Analysis of Advanced Hydrogen Production Pathways

Brian D. James (Primary Contact), Daniel DeSantis, Genevieve Saur (National Renewable Energy Laboratory)
Strategic Analysis, Inc.
4075 Wilson Blvd, Suite 200
Arlington, VA 22203
Phone: 703-778-7114
Email: bjames@sainc.com

DOE Manager: Katie Randolph
Phone: 720-356-1759
Email: Katie.Randolph@ee.doe.gov

Subcontractors:

- National Renewable Energy Laboratory, Golden, CO
- Argonne National Laboratory, Argonne, IL

Project Start Date: October 1, 2016
Project End Date: September 30, 2020

Overall Objectives

- Perform cost analysis of various hydrogen production and delivery pathways.
- Identify key cost and performance bottlenecks of the given pathways.
- Conduct deep-dive analyses and optimization studies on hydrogen delivery scenarios.
- Supply information from techno-economic studies to DOE for life cycle analysis.
- Respond to the scope and topic areas as defined by DOE.

Fiscal Year (FY) 2019 Objectives

- Conduct a techno-economic analysis of proton exchange membrane (PEM) electrolysis.
- Conduct a techno-economic analysis of solid oxide electrolysis (SOE).

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery and Hydrogen Storage sections of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

- (F) Capital Cost
- (G) System Efficiency and Electricity Cost
- (K) Manufacturing.

Technical Targets

This project conducts cost modeling to attain realistic cost estimates for the production and delivery of hydrogen fuel for fuel cell vehicles. These values can help inform future technical targets.

- DOE production and delivery cost goals <$4/kg of H_2 (dispensed, untaxed).

FY 2019 Accomplishments

- Completed a techno-economic analysis of PEM electrolysis
- Case studies were submitted to DOE for publication for distributed production (1,500 kg H_2/day) and central production (50,000 kg H_2/day) for both *projected current* (2019) and *projected future* (2035) technology years.
- The system electrical requirement decreases between the *projected current* and *projected future* cases (from ~55 kWh/kg H_2 to 51 kWh/kg H_2), showing technological improvement.
- Completed a techno-economic analysis of SOE
- Case studies were submitted to DOE for publication for central production (50,000 kg H_2/day) for both *projected current* (2019) and *projected future* (2035) technology years.
- Relevant information for the cases was solicited from independent research groups and electrolyzer companies via a questionnaire covering engineering system definition, capital costs, operating costs, variable and fixed expenses, and replacement costs.
- In both water splitting cases, the primary cost driver was found to be electricity.

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

INTRODUCTION

Two main tasks were conducted in Year 3 of the project: techno-economic analyses of PEM and SOE. Both analyses use H2A v3.2018[2] as the main analysis tool for the techno-economic assessment. The two analyses follow a similar methodology for developing the cases. Relevant techno-economic data and information for the cases were solicited from independent electrolyzer companies and research groups via questionnaire spreadsheets. The requested data included H2A input parameters needed for developing the cases as well as supplemental information for the documentation and vetting of the underlying technology assumptions. Data collected fell into the following five primary categories: (1) engineering system definition; (2) capital costs; (3) operating costs; (4) variable and fixed expenses; and (5) replacement costs. The data and information were used as inputs for the various H2A case studies. For each case, an engineering system performance model was developed from the baseline inputs, creating a generalized electrolyzer system design. The engineering model was supplemented with a detailed ASPEN-based model including economic analysis. Further details are provided for each analysis below.

APPROACH

Proton Exchange Membrane Electrolysis

Four case studies examining PEM-based electrolysis with a production rate of 1,500 or 50,000 kg H_2/day were performed using the H2A v3.2018 model. The four cases comprised two technology years[3]: *projected current*[4] (2019) and *projected future*[5] (2035); and two production capacities: distributed (1,500 kg H_2/day) and central (50,000 kg H_2/day). Relevant techno-economic data and information for the cases were solicited from four independent electrolyzer companies via questionnaire spreadsheets. Based on the manufacturer inputs, literature review, and ASPEN design models, generalized system designs were developed for the *projected current* baseline cases that model electrolyzers operating at 2,000 mA/cm^2 and 1.9 volts/cell with an H_2 outlet pressure of 300 psi. The generalized system designs developed for the *projected future* baseline cases were based on technologically advanced electrolyzers operating at 3,000 mA/cm^2 and 1.8 volts/cell with an H_2 outlet pressure of 700 psi. Capital costs[6] for each case were developed through a combination of the questionnaire responses, quoted equipment prices, and use of the ASPEN model economic adviser. Capital costs assume a production rate of 700 MW/yr.[7]

Solid Oxide Electrolysis

Two case studies examining SOE with a production rate of 50,000 kg H_2/day were performed using the H2A v3.2018 model. The two cases examined covered *projected current*[4] (2019) and *projected future*[5] (2035) technology years. Relevant techno-economic data and information for the cases were solicited from independent electrolyzer companies and research organizations via questionnaire spreadsheets. Based on the manufacturer inputs, literature review, and ASPEN design models, generalized system designs were developed. Both cases envision the electrolysis cells operating very close to the thermo-neutral operating point.[8] The system design for the *projected current* baseline case represents a system with a stack temperature of 800°C and a system H_2 outlet pressure of 300 psi. (The stack is assumed to run at 5 bar but the product H_2 is mechanically compressed to 300 psi prior to exiting the system.) Heat to warm the reactants to the stack inlet

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[2] H2A is a discounted cash-flow model providing transparent reporting of process design assumptions and a consistent cost analysis methodology for hydrogen production at central and distributed facilities: https://www.hydrogen.energy.gov/h2a_production.html.
[3] Technology development year is defined as the year in which a system design and performance level have been demonstrated in the laboratory with high confidence that it can be developed into a full-scale system able to achieve the stated performance, durability, and cost targets.
[4] *Projected current* cases reflect demonstrated state-of-the-art 2019 technology but manufactured at production volume. (This differs from the existing commercial systems, which are manufactured as much lower production rates using slightly older technology.)
[5] *Projected future* cases use advanced electrolyzer systems that will be technology-ready in 2035, with market entry assumed in 2040. Compared with the *projected current* cases, the *projected future* cases incorporate expected reductions in capital cost, electricity usage, and site preparation cost as well as increases in replacement interval.
[6] All capital costs in this record are inclusive of markup.
[7] Production rate refers to total electrical input of all PEM electrolyzers produced in a year regardless of individual hydrogen production capacity.
[8] The thermo-neutral operating point refers to a cell operating voltage where ohmic losses within the cell (which releases heat) are balanced by the water splitting heat of reaction (which consumes heat). Thus the cell operates without a large temperature gradient between inlet and outlet streams. The thermo-neutral operating voltage is approximately 1.28 V at 800°C.

temperature is provided from a generic heat source, without judgment as to the heating source. Air is used as a sweep gas on the oxygen-generating side of the cells (anode).

While similar to the *projected current* baseline case, the *projected future* case represents a more technologically advanced version with the following differences:

- Reduced stack operating temperature to 600°–650°C—assumes no loss in performance due to lower temperature
- Removal of air sweep of the oxygen side (anode)—assumes no loss in stack performance without air sweep
- Stack pressure and H_2 outlet pressure are both 300 psi—absence of the air sweep allows the stack pressure to be increased without a large rise in parasitic power
- Increased current density with no corresponding increase in degradation or other performance losses.

RESULTS

Proton Exchange Membrane Electrolysis

The hydrogen production cost breakdown for the four H2A v3.2018 PEM electrolysis baseline cases is shown in Figure 1. As shown in the figure, the primary cost driver for hydrogen production is the electricity cost. The system electrical requirement decreases between the *projected current* and *projected future* cases (from ~55 kWh/kg H_2 to 51 kWh/kg H_2), while the average electricity price over the analysis period rises (from ~$0.073/kWh to ~$0.079/kWh). As a result of this combined effect and other factors, hydrogen costs are only slightly lower for the *projected future* than the *projected current* cases in Figure 1. To further demonstrate the effect of electricity price on the hydrogen cost, each case was run in H2A with a set price of $0.03/kWh of electricity, representative of future low-cost renewable electricity supplies. These results are also shown in Figure 1. Overall, there is only a small cost reduction in moving from small distributed plants to large central plants and only a modest (~10%) cost reduction between *projected current* and *projected future* plants.

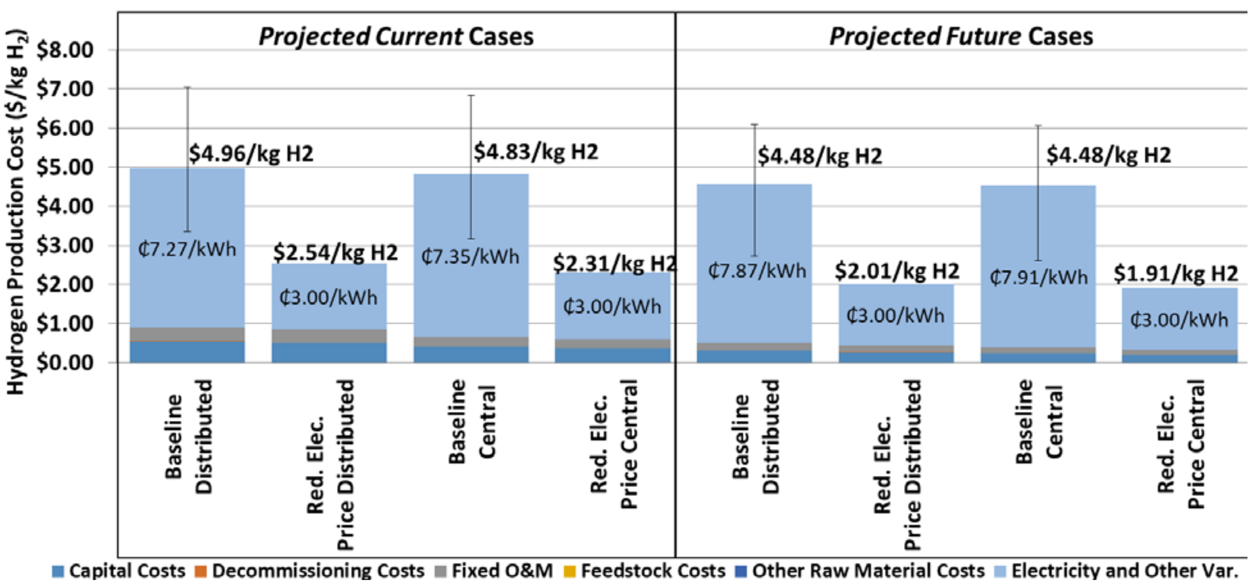

Figure 1. Projected hydrogen production cost for PEM electrolysis (2016$/kg) case studies with effective electricity prices listed for each case. A cost breakdown is shown for each case at a reduced electricity price of $0.03/kWh. Error bars were determined by Monte Carlo analysis (baseline cases only).

Solid Oxide Electrolysis

The projected hydrogen production costs for the two H2A v3.2018 SOE baseline cases are shown in Figure 2. Unlike other cost categories, the price of electricity (as projected by the Annual Energy Outlook) is seen to increase between the *projected current* and *projected future* cases. This electricity price increase is partially offset by the higher system electrical efficiency projected for the *projected future* case. The largest cost contribution to hydrogen production via SOE is the cost of electricity. This result is consistent with PEM electrolysis. To further demonstrate the effect of electricity price on the hydrogen cost, each case was run in H2A with a set electricity price of $0.03/kWh.

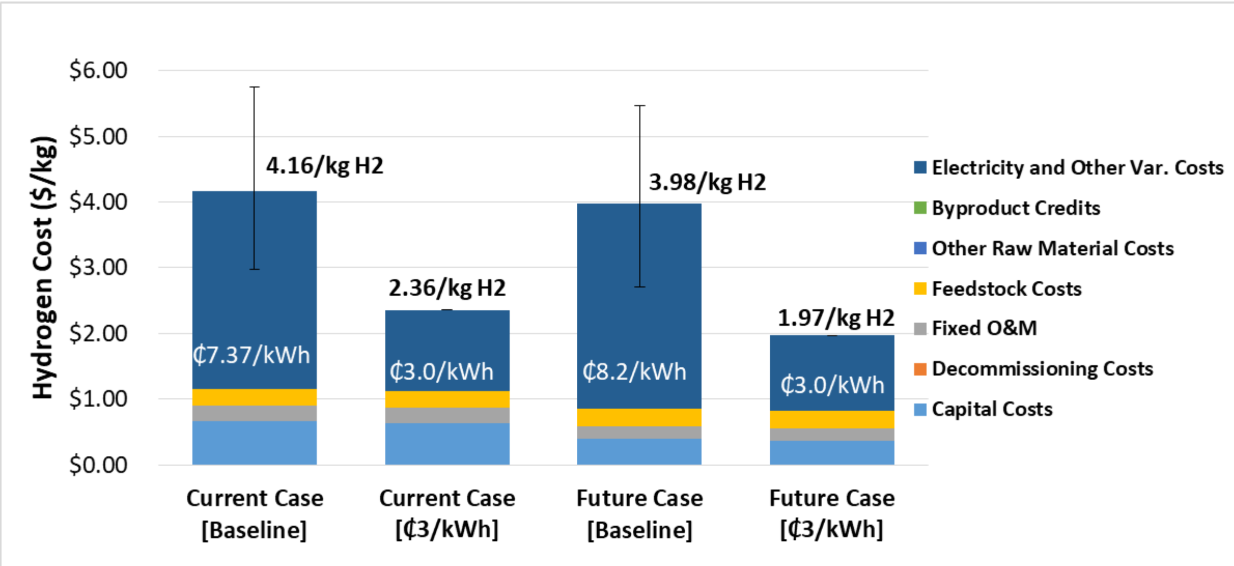

Figure 2. Projected hydrogen production cost for SOE (2016$/kg) case studies with effective electricity prices listed for each case. A cost breakdown is shown for each case at a reduced electricity price of $0.03/kWh. Error bars were determined by Monte Carlo analysis (baseline cases only).

CONCLUSIONS AND UPCOMING ACTIVITIES

In both water-splitting cases, the primary cost driver is electricity. Due to the large cost contribution of electricity, even significant changes to the system capital costs do not change the cost of hydrogen significantly. Efforts to increase electrical efficiency or reduce electrical costs will have the greatest effect on reducing hydrogen costs.

In FY 2020, similar analyses will be conducted on two other water-splitting technologies: alkaline exchange membrane electrolysis and photoelectrochemical. Similar to the water-splitting analyses presented above, these technologies will be examined through the use of a questionnaire sent to industry and research experts, a supporting performance model, and a literature review to determine appropriate operating parameters and costs. H2A v3.2018 will then be used to obtain a projected cost of hydrogen.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. Brian D. James, Cassidy Houchins, Genevieve Saur, and Daniel A. DeSantis, "Analysis of Advanced H_2 Production Pathways," presented at the DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Washington, DC, April 30, 2019.