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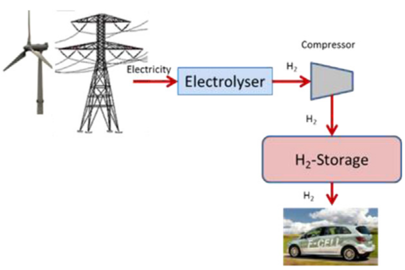
Economic prospects and policy framework for hydrogen as fuel in the transport sector

Amela Ajanovic*, Reinhard Haas

Vienna University of Technology, Energy Economics Group, Vienna, Austria

GRAPHICAL ABSTRACT



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ABSTRACT

For a long time hydrogen has been considered a clean energy carrier to be applied universally and contribute to a sustainable energy system. However, in the real energy world hydrogen has not yet delivered. The major reason is that it has still to become economically feasible. With increasing electricity generation from variable renewables and its temporarily cheap surplus production, new prospects for hydrogen are on the horizon especially due to the rising need for a solution to the problem of the long-term storage of excess electricity.

The core objective of this paper is to analyze the economic prospects of hydrogen use in the energy system keeping in mind two challenges: (i) integration of variable renewables in power systems, and (ii) substitution of fossil fuels in the transport sector. The future economics of hydrogen in passenger car transport is investigated regarding hydrogen production costs and possible learning effects of the fuel cell vehicles.

The major conclusion is that the future perspective of hydrogen use depends on the policy framework, the full exploitation of economies-of-scale and technological learning for electrolysis as well as possible full-load hours per year. However, cost reduction of fuel cells for mobility through technological learning is essential for the economic competitiveness of hydrogen use in transport.

1. Introduction

The global energy system currently faces two major challenges. On the one hand it is important to ensure a sufficient and secure energy supply. On the other hand, it is important to reduce energy-related greenhouse gas (GHG) emissions and to move towards a sustainable energy system. In this context two issues are of highest priority: (i) the increasing use of renewable energy sources (RES), and (ii) the provision of clean energy carriers.

For a long time, hydrogen has been discussed as the energy carrier of the future. Already in 1874, in his novel "The Mysterious Island" the French science-fiction writer, Verne saw hydrogen and oxygen as the energy sources of the future (Verne, 1874). In his vision, hydrogen was produced by the breaking down of water (via electrolysis) and would

* Corresponding author.
E-mail addresses: ajanovic@eeg.tuwien.ac.at (A. Ajanovic), haas@eeg.tuwien.ac.at (R. Haas).

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replace coal, which at the time was the primary energy source (Shell, 2017).

Due to increasing fossil fuel prices in the 1970s and more and more visible environmental problems, the interest in alternative fuels and technologies intensified. At that time the concept of a solar economy was developed, with hydrogen as the central energy carrier (Shell, 2017; Ajanovic, 2015).

With technological progress achieved in the 1990s, the discussion on hydrogen has intensified at the beginning of the 21st century. Hydrogen is considered to be a clean energy carrier to be applied virtually universally leading the world towards a sustainable energy future, see Rifkin (2003). In his seminal contribution, “The Hydrogen Economy”, Rifkin envisions the dawn of a new economy powered by hydrogen that will fundamentally change the nature of our market, political and social institutions, just as the change to coal and steam power did at the beginning of the industrial age. Rifkin observes that we are fast approaching a critical watershed in the fossil-fuel era with potentially dire consequences for industrial civilization. He claims that policy makers have to anticipate the consequences and make significant interventions to turn the energy system towards a CO_2-emission free future.

The possible benefits of hydrogen in the energy transition were recognized by European policy makers and stakeholders in the early 2000s, see (EC, 2003). The strategies for the transformation of the current energy system towards a more sustainable one include, among others, further technological developments in the concepts of converting renewable power into easily-storable energy carriers such as hydrogen, as well as the implementation of corresponding policies.

In 2003 the European Commission presented a roadmap showing how an integrated energy system based on hydrogen and fuel cells might appear up to 2050. A skeleton proposal with the main elements and time lines of the European hydrogen and fuel cell roadmap is presented in Fig. 1 (EC, 2003).

More recently, the IEA (International Energy Agency) has published a technology roadmap discussing the role of hydrogen, and providing recommendations for actions for different stakeholders when heading towards hydrogen-based energy systems (IEA, 2015a, 2017). However, in the real energy world hydrogen has not yet delivered. The major reason is that it has yet to become economically feasible.

However, rapidly growing electricity generation from variable RES, such as wind and solar energy could lead to new chances for hydrogen due to an increasing imbalance between energy supply and demand. As an example, in Fig. 2a hypothetical scenario is depicted with a high level of electricity generation from wind, solar and run-of-river hydro plants using synthetic hourly data for an average year in Austria over a week in summer. Imbalance between electricity supply and demand can be observed, as well as the corresponding volatility in electricity market prices. With the increasing use of photovoltaics (PV) and wind for electricity generation, increasing amounts of temporarily cheap or even free surplus electricity could also become available (Haas et al., 2013). Already in recent years, for example in Germany, prices on the electricity market have fluctuated greatly mainly due to the increasing quantities of the new variable RES.

One of the means of coping with this challenge is to convert electricity to hydrogen and create a back-up capacity for electricity generation or to use hydrogen for other energy services.

Over the last few years, different aspects of hydrogen have been analyzed in literature. Bartels et al. (2010) analyzed the economic attractiveness of different hydrogen production technologies, concluding that coal and natural gas are the most attractive processes from an economic perspective, however, without considering technological improvements and environmental concerns. Environmental aspects of mobility with hydrogen are evaluated by Ajanovic (2013), Burkhardt et al. (2016), and Sweeting and Winfield (2012). A comprehensive literature review on economics of fuel cell vehicles, as well as other electric vehicles, is provided by Veziroglu and Macario (2011), Hervey (2018). Economic assessment of hydrogen as a renewable fuel for a transport is analyzed by Specht et al. (1998), Ajanovic (2008) and Singh et al. (2015). Detailed cost analyses of fuel cell systems have been conducted by Sinha et al. (2008) and James et al. (2010). They have reported that economies-of-scale have a major influence on fuel cell component costs. Based on work of these authors, Miotti et al. (2017) conducted an integrated environmental and economic assessment of current and future fuel cell vehicles. They find out that economies-of-scale effects alone are not sufficient to make fuel cell vehicles competitive with conventional cars. Marchenko and Solomin (2015) have compared hydrogen and electricity in terms of energy and economic expenditure for each stage of these technologies, concluding that in case of short-term energy storage it is more preferable to use the electric system, whereas in the long-term energy storage the hydrogen system is more efficient. Ball and Weeda (2015) provide a comprehensive coverage of the most relevant aspects related to the wider use of hydrogen in the energy system. They state the relevance of a higher number of full-load hours and low electricity prices for economic viability of hydrogen production. Several authors address the role of hydrogen in different countries or regions (e.g. Sgobbi et al., 2016; Usher and Strachan, 2012; Ball et al., 2007; Sigal et al., 2014; Sacramento et al., 2013; Rahmouni et al., 2017; Ogden et al., 2014; Liu et al., 2018). Regardless of different focusses and approaches, most common conclusion of all these studies is that investment costs of hydrogen

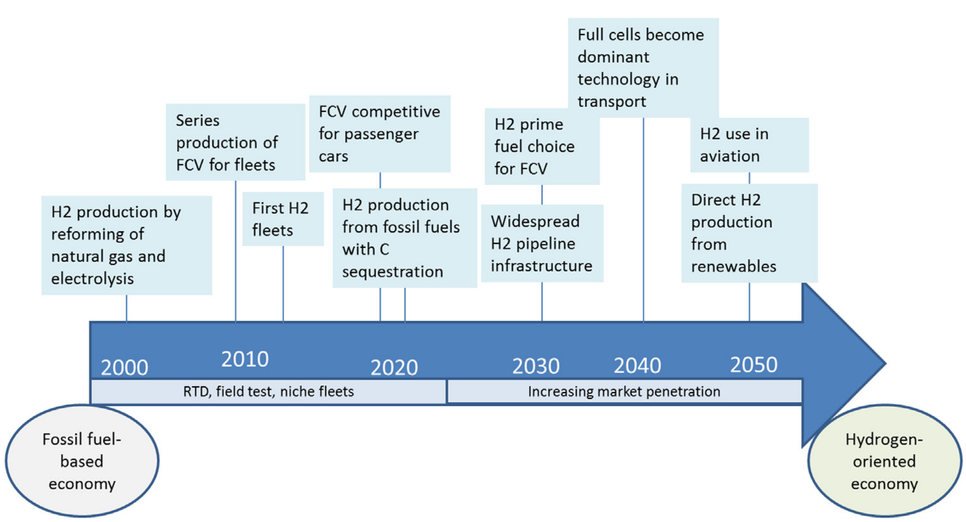

Fig. 1. Major milestones in the European hydrogen vision.