar, a hybrid strategy for the roll-out of both infrastructures will help to maximize energy efficiency and to optimize the use of renewable energy resources while minimizing CO_2 emissions over a broad range of purposes and transportation modes. Both infrastructures require a small amount of investment compared to other infrastructures (e.g. roll-out of renewable electricity generation or the maintenance and expansion of transportation routes, see figure 6-31).

While electric charging infrastructure allows for higher efficiency, hydrogen infrastructure roll-out for transportation enables further large-scale applications in other sectors like industry. Understanding hydrogen fueling infrastructure as energy systems solution can unleash the full potential of realizing sector coupling.