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RESEARCH BRIEF

Energy Conversion and Storage: The Value of Reversible Power-to-Gas Systems

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Power-to-Gas technology has recently seen falling acquisition costs and lower conversion efficiency losses. At the same time, wholesale power markets have experienced increasing volatility with significant amounts of surplus electricity at select hours of the year. Here we examine the economic potential of reversible Power-to-Gas systems that can convert electricity to hydrogen or operate in the reverse direction to deliver electricity during times of high power prices. Our model framework is applied to the current market environment in both Germany and Texas. We find that the reversibility feature of solid oxide fuel cells makes such systems already competitive at current hydrogen prices, provided the fluctuations in electricity prices are as pronounced as currently observed in Texas. We project that the flexibility inherent in reversible fuel cells would leave investments in such systems economically viable in the future even at substantially lower hydrogen prices, provided recent technological improvements continue over the coming decade.

The large-scale deployment of intermittent energy resources, like wind and solar, has generally resulted in deregulated power markets becoming more volatile (Olauson et al., 2016; Davis et al., 2018). To balance supply and demand for electricity in real time, energy storage in the form of batteries or pumped hydro power is playing an increasingly important role. At the same time, hydrogen is increasingly viewed as an energy carrier with broad application potential in decarbonized energy economies (De Luna et al., 2019; Staffell et al., 2019).

Power-to-Gas (PtG) systems that split water molecules into hydrogen and oxygen via electrolysis can rapidly absorb surplus electricity during times of low prices (Shaner et al., 2016; Van Vuuren et al., 2018). This buffering capacity of PtG systems can be enhanced further by systems that are also capable of operating in the reverse direction, converting hydrogen to electricity during periods of limited power supply and accordingly high power prices (Albertus, Manser and Litzelman, 2020).

Reversible PtG systems can be designed in a modular manner, for instance by combining a one-directional electrolyzer for hydrogen production with a one-directional fuel cell or gas turbine for power generation (Guerra et al., 2020; Uniper SE, 2020). While electrolyzers have been found to become increasingly competitive in producing hydrogen (Guerra et al., 2019), fuel cells and gas turbines have so far been regarded as too expensive for producing electric power sold in wholesale markets (IEA, 2019).

Alternatively, solid oxide fuel cells constitute integrated PtG systems, as the same equipment can be utilized to deliver either hydrogen or electricity depending on the state of electricity prices at any given point in time. Solid oxide cells have been brought to market recently and their reversibility feature has been established in several studies and demonstration projects (elcogen, 2018; Regmi et al., 2020).

This paper first presents a novel analytical model examining the economic viability of reversible PtG systems. We then calibrate the model in the context of the electricity markets in Germany and Texas. Despite improvements in the cost and conversion efficiency of modular PtG systems, we confirm the findings of earlier studies that there is no economic case, either now or in the foreseeable future, for investing in modular systems that convert hydrogen back to electricity.

In contrast, we find that integrated PtG systems are competitive at current hydrogen prices, given sufficient variation in daily electricity prices, as is already encountered in the Texas market. While it is efficient for such systems to mostly produce hydrogen, they can also respond to high power prices with additional electricity supply. Due to this improved capacity utilization, integrated systems are positioned more competitively than one-directional electrolyzers on their own.

Finally, if recent trends regarding the acquisition cost of solid oxide cells continue, such systems will remain economically viable even with substantially lower hydrogen prices in the future. The reason is that the inherent flexibility of integrated reversible PtG systems allows them to respond to lower hydrogen prices by engaging more frequently in power generation.

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