Is There a Winner: A Study of Competition Among Hydrogen Technologies

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Overview

Over the past decade, hydrogen emerged as the innovation in support of energy transition across the world (IEA, 2019; IRENA, 2018; Agora, 2019; NRC & NAE, 2004). Hydrogen is a carbon-free versatile source of energy that can be used in a variety of sectors, including electric power generation, heating, transportation, and has other industrial uses. Despite its attractive characteristics, the development of hydrogen has been obstructed by costs related to 1) co-produced CO2 or solid carbon, 2) input factors of production, and 3) infrastructure related barriers. Reviews of the potential for the hydrogen industrialization and energy mixture penetration, however, recognize that the mentioned costs vary dramatically across hydrogen production technologies (Chapman et al., 2019). In this context, for industrial developers, choosing the technologies to invest, and for governments, asking which technology to support, it is important to know how to compare the future competitiveness of hydrogen technologies against each other and against other energy sources.

The purpose of our analysis is twofold: 1) develop a comprehensive bottom-up workflow to evaluate hydrogen supply and 2) apply that workflow, confirming the approach is granular and broad enough, to determine competitiveness and potential barriers of various hydrogen technologies. The developed integrated workflow for assessing economic viability of the hydrogen technology considers the key elements of the value chain, including:

- the input factors of production (fossil / non-fossil natural occurring, like water / synthetic, like biogas),
- generation and marketing of useful energy output (measured in kWh), and
- management of carbon residuals (solid carbon vs. carbon dioxide).

We test the workflow by looking in the hydrogen projects realized across the world, focusing on the regions with different input and final product market environments.

The performed analysis allows us revealing what impedes and what facilitates hydrogen development in different regions. Especially, we focus on how input factor costs, output energy prices, options and costs of carbon management, and uncertainty with regard to infrastructure development in the future.

Methods

Our analysis starts with the review of the currently realized hydrogen production projects and development of the related infrastructure, e.g. for storage, transportation, and cooling. We collect the data on 1) the companies funding or participating in those projections, distinguishing oil and gas upstream and midstream operators, downstream energy and power distributors, energy consumers, and new "green industry" players, 2) type of hydrogen technology used, i.e. methane-based, coal-based, land-fill gas-based, water-based, renewable-energy based, 3) energy efficiency of technologies in terms of energy used, produced, and carbon emissions saved, and 4) carbon output and the suggested ways for the captured carbon management.

The compiled database is used to draw a block scheme of capturing a variety of possible hydrogen supply chains architectures. The block scheme is then translated into the workflow for the hydrogen technologies evaluation, embracing the steps and decisions in the evaluation process.

Based on the schematic, we find that hydrogen supply can be represented either by a) a supply network with potentially multiple input, output, and infrastructure players or by b) a vertically integrated supply chain. We build the framework for comparative analysis adopting the model by Kranton & Minehart (2000) and Zhang (2006). The model is used to analyse how the hydrogen supply profits are distributed among the supply chain or network players depending on the supply structure, competition or prices at each supply link, and capacity constraints.

We expand the model by allowing for input price discounting, scale and network effects, pre-existing business integration. In the context of the model, we describe the evaluation of each link of the hydrogen supply chain depending on its connection to the other links.

The formation of supply chains and networks is seen as a two-stage game, when firms first invest in technologies, which termine the supply structure in the next stage, when production and supply gains are realized.

Results

The model of hydrogen supply economics reveals the differences in cost structures, and therewith profitability drivers depending on the supply structure. The profit-sharing among supply chain and supply network players explains why some technologies are supported by upstream companies, who also are input factor providers; whereas other technologies are chosen to support and benefit the pre-existing business with positive network externalities. The large players enjoy input price discounts and benefit from economies of scale, focusing on a trade-off beween technology choice and supply flexibility. The smaller players with weaker network position are more sensitive to price uncertainty and prone to invest in technologies with positive externalities on their pre-existing business.

Our preliminary results are based on several hydrogen (incl. pilot) projects realized in UK, Germany, U.S., Australia, Japan, and Canada. Those projects include hydrogen production from: fossil fuels, such as steam reforming, partial oxidation, methane pyrolysis, and water-gas shift; and renewable sources, such as biomass and land-fill gasification, electrolysis, and thermochemical water splitting. The analysed projects were initiated and supported by heterogeneous players: upstream and midstream oil and gas companies; natural gas and power distributors; industrial energy consumers; and small business companies.

We find that the choice of the technology is linked to the local prices of inputs and their availability. Thus, regions producing or exporting natural gas are prone to develop methane-based technologies. We also found that the energy and capital evaluation of the technology is affected by the input power requirements and consequently, power prices. We find the greatest diversity of projects to be implemented, under development and proposed in the energy importing regions, such as Germany, France, and Japan. Yet, based on the project developers we also find that local energy suppliers are prone to build hydrogen production integrating some of their existing energy distribution businesses.

Conclusions

The main conclusion of our analysis is that different hydrogen technologies are likely to co-exist in the future across different regions depending on 1) input factor pricing and availability, 2) regulation and possibilities for carbon product management, and 3) local and global hydrogen marketing opportunities.

For instance, our model confirms that regions, like California, with available and relatively cheap water resources, expensive fossil energy, possibility to develop needed supply infrastructure, and with available investor capital would find electrolysis production to be more attractive. While regions like Texas or Australia with abundant and cheap natural gas but expensive infrastructure, would prefer methane-based production technologies.

Based on our study, the European Union has will continue to struggle choosing the preferred technology facing the expensive exporter-decision dependent supply of natural gas, difficulties in infrastructure expansion or modification, and coordination across EU countries. In this regard, the push towards "green" hydrogen can be explained by the disadvantages of the alternative, rather than the attractiveness of the "green" technology.

Finally, we find that the issue of carbon management may affect the competitiveness of hydrogen technologies not only from the cost perspective, but also as a potential constraint.

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