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An economic analysis of the production of hydrogen from wind-generated electricity for use in transport applications

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ABSTRACT

Wind-generated electricity is often considered a particularly promising option for producing hydrogen from renewable energy sources. However, the economic performances of such systems generally remain unclear because of unspecified or favorable assumptions and operating conditions. The aim of this paper is to clarify these conditions by examining how the hydrogen produced is used. The analysis that has been conducted in the framework of the HyFrance 3 project concerns hydrogen for transport applications. Different technical systems are considered such as motorway hydrogen filling stations, Hythane®-fueled buses or second-generation biofuels production, which present contrasted hydrogen use characteristics. This analysis reveals considerable variations in hydrogen production costs depending on the demand profiles concerned, with the most favorable configurations being those in which storage systems are kept to a minimum.

1. Introduction

While the prospects for developing hydrogen use in stationary applications should not be ignored, the main focus today is on the use of this energy carrier in mobile applications. Most studies that have looked into the development of hydrogen consider its use in transport applications and in the framework of ambitious climate policies (European Commission (EC), 2006; Protech-H2, 2009). In this type of context, producing hydrogen from zero-carbon sources would become a prerequisite, albeit not always sufficient on its own, implying important changes in the energy mix used to produce hydrogen beyond 2030: introduction of CO_2 capture, the use of nuclear power and the gradual inclusion of higher proportions of renewable energy. Among these renewables, wind energy could play a key role since this is a sector that is growing rapidly and one in which performance is constantly improving. This growth could be further consolidated by the hydrogen sector through the development of storage systems to compensate for the intermittent nature of wind energy.

Detailed analyses of the production of hydrogen from wind energy have been carried out over the last several years. While some of the results appear promising, generally speaking the associated costs are far higher than those entailed in producing hydrogen by methane reforming, and to a lesser extent, by coal gasification or water electrolysis using the existing electricity mix (IEA, 2005; Bartels et al., 2010; Protech-H2, 2009). However, it is not always possible to analyze these published results because the assumptions are insufficiently explicit (HyWays, 2007) with regard to production and operating conditions.

The aim of the present study, which was conducted in the framework of HyFrance3 (cf. Box 1), is to show that while results clearly depend on the technical and economic assumptions that are made, they also depend to a large degree on the hydrogen demand profiles concerned. While the most obvious case is that of meeting hydrogen demand for hydrogen-powered vehicles in motorway filling stations, we shall also examine more specific profiles that also involve the use of hydrogen as a fuel: a fleet of Hythane®-fueled buses (methane–hydrogen mixture) and a process for producing second-generation biofuels (BtL 2G). Finally, we also present results for a non-transport configuration involving the storage of wind-generated electricity in the form of hydrogen, the aim being to evaluate the interest in such a system in the context of intermittent electricity supply sources.

The HYFRANCE3 Project

The aim of the HyFrance3 project is to assess developments in the use of hydrogen in industry and the cost of hydrogen for mobile applications in French regions (Le Duigou et al., 2010).

The project lasting 20 months (May 2009–Nov. 2010) involve a consortium of 10 partners: Air Liquide, Total, EdF

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R&D, GDF Suez, CNRS-LEPII, IFP, AFH2, ALPHEA, ADEME (co-funder and partner) and the CEA (coordinator).

Complementing the medium- and long-term vision (2020–2050) developed in HyFrance1 and HyFrance2 (Agator et al., 2006), which were national applications of the European HyWays project, HyFrance3 was set up to examine prospects and developments, as well as the economic competitiveness of different steps of the hydrogen value chain, for the mid-term 2020–2030, in the context of industrial and energy applications.

– current situation and changes in demand for hydrogen in industrial markets,
– mass storage and distribution in the Rhône-Alpes and PACA regions and
– estimation of the costs of producing hydrogen from wind power for different transport requirements.

2. Statement of problem

Producing hydrogen from wind energy is often cited as a method for increasing the proportion of wind power in the energy mix since such production can absorb the fluctuations in the resource and create new uses for the electricity produced, particularly in transport applications. But the technical and economic analyses performed for wind–hydrogen systems remain partial and should be developed further.

A hydrogen production system based on wind energy can be set up in three different ways:

– Electricity produced from the wind turbine, or the wind turbine array, can be dedicated solely to hydrogen production, without connection to the grid;
– Grid connection can provide back-up electricity for hydrogen production to ensure that the electrolyzer can operate at full capacity even if there is insufficient wind;
– Grid connection can ensure back-up electricity when there is insufficient wind power, as in the previous configuration, but it can also provide the opportunity for injecting surplus electricity production into the grid if the electrolyzer does not have the capacity to use it.

With the addition of hydrogen storage, production can be adapted to the characteristics of hydrogen demand. Grid electricity prices must also be taken into account, since it does not always make sense economically to purchase electricity at peak tariffs in order to continue to produce hydrogen at times when there is insufficient wind power.

These configurations differ therefore in terms of the volume of hydrogen produced for a given wind energy production capacity, the technologies chosen (in particular for the electrolyzer), the hydrogen production costs and the impact on the electricity grid.

The present study estimates the cost of producing hydrogen from wind energy by simulating different options for producing hydrogen by electrolysis using wind energy, grid electricity and hydrogen storage, taking into account the end-use of the hydrogen.

3. Literature review

Over the last few years there has been growing interest in the possibilities offered by hydrogen storage and the direct use of hydrogen (for example, in fuel vehicles) as ways of overcoming the problems of large-scale storage of electricity. It is not possible to mention all of the studies published on the subject, but we have reviewed the results of some studies that are closely related to the particular aspects of our own (hydrogen production from wind energy with or without grid connection).

The configurations described in the literature differ widely: a system with electrolyzer to produce hydrogen at the wind farm then transport and store it elsewhere, or a system with electricity transmitted via the grid and production of hydrogen at the point of use, for example. Similarly, the capacity of the electrolyzers and storage facilities varies depending on the demand profiles in question. Finally, and most importantly, the assumptions concerning the costs of the different segments of the hydrogen production/storage chain vary considerably and of course have a decisive influence on the hydrogen production costs obtained. For these reasons, rather than comparing the results with our own, we simply review the assumptions made in these studies and the general level of the costs obtained.

Linnemann and Steinberger-Wilckens (2007) examined the possibilities and economic interest of utilizing intermittent wind-generated electricity in the form of hydrogen. The authors looked at two contrasting technical solutions: a small (experimental) system to supply 100 vehicles for 1 yr with the hydrogen produced by a single 1.5 MW wind turbine; and a large system with a group of 100 MW electrolyzers supplied by a 1000 MW wind farm. The first case is quite similar to the configurations studied in the HyFrance3 project. The second is considerably different in that it requires a transport and distribution infrastructure to supply the filling stations and industrial and domestic consumers. The overall production cost, including the costs of production, transport and distribution (2nd case) and storage, was estimated at 24 €/kg[1] for the experimental system, and 10 €/kg for the large-scale configuration. According to the authors, cost reductions can be obtained, thanks to the possibility of economies of scale for the different components, especially the electrolyzers, which represent a large part of the required investment.

These results have been confirmed by several studies, including in particular that by Jørgensen and Ropenus (2008). For several wind energy development scenarios, they observed that hydrogen production costs were extremely high when the rate of use of the electrolyzers was low. They concluded that it would be difficult to envisage installing electrolyzers that would operate essentially to utilize surplus wind-generated electricity during periods of excess production, even in situations where there is a high penetration of wind energy. Similarly, Aguado et al. (2009) confirmed that a wind farm with a hydrogen energy storage system avoided the problems of grid management associated with wind-generated electricity production and helped increase grid penetration of intermittent energy sources. But they also found that the benefits of having better control of intermittent electricity generation did not compensate for the additional investment in the hydrogen storage system.

Bartholomy (2005) looked at the possibilities of producing hydrogen from wind sources to fuel vehicles in California. He too studied two options. In the first, electrolyzers produced hydrogen at the wind farm site itself, as and when the wind power was available. But the large underground storage reservoirs required for such an option would make this type of scheme uneconomic at present. In the second, a distributed production model, the wind-generated electricity was transmitted through the grid to electrolyzers installed at the points of use. The costs of each option were estimated assuming huge growth in the hydrogen

[1] All costs have been converted to Euros (2008 economic conditions) to facilitate comparison.