VII.D.1 H2@Scale Analysis

Mark F. Ruth (Primary Contact), Nicholas Gilroy, Elizabeth Connelly, Josh Eichman, Paige Jadun, Amgad Elgowainy*, Max Wei[†], Karen Studarus[§]
National Renewable Energy Laboratory (NREL)
15013 Denver West Parkway
Golden, CO 80401-3305
Phone: (303) 384-6874
Email: mark.ruth@nrel.gov
* Argonne National Laboratory
[†] Lawrence Berkeley National Laboratory
[§] Pacific Northwest National Laboratory

DOE Manager: Fred Joseck
Phone: (202) 586-7932
Email: Fred.Joseck@ee.doe.gov

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 in-depth analysis of market potential and economics.
- Quantify potential impacts on economic, resource use, and emissions metrics.
- Identify regional opportunities and challenges.

Fiscal Year (FY) 2017 Objectives

- Quantify the technical potential of hydrogen demands and hydrogen production technologies.
- Identify potential regional issues that would be challenges for the H2@Scale concept.
- Quantify the national economic potential of the H2@Scale concept under several scenarios.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(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 Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration 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 achievement of the following DOE milestone from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration 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 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 achievement of the following DOE milestone from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 3.9: Validate 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 2017 Accomplishments

- Estimated the current technical potential demand for hydrogen at 60 million metric tonne (MMT) annually, including demands from refineries and the chemical processing industry, metals refining, ammonia production, direct injection into the nation's natural gas system, light-duty fuel cell electric vehicles (FCEVs), and other transportation including medium-duty trucks and buses.

- Quantified the impact on renewable resources' technical potential if each resource is used to produce 60 MMT/yr hydrogen in addition to its current demand. Current demand for each resource plus production of 60 MMT/yr hydrogen is satisfied by less than 1% of the technical potential of solar energy, about 6% of the technical potential of wind, and about 100% of the technical potential of solid biomass.
- Quantified the impact on fossil and nuclear resources if each resource is used to produce 60 MMT/yr hydrogen in addition to its current demand. The domestic natural gas resource has 70 years to depletion at its current usage plus the additional requirement to meet the technical potential demand for hydrogen. The domestic coal resource has over 300 years to depletion. The domestic uranium resource has over 400 years to depletion.
- Estimated the impacts if 60 MMT/yr hydrogen is produced via water electrolysis using renewable electricity and that hydrogen is used for the markets listed in the first bullet. Based on analysis assumptions and without considered secondary benefits such as increasing generation of renewable electricity, hydrogen has the potential to reduce total national greenhouse gas (GHG) emissions and fossil energy use by approximately 15%.

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INTRODUCTION

The H2@Scale concept was presented by the national laboratory-led team during the FY 2016 Big Idea Summit because it has the potential to enable large reductions in national GHG emissions, both by increasing the profitability of low-carbon electricity generators via providing value for otherwise potentially curtailed electricity, and by supplying a clean energy source for industry and transportation. The concept is graphically portrayed in Figure 1. It is based on utilizing hydrogen's unique ability to both support the electric grid and provide clean energy to a variety of demands. Hydrogen can support an electric power grid with high penetrations of fixed generation (i.e., constant generation from nuclear reactors) and variable renewable generation (i.e., from photovoltaic (PV) solar and wind) by being generated by low-cost electrolyzers that can be used as a controllable load. The hydrogen that is produced in that way can be stored for months without degradation and then

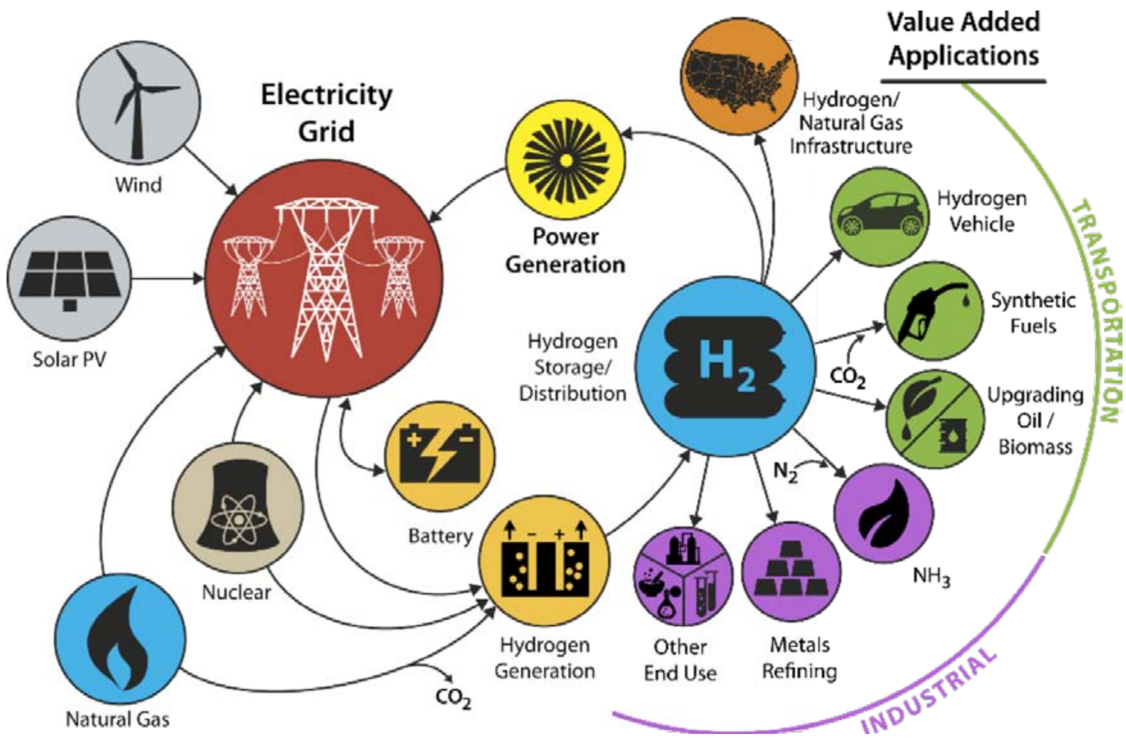

FIGURE 1. Graphical depiction of the H2@Scale concept, showing the use of otherwise curtailed electricity and other hydrogen generation resources and potential uses of hydrogen, including on-demand electricity, transportation, and industrial uses, in addition to injection into the natural gas infrastructure.

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.

When the H2@Scale concept was originally proposed, only preliminary analysis had been performed. Thus, market size and impact estimates were not precise and the analysis results and methods had not been reviewed sufficiently. This project is focused on improving those estimates by analyzing both the technical and economic potential for hydrogen markets during FY 2017. Proposed work in later years extends the analysis to consider regional issues, storage and infrastructure development challenges, and macroeconomic impacts.

APPROACH

This project is composed of three stages with the first two being performed in FY 2017. The first two are estimating (1) the technical potential for the H2@Scale concept and (2) the economic potential of the H2@Scale concept. The third stage, including additional analysis related to topics such as regional needs and constraints, transport and storage, and macroeconomic issues, is proposed for future years.

To estimate the technical potential of hydrogen demands, the team reviewed literature and worked with experts to determine the potential market size for hydrogen in seven markets [1–5]. To estimate production technical potential, the team used the methodology previously developed (when possible [6]) to estimate resources. To estimate the wind, utility-scale PV, and biomass technical potential, the team used resource data developed at NREL [6–8] and calculated the potential annual hydrogen production using an efficiency of 46 kWh/kg hydrogen as used in Melaina et al. [6]. The team calculated impacts on fossil energy resources and GHG emissions using the GREET® model developed by Argonne National Laboratory [9].

RESULTS

The technical potential demand for hydrogen under the H2@Scale concept is 60 MMT/yr. It is comprised of the following categories:

- 8 MMT/yr for refineries and the chemical processing industry
- 5 MMT/yr for metals refining (primarily for steel production)
- 5 MMT/yr for ammonia production
- 7 MMT/yr for direct injection into the nation's natural gas system
- 4 MMT/yr for hydrotreating biofuels
- 28 MMT/yr for light-duty FCEVs
- 3 MMT/yr for other transportation including medium-duty trucks and buses

The domestic technical potential of electricity supply from utility-scale solar power is 1,360 quadrillion Btu (quads) per year. Of that supply, only 9 quads would be necessary to produce 60 MMT/yr hydrogen, and thus the utilization of the solar potential would be less than 1%. The domestic potential for land-based wind power in the United States is 170 quads per year, so the 9 quads of electricity necessary to produce 60 MMT/yr hydrogen is only 6% of that total. The biomass technical potential in the United States is 20 quads per year and its conversion efficiency is lower than electrolysis, so 75% of that resource would be needed to produce 60 MMT/yr hydrogen. Since 25% is currently used for wood products, pulp and paper and other demands, the full biomass resource

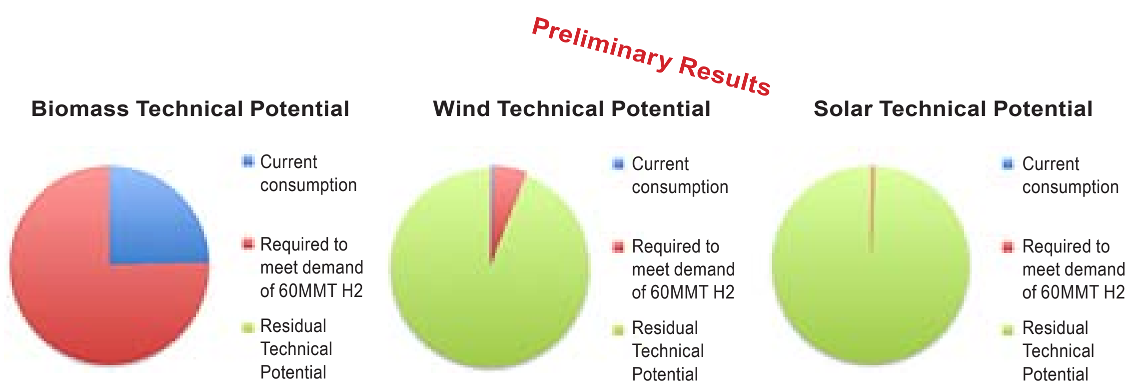

FIGURE 2. Fractions of the technical potential of three renewable resources that are utilized today and required to produce 60 MMT/yr hydrogen. Current demand for each resource plus production of 60 MMT/yr hydrogen is satisfied by less than 1% of the technical potential of solar energy, about 6% of the technical potential of wind, and about 100% of the technical potential of solid biomass. Results are in the process of being finalized.

would be necessary to meet the demand. Figure 2 shows those fractions.

Sufficient domestic fossil and nuclear resources are also available to meet the technical potential hydrogen demand. The domestic natural gas resource (proven and unproven reserves) has 70 years to depletion at its current usage plus the additional requirement to meet the technical potential demand for hydrogen. The domestic coal resource has over 300 years to depletion. The domestic uranium resource has over 400 years to depletion based on reasonably assured reserves at <\$260/kg uranium and the use of both once-through and breeder reactors.

Figure 3 shows the difference between technical potential hydrogen production from wind and utility-scale PV, and technical potential hydrogen demand by counties (overlaid with locations of nuclear power plants). Only the counties colored red have less potential generation from those two sources than the potential demand. Note that many of those counties are urban areas with high demand for transportation energy use. However, all the counties with less wind and solar resource than potential demand are close to counties with sufficient resources or to nuclear plants (noted by the green, black, and purple dots).

Producing 60 MMT/yr hydrogen via water electrolysis using renewable electricity and using that hydrogen in markets identified by the technical potential demand analysis has the potential to reduce GHG emissions and fossil energy use by approximately 15%. Consideration of secondary benefits such as from increasing generation of renewable electricity would increase that potential reduction.

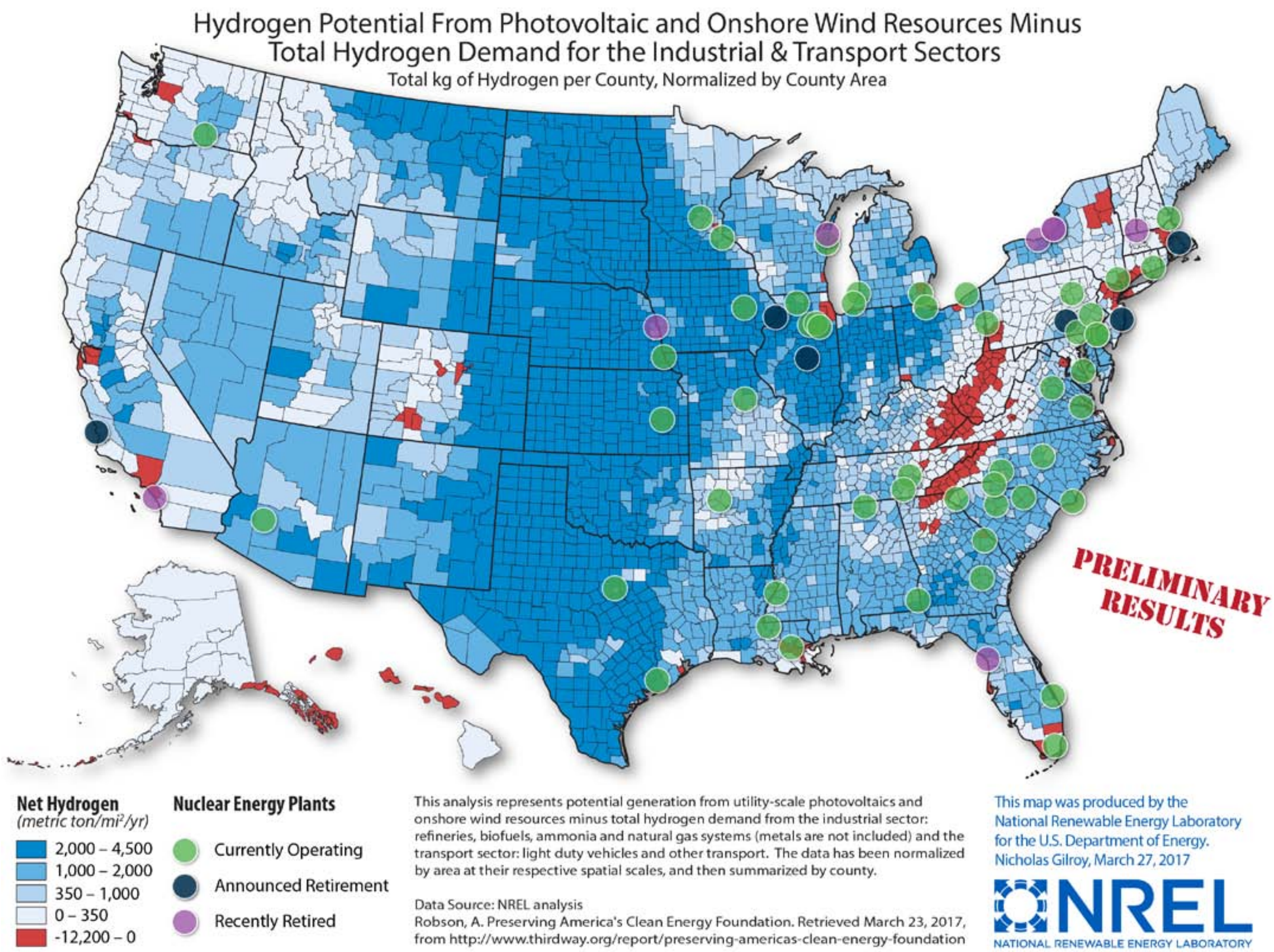

FIGURE 3. Difference between technical potential hydrogen production from wind and utility-scale PV and technical potential demand by counties overlaid with locations of nuclear power plants. Counties colored blue have more wind and PV resource than potential demand. Counties colored red have more potential demand than production. Results are in the process of being finalized.

CONCLUSIONS AND UPCOMING ACTIVITIES

Technical potential analysis estimates a potential market for 60 MMT of hydrogen per year. If that hydrogen is produced via water electrolysis using renewably generated electricity, it would directly reduce national GHG emissions and fossil energy use by 15%. Additional indirect reductions are possible if providing a value for curtailed electricity improves the economics of solar, wind, and nuclear generation, resulting in higher penetration of those resources.

During the remainder of FY 2017, the team will analyze the economic potential of H2@Scale by using supply and demand curves to estimate hydrogen demand at market equilibrium. Supply curves will consist of national hydrogen production estimates at prices from $0.50/kg to $3.00/kg. Production estimates will be developed for hydrogen produced from otherwise curtailed electricity, steam methane reforming of natural gas, and nuclear energy. Demand curves will consist of national demand estimates for each of the seven hydrogen markets that were identified in the technical potential analysis. The intersection of the supply and demand curves will indicate the hydrogen price and quantity, which will be used to estimate the resulting economic and environmental impacts. The need for and the type of additional analyses will be identified as well. Possible work in later years extends the analysis to consider regional analysis, storage and infrastructure development challenges, and macroeconomic impacts.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Mark Ruth "H2@Scale Resource and Market Analysis" (presentation to the Hydrogen Technical Advisory Committee, May 4, 2017).

2. Mark Ruth "H2@Scale: Concept Overview and Preliminary Analysis" (presentation at the U.S. Department of Energy H2@Scale Workshop, May 23, 2017).

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