H2@Scale Analysis

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Project Start Date: January 2, 2017
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Improve fidelity of the value proposition of H2@Scale.
- Provide results that are supported by an in-depth analysis of market potential and economics.
- Quantify potential impacts on economics, resource use, and emissions metrics.
- Identify regional opportunities and challenges.

Fiscal Year (FY) 2019 Objectives

- Incorporate feedback on the technical potential of hydrogen production in the U.S. via diverse approaches and the maximum market size for potential hydrogen demands.
- Quantify the potential of the H2@Scale vision for the 48 contiguous states in the U.S.
- Estimate the maximum market potential and resource technical potential where the maximum market potential is the estimated market size and resource availability constrained by the services for which society currently uses energy, real-world geography, and system performance, but not by economics.
- Estimate the economic potential—the quantity and price of hydrogen at which suppliers are willing to sell and consumers are willing to buy, assuming various market and technology-advancement scenarios.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration (MYRDD) Plan[1]:

- (A) Future Market Behavior—Potential market for low-value energy and potential hydrogen markets beyond transportation
- (D) Insufficient Suite of Models and Tools—Tools integrating hydrogen as an energy carrier into the overall energy system and quantifying the value hydrogen provides
- (E) Unplanned Studies and Analysis—H2@Scale is a new concept and requires analysis of its potential impacts for input in prioritizing research and development.

It also addresses the following technical barriers from the Technology Validation section of the FCTO MYRDD Plan:

- (F) Centralized Hydrogen Production from Fossil Resources—Investigating potential value stacks for hydrogen production from various resources
- (G) Hydrogen Production from Renewable Resources—Investigating the potential for hydrogen to be produced from renewable electricity and support higher penetrations of renewable electricity generation.

Contribution to Achievement of DOE Milestones

This project will contribute to the achievement of the following DOE milestone from the Systems Analysis section of the FCTO MYRDD Plan:

- Milestone 1.19: Complete analysis of the potential for hydrogen, stationary fuel cells, fuel cell vehicles, and other fuel cell applications such as material handling

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

equipment including resources, infrastructure, and system effects resulting from the growth in hydrogen market shares in various economic sectors (4Q, 2020).

In addition, this project will contribute to the achievement of the following DOE milestone from the Technology Validation Section of the FCTO MYRDD Plan:

- Milestone 3.9: Validate a large-scale system for grid energy storage that integrates renewable hydrogen generation and storage with fuel cell power generation by operating for more than 10,000 hours with a round-trip efficiency of 40% (4Q, 2020).

FY 2019 Accomplishments

- Updated the estimate of the current maximum hydrogen demand market size to be 166 million metric tonne (MMT) annually, including demands from refineries and the chemical processing industry, metals refining, ammonia production, hydrogen use for biofuels refining, hydrogen use for synthetic fuels and chemicals production, direct injection into the nation's natural gas system, light-duty fuel cell electric vehicles (FCEVs), other transportation including medium-duty and heavy-duty trucks, and seasonal energy storage for the electricity grid.
- Developed five national supply curves for hydrogen consisting of supplies from steam reforming of natural gas, high-temperature electrolysis using nuclear energy, biomass (via gasification), and low-temperature electrolysis of otherwise curtailed electricity. The scenarios vary based on varying assumptions of natural gas prices, low-temperature electrolyzer prices, and electricity market structures.
- Developed three national demand curves for the updated hydrogen demands. The curves vary depending upon assumptions regarding the evolution of the U.S. electricity system and the U.S. metals industry.
- Quantified the national economic potential for H2@Scale ranging from 14 MMT/yr to 48 MMT/yr over five scenarios with various technology and market assumption.
- Completed a draft report summarizing the technical/maximum market potentials and economic potential. Completed an external review and several internal reviews of the draft report. Adjusted analyses and scenarios based on review feedback. Updated the report for final review.

INTRODUCTION

H2@Scale is a U.S. Department of Energy (DOE) initiative that brings together stakeholders to advance affordable hydrogen production, transport, storage, and utilization to increase revenue opportunities in multiple energy sectors. The focus of this report is technoeconomic modeling and analysis that was completed to characterize the overall potential of the H2@Scale vision, given evolutions in the U.S. energy system and future R&D advances. Figure 1 graphically represents H2@Scale by showing how hydrogen could fit into the overall energy system. It is based on utilizing hydrogen's unique ability to both support the electric grid and serve as a clean feedstock to a variety of demands. Hydrogen production can utilize intermittent electricity and heat, and can, therefore, be used to stabilize the electricity grid and enhance the financial viability of both baseload nuclear power and variable renewable generation. The hydrogen that is produced in that way can be stored for months without degradation and then used to provide electricity back to the grid or for a number of alternative purposes shown in Figure 1, including as fuel for FCEVs, as a chemical feedstock for refining and ammonia production, and as a clean energy supplement in the natural gas system.

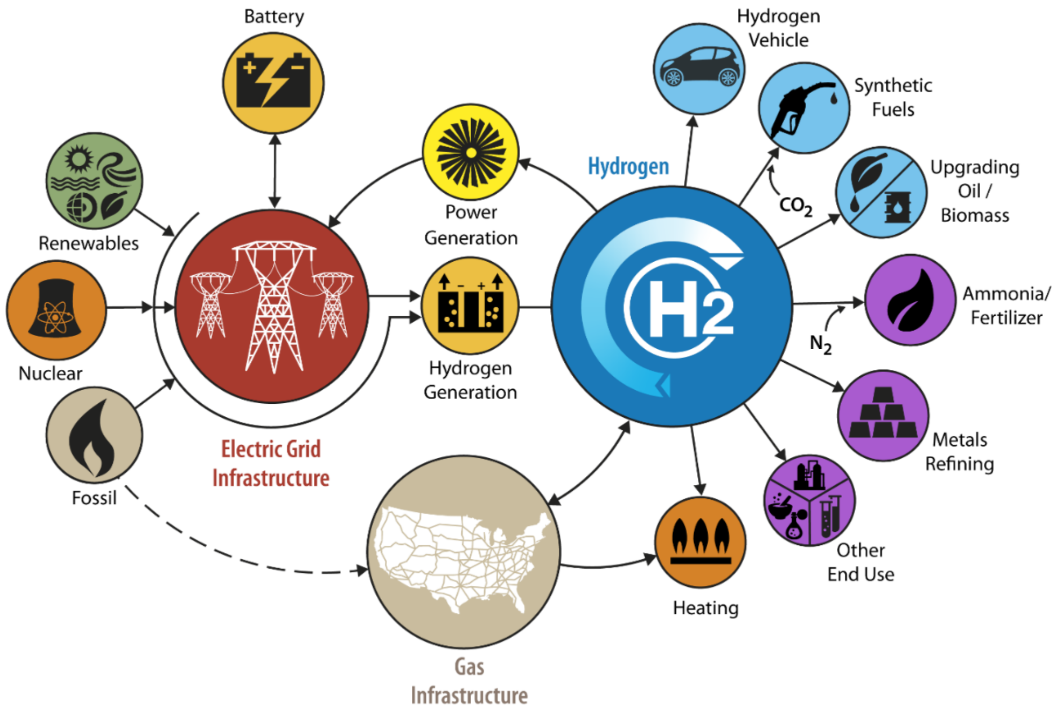

Figure 1. The H2@Scale concept is based on hydrogen connecting a number of energy sources with a variety of demands ranging from transportation to the chemical industry and from heating to the natural gas system [1]

This project analyzes the economic potential of H2@Scale. It focuses on developing and communicating potential market size and impacts using techniques that can be justified and communicated to a broad range of audiences. Preliminary regional analyses and transition conceptualization is being performed in this project. Proposed work in future years extends the analysis to consider regional issues in-depth, as well as storage and infrastructure development opportunities and challenges.

APPROACH

This project is composed of three stages. The first two are estimating (1) the maximum hydrogen market size under the H2@Scale concept and (2) the economic potential of the H2@Scale concept. They were initiated in FY17, the first set of results were completed in FY18, and the methods, data, and results were reviewed in detail both internally and externally during FY19. The third stage, including additional analysis related to topics such as regional needs and constraints and storage and infrastructure development opportunities and challenges, has been initiated but will not be reported here.

The team estimated the economic potential as the market equilibrium between supply and demand using traditional microeconomic analysis techniques based on a theory of competitive markets, in which the price of a particular good will settle at a point where the quantity demanded at that price matches the quantity supplied at that price [2, 3]. Demand curves were developed by estimating hydrogen price points based on users' willingness to pay for hydrogen (which is impacted by alternatives and elasticity), and potential locations for the following potential hydrogen demands: oil refining, metals refining, ammonia, biofuels, synthetic fuels and chemicals, supplementing natural gas, light-duty vehicles, medium- and heavy-duty vehicles, and seasonal energy storage for the electrical grid. Supply curves for hydrogen production via steam reforming of natural gas, low-temperature electrolysis of otherwise curtailed electricity, and high-temperature electrolysis using heat from nuclear energy were developed based on energy resource and technology cost assumptions [4, 5, 6].

RESULTS

The maximum market sizes for hydrogen demand in the U.S. is estimated as 166 MMT/yr. This demand estimate comprises 86 MMT/yr for use in fuel cell vehicles, 28 MMT/yr for seasonal storage to ultimately be used in electricity generation, and 52 MMT/yr for industrial use (including oil refining and the CPI, metals, ammonia, biofuels, and synthetic fuels and chemicals) and blending into the natural gas system. Table 1 summarizes the maximum market sizes for hydrogen demands. The technical potential of U.S. resources is sufficient to supply the maximum potential hydrogen market.

Table 1. Preliminary Estimates of Maximum Market Size for Hydrogen Demands

Application	Maximum Market Size (MMT/yr)
Refineries and the chemical processing industry (CPI)[a]	8
Metals	12
Ammonia	4
Biofuels	4
Synthetic fuels and chemicals	14
Natural gas supplementation	10
Light-duty FCEVs	57
Other transportation (medium- and heavy-duty FCEVs)	29
Seasonal energy storage for the electricity grid	28
Total	166

[a] CPI not including metals, ammonia, methanol, or biofuels.

The team developed aggregated demand curves by combining demand quantities across the range of estimated price points at which the user may be willing to pay for hydrogen. The aggregated demand curves for each scenario are shown in Figure 2. The Business As Usual and Low NG Resource scenarios have the same demand curves above a hydrogen price of $1.48/kg. Below this price point, deviations in these scenarios are due to differences in assumed natural gas prices, which influence hydrogen's viability in seasonal energy storage. The Increased Metals Refining, Improved Electrolysis, and Low-Cost Electrolysis scenarios all assume the same demand curve, which is 4 MMT greater than in the Low NG Resource scenario at prices above $1.70/kg and below $2.50/kg; this additional demand is expected to come from the metals refining sector. Secondary effects, such as competition between industries that use hydrogen (e.g., demand for hydrogen in gasoline production for use in internal combustion engine vehicles vs. hydrogen for use in fuel cell vehicles), is outside the scope of this analysis.

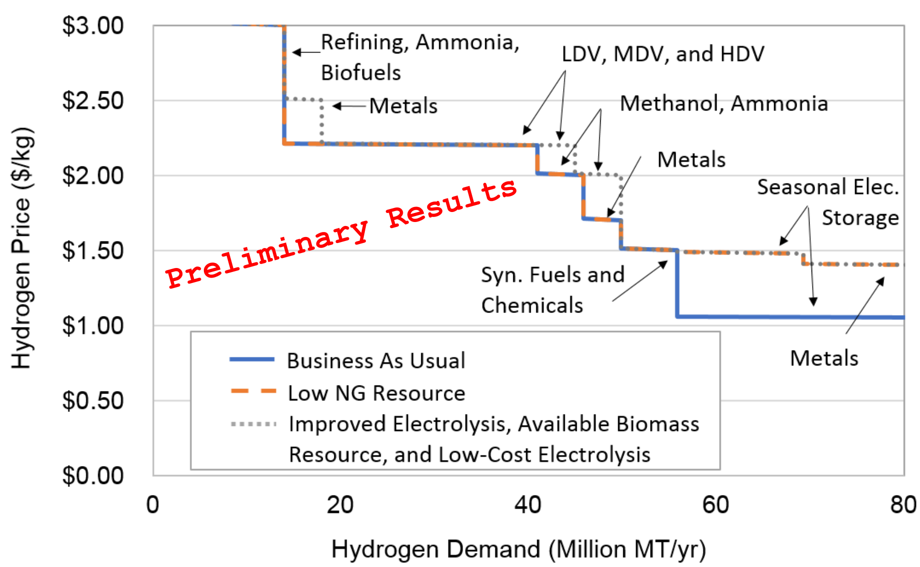

Figure 2. Aggregated demand curves for H2@Scale scenarios

The team estimated national supply curves based on production cost estimates for natural gas reforming, high-temperature electrolysis of nuclear energy, biomass gasification, and low-temperature electrolysis of otherwise curtailed electricity, along with assumptions of the cost of delivery. The cost of hydrogen delivery can vary widely, given the proximity of production to demand. In the current work, simple assumptions of delivery cost have been made – $0.12/kg for local production and $0.39/kg for longer-distance delivery requirements. Delivery and infrastructure cost estimates are expected to be improved in future years. Figure 3 shows the supply curves used for three of the scenarios we developed the analysis.

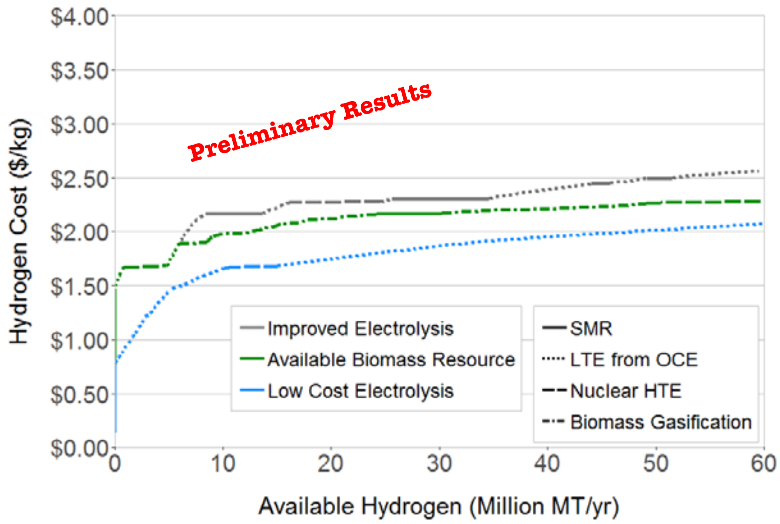

Figure 3. Aggregated supply curves for the Improved Electrolysis, Available Biomass Resources, and Low-Cost Electrolysis scenarios

The team estimated the economic potential of H2@Scale at the intersection between national supply and demand curves for five scenarios. The scenarios include varying assumptions about future conditions, including the performance of related markets (e.g., natural gas prices), the potential for market accessibility (e.g., the opportunity to purchase OCE at the selling price into the wholesale market), and other national decisions (e.g., whether a premium will be paid for domestically produced metals). Figure 4 shows the resulting market size and supply and demand mixes for each scenario. The results range from 14–48 MMT/yr hydrogen market sizes. Across all the scenarios, hydrogen is demanded for refineries and the CPI, ammonia production, biofuels production, light-duty vehicles, and other transport; however, the quantities for light-duty vehicles and other transport vary. Some scenarios indicate a potential hydrogen demand for metals refining and methanol production.

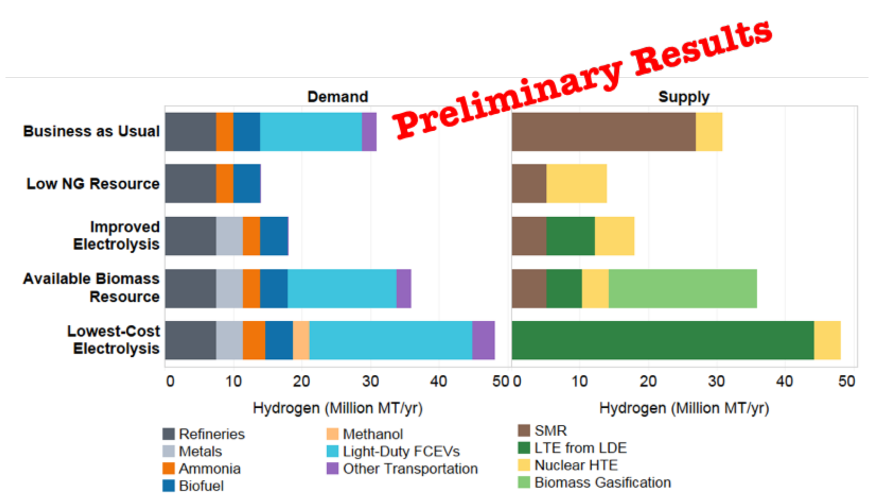

Figure 4. Resulting market sizes and supply and demand shares for five H2@Scale scenarios

The multi-lab team completed analysis reviews during FY19. Over 15 colleagues in related industries ranging from energy companies and utilities to electrolyzer developers provided input. In addition, over 10 colleagues within DOE and national laboratories provided input. Reviewer comments indicated that methodology seemed reasonable, but some reviewers were concerned about some of the values used in both hydrogen production and utilization technologies. Based on those responses, the multi-lab team adjusted scenarios and parameters used within them, including adding conversion of biomass to hydrogen.

CONCLUSIONS AND UPCOMING ACTIVITIES

The analysis indicates that the H2@Scale concept could have a large impact on the U.S. energy system. At 166 MMT/yr, the maximum potential hydrogen market is approximately 16 times larger than the current market. Most of that potential demand would be for applications that hydrogen is not currently supporting, and all of it is not likely to be achieved economically. The team estimated the economic potential of hydrogen in the United States to be 14–48 MMT/yr, depending on resource prices, hydrogen production technology R&D, and the price various users will pay for hydrogen, which depends in part on the cost of other technologies that provide the same services. These estimates are based on markets reaching equilibrium.

The team attempted to consider the full spectrum of hydrogen demands and most production options, but others should be considered as they are identified. While these feedstocks already have other markets, an understanding of the competition between these markets would improve estimates of hydrogen supply potential. Delivery costs estimated in this analysis were simple assumptions. In-depth estimates of the necessary delivery and storage infrastructure would improve the characterization of hydrogen supply potential. Finally, the estimates described here are based on markets achieving equilibrium. Market development and regional transition studies would improve understanding of challenges in achieving these penetrations.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. M. F. Ruth, P. Spitsen, R. Boardman, S. Bragg-Sitton. "Opportunities and Challenges for Nuclear-Renewable Hybrid Energy Systems." NREL/PR-6A20-72564. https://www.nrel.gov/docs/fy19osti/72564.pdf. Presented at the International Atomic Energy Agency's Workshop on Nuclear-Renewable Hybrid Energy Systems. 2018

2. M. F. Ruth, J. Engel-Cox. "H2@Scale and Tightly-Coupled Nuclear-Renewable Hybrid Energy Systems." NREL/PR-6A20-72022. https://www.nrel.gov/docs/fy19osti/72022.pdf. Presented at the 5th Nuclear and Renewable Energy Resources Meeting. 2018.

3. M. F. Ruth. "Ammonia: Opportunities for Grid Support." NREL/PR-6A20-72635. https://www.nrel.gov/docs/fy19osti/72635.pdf. Presented at the Ammonia Energy Association Conference. 2018.

4. A. Mayyas, M. Ruth, B. Pivovar, G. Bender, K. Wipke. *Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers.* NREL/TP-6A20-72740. https://www.nrel.gov/docs/fy19osti/72740.pdf. 2019.

5. M. Ruth, B. Pivovar, J. Eichman. "Hydrogen's Expanding Role in the Energy System." *Chemical Engineering Progress* 115 (2019): 33–40. https://www.aiche.org/resources/publications/cep/2019/august/hydrogens-expanding-role-energy-system.

6. M. F. Ruth, P. Jadun, A. Elgowainy, B. Pivovar. "Hydrogen's Potential Role in Future Energy Systems." NREL/PR-6A20-74268. https://www.nrel.gov/docs/fy19osti/74268.pdf. Presented at the World Hydrogen Technologies Conference, 2–7 June 2019, Tokyo, Japan.

7. P. Jadun. "H2@Scale: Concept and Opportunities." NREL/PR-6A20-73060. Presented at the Hydrogen: Energy & Supply Conference, 4 January 2019, Salt Lake City, Utah.

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