Hydrogen Opportunities in a Low Carbon Future: An Assesment of Long-Term Market Potential in the Western United States

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Overview

The potential for hydrogen to serve as a source of zero-carbon energy across a wide range of applications has generated significant attention, given decarbonization targets across the globe and the increasingly urgent need to mitigate the worst impacts of climate change. Within this backdrop, Energy and Environmental Economics, Inc. ("E3")1, an industry-leading consultancy, was retained by Mitsubishi Hitachi Power Systems Americas, Inc. (MHPS) and Magnum Development, LLC (Magnum), to provide an evaluation of the potential opportunities for hydrogen in the Western United States under a low-carbon future.

This analysis stems from MHPS and Magnum's 2019 announcement of the Advanced Clean Energy Storage (ACES) project. The project proposes to utilize renewable electricity to produce hydrogen via electrolysis. ACES's stored hydrogen has the potential to provide zero-carbon fuel to generate electricity via thermal cycle power plants or fuel cells.

E3's investigation focused on four broad research questions:

- What are the most viable hydrogen production methods, based on expected future cost trajectories?
- What is the market outlook for hydrogen across sectors in the Western United States under a deep decarbonization future?
- What is the potential role of hydrogen as a long-duration storage medium in a deeply decarbonized Western electricity system?
- What does the hydrogen supply chain in the West look like today, and how may this supply chain evolve in a deep decarbonization future?

Methods

E3 evaluated a low-carbon, high renewables future in the West using two E3 models, PATHWAYS (for the Western U.S.) and RESTORE, which have been used by state agencies, utilities and stakeholders to examine questions related to deep decarbonization strategies. While both models evaluate low carbon futures in the West, the models differ significantly in their structure and assumptions. Thus, E3's analysis of hydrogen's potential in buildings, industry and transportation is not perfectly comparable with its analysis of the power sector.

The PATHWAYS model, an economy-wide GHG accounting tool, is used to create economy- wide decarbonization scenarios for the West. The model is an infrastructure-based stock rollover model that has been used to design a range of plausible strategies to achieve deep decarbonization. PATHWAYS is a scenario planning tool to explore deep decarbonization futures based on what is currently known about costs, technical potential, policy incentives and barriers, and other factors. For this project, E3 developed three deep decarbonization scenarios for the West, including:

- **Mid-Hydrogen Scenario** reflects a future in which hydrogen plays a moderate role in heavy-duty transportation and supports some limited industrial applications. This scenario is built to be consistent with a world in which the West achieves economy- wide 80% reductions relative to 1990 by 2050.
- **High-Hydrogen Scenario** reflects a future in which hydrogen realizes much of its technical potential in all sectors with moderate requirements for supporting policy and infrastructure upgrades. This scenario is also built to be consistent with a future in which the West achieves economy-wide 80% reductions relative to 1990 by 2050, but reflects a worldview where lower costs and other potential incentives lead to significantly greater hydrogen usage.
- **Transformative Scenario** reflects a future in which hydrogen has a substantial presence in transportation, buildings, and industry, assuming commensurate policy drivers and enabling infrastructure. This scenario is

consistent with a world in which the West achieves decarbonization consistent with a "net zero" carbon outcome, in line with existing policies in several states. This scenario assumes major upgrades

These scenarios were designed to create estimates of the potential market size for hydrogen in the future. The costs of the scenarios were not developed or compared, nor was the use of hydrogen across energy demand sectors optimized. These scenarios can be thought of as distinct world-view futures, of what might be needed to achieve a given carbon reduction target. These scenarios are not forecasts of what is likely to happen given current policy or technology trends.

This study separately assessed the potential for hydrogen in the power sector, investigating the total economic market potential for long-duration storage as well as the market opportunity for a "first of its kind" 1000 MW hydrogen storage project. To perform the power sector analysis, E3 first used its proprietary market price forecasts for the West, based on E3's High RPS scenario forecast. The market price scenario represents the view that higher renewables will be achieved in all jurisdictions, including attainment of various 100% clean energy sales targets that are currently legislated.

E3 used the energy market price forecast for two analyses. First, E3 utilized RESTORE, E3's proprietary energy storage model, to estimate the potential revenues associated with the 1000 MW hydrogen project. RESTORE maximizes revenues available from dispatch, subject to the system operating parameters, with market prices as an input and the storage resource treated as a "price taker", i.e., prices are assumed to be fixed across the entire range of storage operations. Because RESTORE allows storage to charge and discharge as is economic, charging can occur during low-price hours when it can be done profitably.

Using the results from RESTORE, E3 then estimated the amount of economically viable long-duration hydrogen storage that could be produced from curtailed electricity, focusing on two regions, California and the Pacific Northwest, where E3's modeling suggests significant renewable curtailment in the 2030s and beyond. E3 first used the RESTORE model outputs to determine average arbitrage revenue from buying curtailed electricity to generate hydrogen and selling electricity back to the grid generated in a hydrogen-fueled combined cycle or combustion turbine power plant. E3 then built a custom model to determine the total viable long-duration hydrogen storage market size that resulted in breakeven fixed system cost and annualized system net revenue in the energy and capacity markets. In this analysis, E3 assumed that only curtailed electricity is available for charging the storage system, generating a conservative estimate of the total economic long-duration storage.

Results

The key findings from this study include:

- The most promising and realistic opportunity for carbon-neutral hydrogen is as long-duration energy storage for the electricity sector in a deeply decarbonized West.
- Carbon-neutral hydrogen could play a role in decarbonizing other sectors of the economy, particularly heavy-duty ground transportation.
- Carbon-neutral hydrogen's role is uncertain in buildings and industry, with potential opportunities foreseeable if the Western U.S. achieves carbon targets close to complete decarbonization.
- The most economic means of producing carbon-neutral hydrogen in the long run remains uncertain.
- When underground storage is available, centralized hydrogen production from renewables in locations with on-site storage is lower cost than decentralized hydrogen production from renewables. Thus, locations with underground storage may serve as cost-effective energy "hubs", providing hydrogen to locations without energy storage.

Conclusions

Hydrogen has emerged in policy discussions across the West as an attractive solution to the decarbonization challenge. As a versatile energy resource with characteristics similar to natural gas, hydrogen has the potential to support decarbonization across a range of end uses, particularly as long-duration energy storage in the electricity sector. To achieve ambitious near-complete economy and electricity sector decarbonization targets, hydrogen must build on existing momentum and continue to realize anticipated cost reductions.