Sustainability Analysis: Hydrogen Regional Sustainability (HyReS)

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Project Start Date: October 1, 2015
Project End Date: September 30, 2018

Overall Objectives

- Develop a regional hydrogen sustainability analysis (HyReS) assessment framework that can be applied to hydrogen supply and fuel cell systems and is consistent with a broad range of existing sustainability assessment tools used by relevant stakeholders.
- Apply the framework as an enhancement to the existing suite of hydrogen systems analysis models developed for the Fuel Cell Technologies Office (FCTO).
- Refine the framework to incorporate the latest developments in the field of sustainable development assessment, including recent data and analytic approaches, and to capture current issues relevant to key stakeholders.
- Implement the framework through a user interface that is accessible to target audiences, including private sector sustainability managers, industry stakeholders, government and non-government agencies, and potential investors.

Fiscal Year (FY) 2018 Objectives

- Complete HyReS framework as part of the Scenario Evaluation and Regionalization Analysis (SERA) modeling outputs.
- Assess scenarios corresponding to H2USA light-duty vehicle demand, H2@Scale hydrogen demand, and FCTO Multi-Year Research, Development, and Demonstration (MYRDD) Plan targets.
- Benchmark the full life cycle impacts of 400-mile range fuel cell electric vehicles (FCEVs) against conventional vehicles, hybrid electric vehicles (HEVs), and battery electric vehicles (BEVs) that are modeled to have a 400-mile range using the Future Automotive Systems Technology Simulator (FASTSim).
- Apply the Sustainability Accounting Standards Board (SASB) framework to HyReS results to address the business community perspective.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the FCTO MYRDD Plan[1]:

- Future Market Behavior
- Stove-piped/Siloed Analytical Capability
- Insufficient Suite of Models and Tools.

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones 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 equipment including resources, infrastructure and system effects resulting from the growth in hydrogen market shares in various economic sectors. (4Q, 2020)
- Milestone 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)

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

FY 2018 Accomplishments

- Developed and implemented an analytic framework that integrates Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model and the National Renewable Energy Laboratory's SERA, Automotive Deployment Options Projection Tool (ADOPT), and FASTSim models, updating results to reflect current model capabilities (Milestone 2.2).
- Compared petroleum fuel impacts from the four FCEV case study life cycles to the life cycle impacts from conventional gasoline vehicles, HEVs, and BEVs all with 400-mile range. Results indicate the FCEVs require the least amount of petroleum over the vehicle life cycle.
- Calculated monetized social benefits air pollution reductions associated with FCEV adoption in the H2USA scenarios. Benefits range from $1.2 billion to $2.2 billion from the Urban Markets to the State Success scenarios, respectively.

INTRODUCTION

The Hydrogen Regional Sustainability (HyReS) project examines environmental burdens in a regional life cycle assessment approach that takes into account the economic and social aspects of hydrogen supply chains and FCEV production and operation. The HyReS framework enhances, extends, and complements the capabilities of a number of analytic models developed for the U.S. Department of Energy, including the SERA and GREET models [1–3]. The HyReS framework will also incorporate data and analytic capabilities from other models relevant to sustainability assessment, such as the Billion-Ton Study [4], the Renewable Electricity Futures (REF) Study [5], and the Estimating Air pollution Social Impact Using Regression (EASIUR) model [6]. The integrated framework will address a number of sustainability metrics, such as petroleum and fossil fuel energy usage, water usage, life cycle costs, and air pollution emissions and the impacts on human health.

Progress to date has involved reviewing the sustainability literature and engaging with stakeholders to better understand how the HyReS framework can interface with and be useful to key stakeholders. The result is a set of proposed HyReS indicators, which include "material" sustainability factors identified by SASB to inform investors [7]. The HyReS framework is integrated into the SERA modeling capabilities and is being used in scenario analysis of the H2USA [8] and H2@Scale [9] demand scenarios. Additionally, the FASTSim model [10] is used to simulate FCEVs, conventional vehicles, HEVs, and BEVs all with a 400-mile range and similar performance attributes for a more apples-to-apples comparison of future vehicle life cycle impacts.

APPROACH

In order to assess regional sustainability impacts of hydrogen supply to FCEVs, HyReS relies upon an analytical framework that integrates the following capabilities: hydrogen demand based upon a detailed geospatial vehicle stock model (SERA) [2], optimized, least-cost hydrogen infrastructure supply chain networks (SERA) [1], life cycle fuel and vehicle impacts based upon GREET [3], market adoption of FCEVs based upon the ADOPT model [8,11], and a health benefits mapping and analysis of criteria pollutant emissions using the EASIUR model [6].

The HyReS framework is used to compare the three H2USA [8] scenarios: Urban Markets, State Success, and National Expansion. Estimating gasoline displacement (and using petroleum and water intensity for a gallon of gasoline) for each scenario results in calculations of net petroleum and water consumption. In addition, sensitivity scenarios relating to FCTO MYRDD goals and REF scenario electric grid mixes are assessed for the "State Success" scenario. The FASTSim model [10] is used to simulate model year (MY) 2010 and 2025 vehicles with a range of 400 miles, and the petroleum consumption over the lifecycle of various vehicle-fuel systems are compared.

RESULTS

Using FASTSim to model MY 2010 and MY 2025 vehicles with 400-mile ranges of similar size and performance, there is an increase in the vehicle cycle energy intensity of the GREET-default BEV300 to the modeled BEV400. On the other hand, because the total vehicle weights of the other FASTSim-modeled vehicles are less than the GREET-default weights, the vehicle cycle energy intensity for the FASTSim-based FCEV, ICEV, and HEV is less, especially for MY 2025. Based on the FASTSim results for MY 2025 vehicles, FCEVs require the least amount of petroleum fuel over the vehicle cycle. Figure 1 presents the lifecycle (A) petroleum and (B) water intensity of the GREET-default vehicles and the FASTSim-based vehicles for MY 2025. Looking at the yellow section indicating the vehicle cycle portion, it is clear that the vehicle cycle water consumption is more variable across vehicle types than petroleum consumption, where ICEVs and HEVs have the lowest vehicle cycle water consumption, though FCEVs consume less water than BEVs.

FASTSim results on the estimated fuel economies of the 400-mile range vehicles is used to calculate the fuel cycle (fuel production and vehicle operation) impacts. The red and blue portions of Figure 1 show the fuel cycle (A) petroleum and (B) water consumption of MY 2025 400-mile-range vehicles. The results show that the FCEV with hydrogen produced from wind electrolysis results in the least consumption of both. The FCEVs and BEVs, regardless of fuel feedstock, realized approximately 95% reductions in life cycle petroleum consumption when compared to conventional gasoline ICEVs. On the other hand, the vehicles fueled by corn, corn stover, poplar, or grid electricity are estimated to consume more water over the vehicle lifetime than conventional ICEVs.

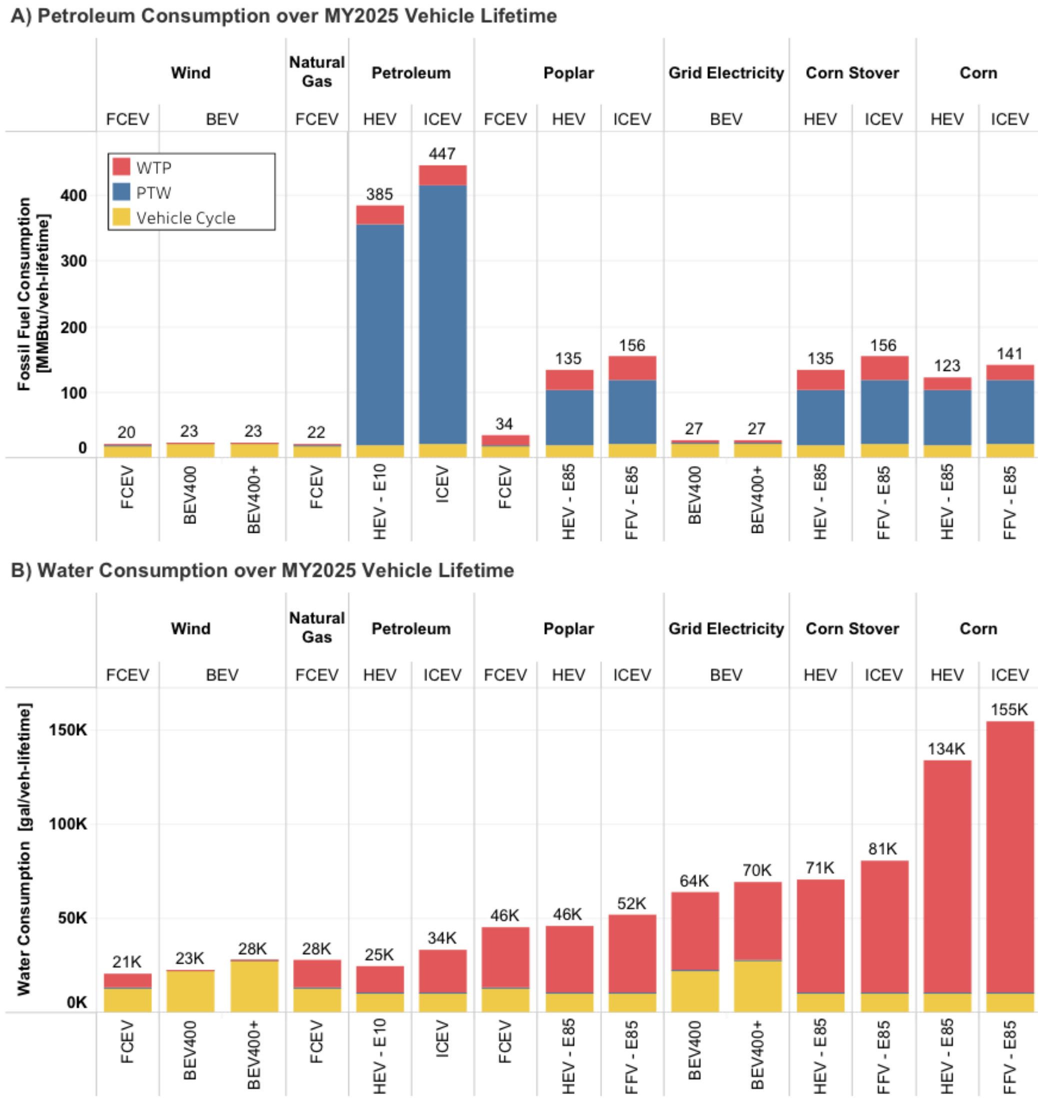

Figure 1. Life cycle (A) petroleum and (B) water consumption for MY 2025 vehicles modeled by FASTSim

The monetized health impacts of the three H2USA demand scenarios were calculated using the EASIUR model. Table 1 describes the cumulative (2016–2040) hydrogen demand for FCEVs in each scenario, along with the calculated emissions reductions and total monetized benefits. Figure 2 shows the geographical distribution of monetized benefits of displacing gasoline miles with hydrogen vehicle miles. Despite the National Expansion scenario displacing the most gasoline miles, the concentration of hydrogen-based miles in population centers in the State Success scenario results in the highest public health benefits.

Table 1. Air Pollution, Petroleum Reductions, and Water Consumption Results for the H2USA Demand Scenarios from 2016–2040

	Urban Markets	State Success	National Expansion
Hydrogen Consumption (kg)	5.0B	7.8B	12.4B
NO_x Reduction (tonnes)	37,000	67,000	105,000
$PM_{2.5}$ Reduction (tonnes)	1,600	2,800	4,500
Monetized Public Health Benefit ($)	$1.23B	$2.21B	$1.70B
Net Petroleum Displacement (gallons)	13.2B	20.6B	33.7B
Net Water Consumption (gallons)	8.1B	3.8B	6.1B

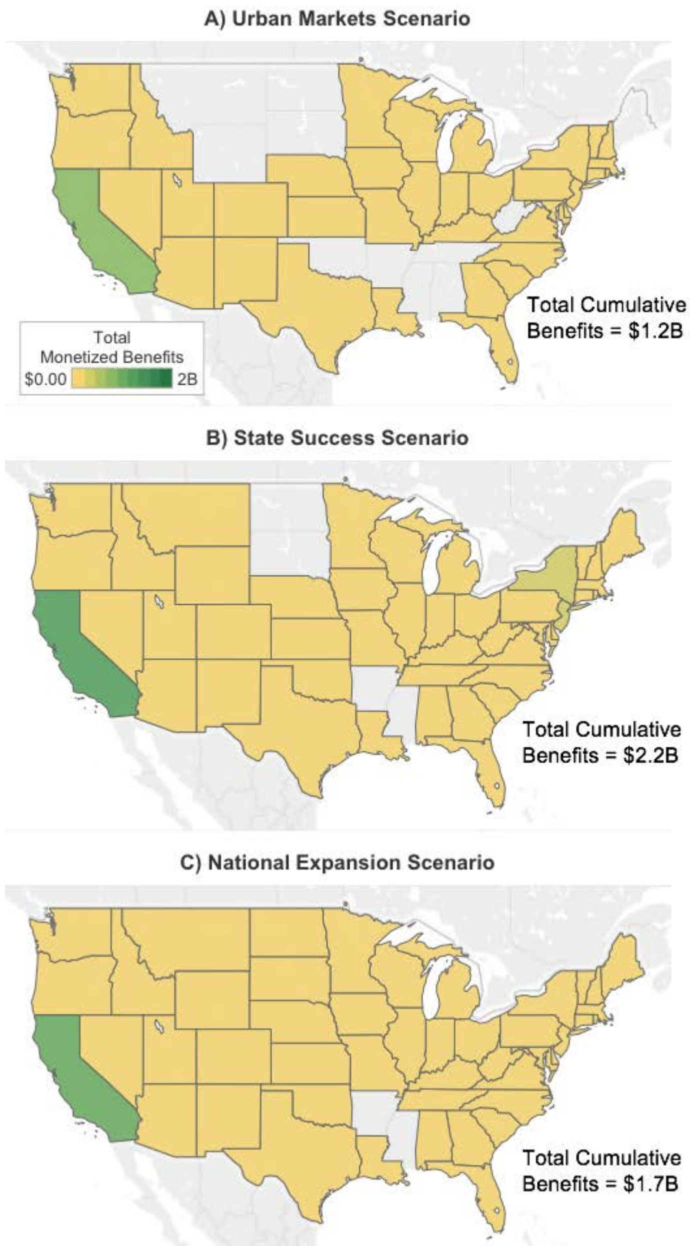

Figure 2. Map of the cumulative (2015–2040) monetized air quality benefits of the H2USA FCEV demand scenarios: (A) Urban Markets, (B) State Success, (C) National Expansion

Figure 3 compares the hydrogen infrastructure modeled for each H2USA scenario. Some combination of existing steam methane reforming (SMR) and new onsite SMR, and central SMR facilities is chosen as the least-cost option for hydrogen production in each of the H2USA scenarios. In each scenario, the most hydrogen is transported via gaseous hydrogen pipeline. However, the liquid truck delivery pathways are actually the longest in length.

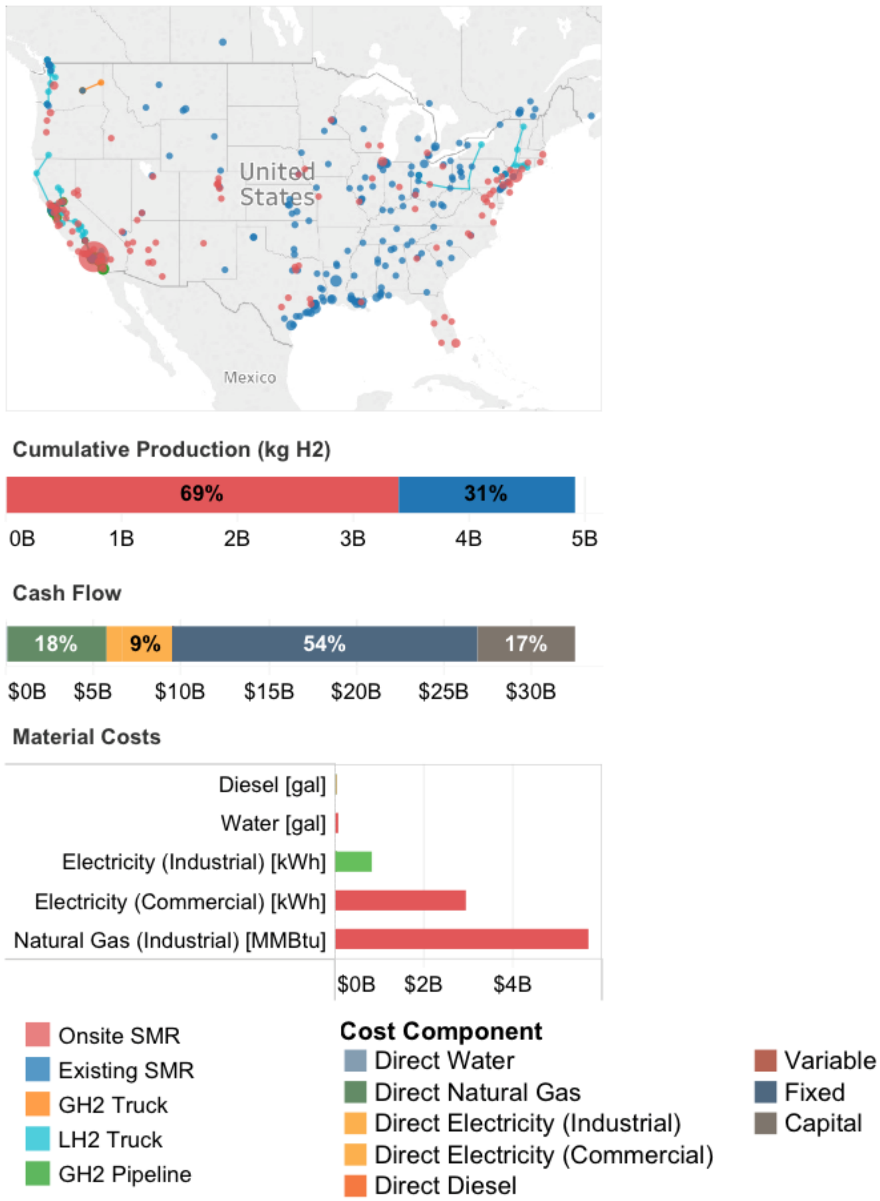

Figure 3. Network infrastructure for hydrogen production and transportation and energy consumption by technology (2016–2040) for the H2USA FCEV demand scenarios: (A) Urban Markets, (B) State Success, (C) National Expansion

Table 1 also describes the SERA model results of cumulative net petroleum displacement and net water consumption for the least-cost infrastructure buildout for each H2USA scenario. Despite the use of diesel for gaseous and liquid truck delivery, there is an increase in petroleum displacement in all of the scenarios. On the other hand, the upstream water consumption embodied in natural gas, electricity, and diesel in combination with direct water consumption for SMR results in a net water consumption in each of the scenarios. Figure 4 describes the net water consumption (upstream and direct consumption, as well as displacement based on the water intensity of gasoline) and the locations of direct water consumption for each scenario. Interestingly, the net water consumption is the least in the State Success scenario. In all scenarios, there is an increase in direct water consumption in California. In the higher demand scenarios (State Success and National Expansion) there is also an increase in water consumption in the northeast, around New York City, as well as near the Gulf Coast in Texas and Louisiana.

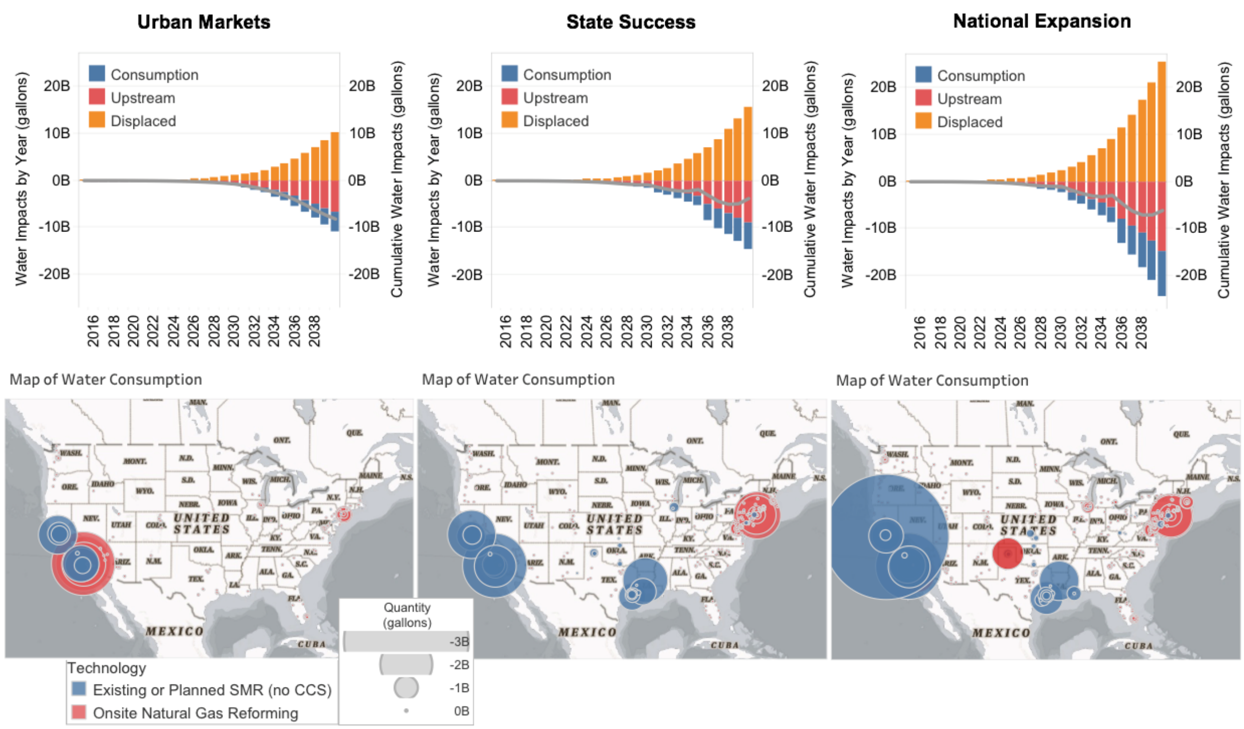

Figure 4. Net and direct water consumption for the H2USA FCEV demand scenarios: Urban Markets, State Success, National Expansion

CONCLUSIONS AND UPCOMING ACTIVITIES

Displacement of gasoline with hydrogen light-duty vehicles results in reductions in petroleum fuel consumption when considering the life cycle of FCEVs relative to ICEVs with comparable vehicle attributes as well as when considering the least-cost infrastructure needed to produce and deliver hydrogen to refueling stations. Water consumption over the life cycle of 400-mile range FCEVs is similar to gasoline ICEVs, and when the upstream and direct consumption for the least-cost infrastructure is considered, net consumption is predicted. Direct water consumption tends to be mostly located around demand centers (highly populated cities) such as Los Angeles, San Diego, New York, and San Francisco, where new and existing SMR facilities are expected to produce hydrogen.

In all three H2USA demand scenarios, air pollution reductions resulted and are estimated through the avoidance of exhaust emissions of gasoline light-duty vehicles. The monetized human health impacts of these reductions (from 2016–2040) are between \$1 billion and \$2 billion. Across all scenarios, over half of the cumulative monetized benefits are accrued in California, where there are a number of population-dense areas.

The air quality benefits of FCEVs are a major reason why applying the SASB framework to compare hydrogen and gasoline production as automotive fuels indicates that hydrogen companies will likely perform relatively better. When comparing across hydrogen production technologies, greenhouse gas emissions, water intensity, (fossil) energy intensity, and price/affordability also become differentiating factors. The HyReS framework can be used to address these and other factors to inform investment decisions on a spatio-temporal basis.

Future work using the SERA model will have HyReS capabilities to enable sustainability analysis for hydrogen production scenarios, including the H2@Scale analysis.

The figures of this report and others were created in Tableau and can be published online to inform stakeholders of the results of the H2@Scale scenario, H2USA scenarios (presented here), and sensitivity scenarios. Metrics addressed in the Tableau workbooks include detailed costs, energy consumption, water consumption, and emissions. Future work will include applying the HyReS framework to the next phases of H2@Scale analysis and other scenarios run with the SERA model. Future refinements could include vehicle emissions data to expand on the human health impacts.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. Connelly, E. "Sustainability Analysis: Hydrogen Regional Sustainability (HyReS)." Presentation at the 2018 Annual Merit Review and Peer Evaluation Meeting, June 13, 2017, Washington, DC. https://www.hydrogen.energy.gov/pdfs/review18/sa059_connelly_2018_o.pdf.

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