IX.0 Systems Analysis Sub-Program Overview

INTRODUCTION

Systems Analysis supports decision making of the U.S. Department of Energy's (DOE's) Fuel Cell Technologies Office (FCTO) by providing a greater understanding of technology gaps, options and risks, and the contribution of individual technology components to the overall system, i.e., from fuel production to utilization, as well as the interaction of the components and their effects on the system. Analysis is also conducted to assess cross-cutting issues, such as integration of hydrogen and fuel cells with the electrical sector for energy storage and hydrogen infrastructure development.

The Systems Analysis sub-program made several significant contributions to FCTO during Fiscal Year (FY) 2015. The Hydrogen Financial Analysis Scenario Tool (H2FAST) was developed to provide in-depth financial analysis of hydrogen refueling stations. The impact of improving the fuel cell efficiency on the costs of the fuel cell and storage systems and the fuel cell electric vehicle (FCEV) performance was studied. The JOBS model, developed by Argonne National Laboratory (ANL) and RCF Economic and Financial Consulting, Inc., was used to assess employment and economic impacts of infrastructure development for the early market penetration of fuel cell vehicles in California. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model continues to be enhanced for the analysis of greenhouse gas emissions, petroleum use, and water consumption for conventional and renewable hydrogen pathways on a life-cycle basis.

GOAL

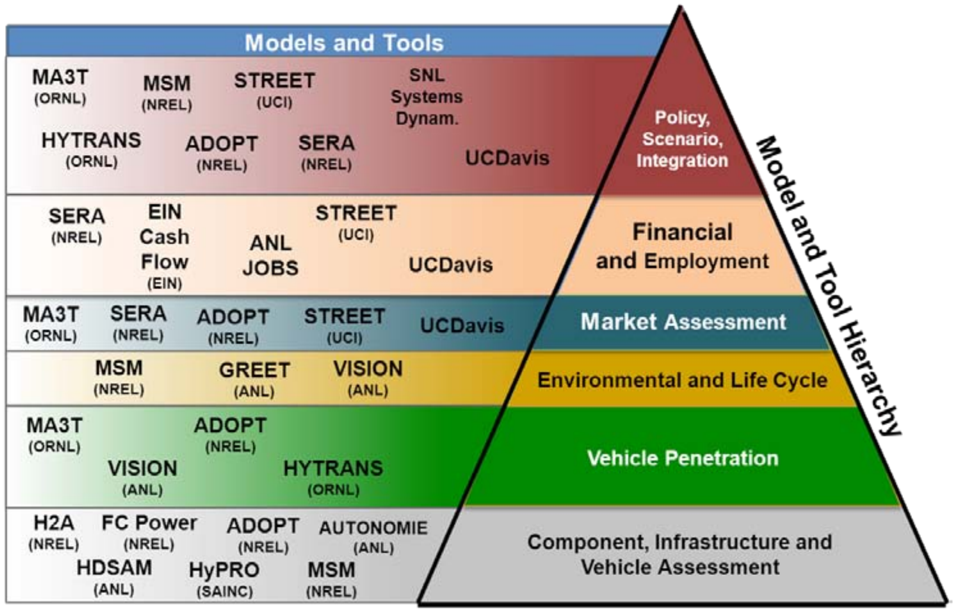
The goal of the Systems Analysis sub-program is to provide system-level analysis to support hydrogen and fuel cell technology development and technology readiness by evaluating technologies and pathways, including resource and infrastructure issues; guiding the selection of research, development, and demonstration (RD&D) projects; and estimating the potential value of RD&D efforts.

OBJECTIVES

- By 2015–2016, complete analysis of milestones and technology targets, including risk analysis, independent reviews, financial evaluations, and environmental analysis to identify technology gaps and risk mitigation strategies.
- By 2017, complete assessment of potential employment impacts and establish linkages with the United States veteran community for growing hydrogen and fuel cell industries.
- By 2017, complete sustainability analysis and develop a framework for incorporating metrics (such as greenhouse gas [GHG] emissions, ecological footprint, economic/societal impact, etc.) into hydrogen production and infrastructure assessments.
- By 2017, complete analysis of program performance, cost status, and potential for use of fuel cells for a portfolio of commercial applications.
- By 2019, complete analysis of the potential for hydrogen, stationary fuel cells, fuel cell vehicles, and other fuel cell applications such as material handling equipment. The analysis will address necessary resources, hydrogen production, transportation infrastructure, performance of stationary fuel cells and vehicles, and the system effects resulting from the growth of fuel cell market shares in the various sectors of the economy.
- Provide milestone-based analysis, including risk analysis, independent reviews, financial evaluations, and environmental analysis, to support the Office's needs prior to technology readiness.
- Periodically update the life-cycle energy, petroleum use, GHG emissions, and criteria emissions analysis for technologies and pathways for FCTO to include technological advances or changes.

FY 2015 STATUS

The Systems Analysis sub-program focuses on examining the economics, benefits, opportunities, and impacts of fuel cells and renewable fuels with a consistent and comprehensive analytical framework. Analysis conducted in FY 2015 included examination of socio-economic impacts such as increased employment from early market infrastructure development in California, development of the financial analysis tool (H2FAST), assessment of the cost improvement of the fuel cell and storage system costs as a result of improved fuel cell efficiency, development of an interim hydrogen cost target for early markets, identification of the impacts of station utilization and fueling pressure on dispensed hydrogen cost, and analysis of life-cycle water use for multiple hydrogen and conventional fuel/vehicle pathways. The Systems Analysis sub-program leverages key models shown in Figure 1 that were developed with sub-program funding in prior years for critical program analyses, as evidenced by the completed and ongoing analysis activities in the accomplishment section.



Source: Argonne National Laboratory
ORNL – Oak Ridge National Laboratory; NREL – National Renewable Energy Laboratory;
UCI – University of California, Irvine; EIN – Energy Independence Now; SAINC – Strategic Analysis, Inc.;
SNL – Sandia National Laboratories; UCDavis – University of California, Davis

FIGURE 1. Key models for critical program analyses performed in the Systems Analysis sub-program

FY 2015 ACCOMPLISHMENTS

Models and Systems Integration

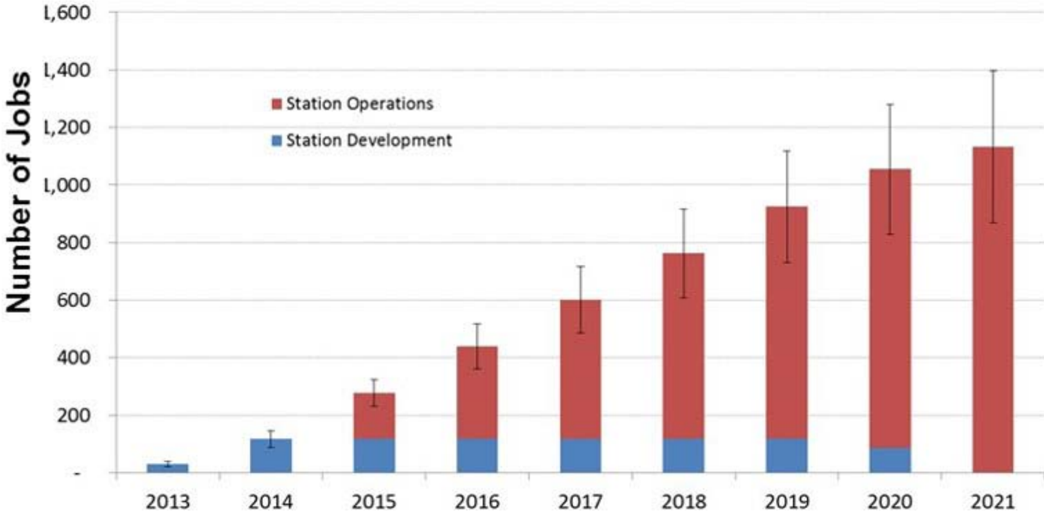
Employment Analysis

ANL, with assistance from RCF Economic and Financial Consulting, Inc., continues to enhance and apply the JOBS H2 model. The model was created to estimate employment and revenue impacts of infrastructure development to support the early market penetration of FCEVs. The JOBS H2 model uses the same model structure and input-output methodology as developed for the JOBS FC (fuel cell) model to estimate changes in industry expenditures as a result of hydrogen fueling infrastructure deployment and calculates the effects of those changes throughout the economy. Recently, the model has been used to estimate the jobs creation and economic impacts of the early market FCEV and supporting infrastructure rollout in California. (ANL)

Figure 2 shows that the development of 25 hydrogen fueling stations over five years, as projected by the California vehicle rollout plans, will create or retain approximately 1,300 jobs. Note that jobs will start to decline once the station construction is completed, but operation-related jobs will be retained.

Water Life-Cycle Analysis

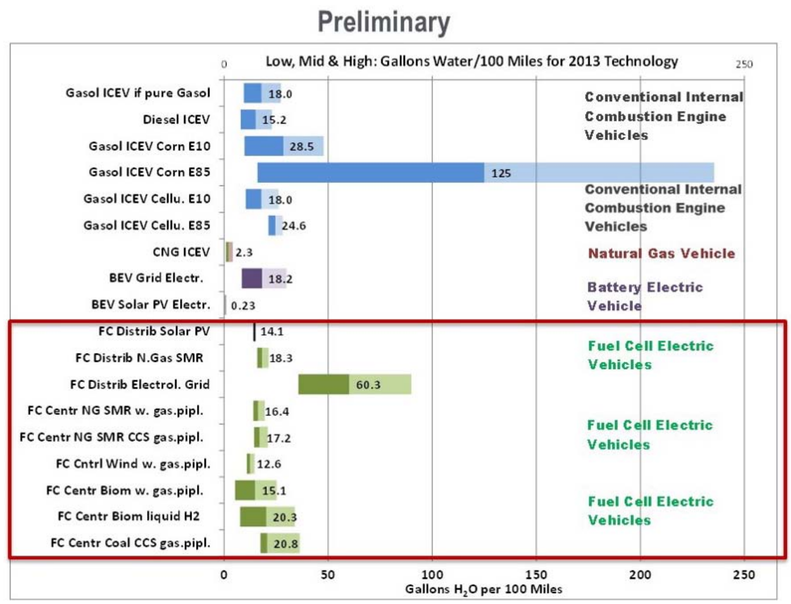
ANL continued to enhance the GREET model's life-cycle analysis capabilities in FY 2015 to examine water consumption for hydrogen production and delivery pathways from natural gas, water electrolysis, and other fuels such



Source: Argonne National Laboratory

FIGURE 2. Job creation from station development in California

as gasoline and ethanol. ANL developed water consumption factors for hydrogen production from biogas and from coal and biomass gasification and updated the water consumption factors for hydrogen production via steam methane reforming (SMR) and electrolysis. A methodology for allocating water consumption to hydropower generation was developed. ANL expanded the GREET model to include the water consumption factors for the new and updated hydrogen production pathways. The water consumption quantities per 100 miles for various fuel/vehicle combinations were compared (Figure 3) to identify the stages with major contribution to life-cycle water consumption. The outstanding issues include the use of different water consumption evaluation methods with respect to system boundary and allocation. Also, the variability of water consumption by region and the water consumption during purification need to be assessed. (ANL)



Source: Argonne National Laboratory
ICEV – internal combustion engine vehicle; CNG – compressed natural gas; BEV – battery electric vehicle; FC – fuel cell; PV – photovoltaic; NG – natural gas; CCS – carbon capture and sequestration

FIGURE 3. Life-cycle water consumption of fuels and vehicle technologies comparable to conventional fuels

The Hydrogen Financial Analysis Scenario Tool (H2FAST)

NREL developed the H2FAST tool to provide quick and convenient in-depth financial analysis of hydrogen fueling stations. H2FAST is available in two formats: an interactive online tool and a downloadable Excel spreadsheet. The spreadsheet version of H2FAST offers basic and advanced user interface modes for modeling individual stations or groups of up to ten stations. It provides users with detailed annual finance projections in the form of income statements, cash flow statements, and balance sheets; graphical presentation of financial performance parameters for 65 common metrics; life-cycle cost breakdown for each analysis scenario; and common ratio analysis results such as debt/equity position, return on equity, and debt service coverage ratio. The online H2FAST can be used to explore the impact of basic financial performance metrics by varying up to 20 user inputs, as illustrated in the model input screen shown in Figure 4. The tool was thoroughly peer reviewed and issued to the public through the following Web address: http://www.nrel.gov/hydrogen/h2fast/. (NREL)

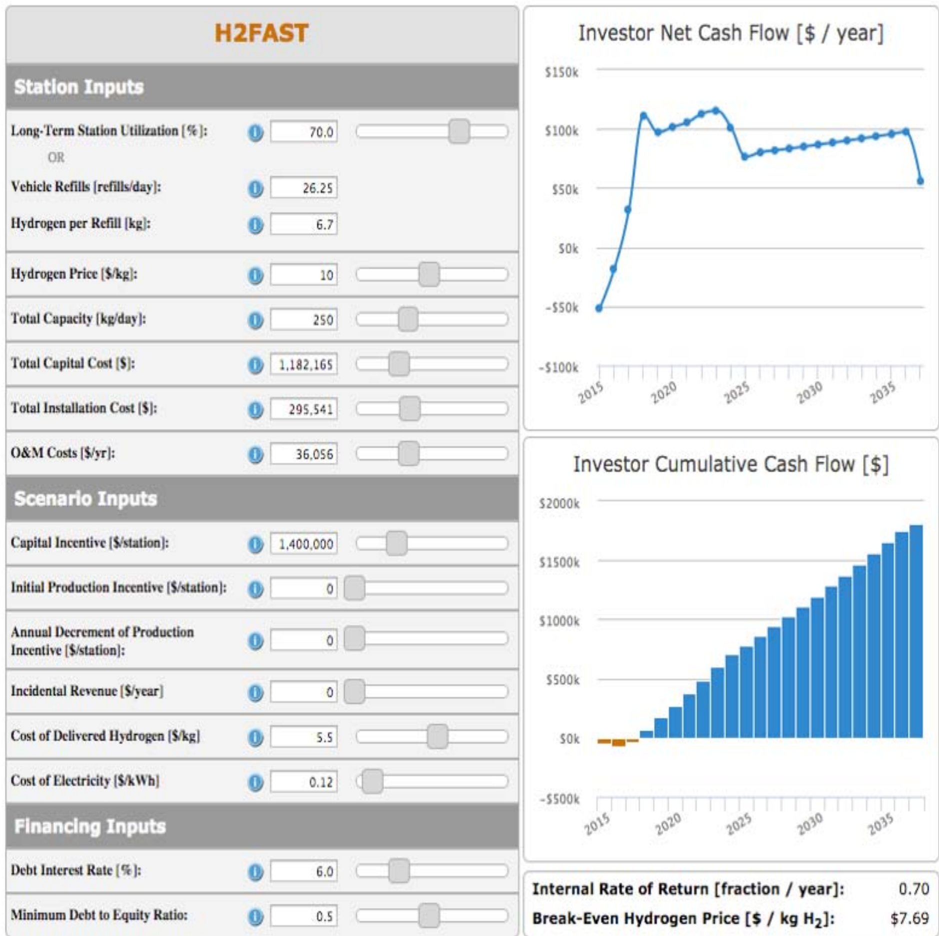


FIGURE 4. H2FAST financial scenario analysis tool input module

Infrastructure Analysis

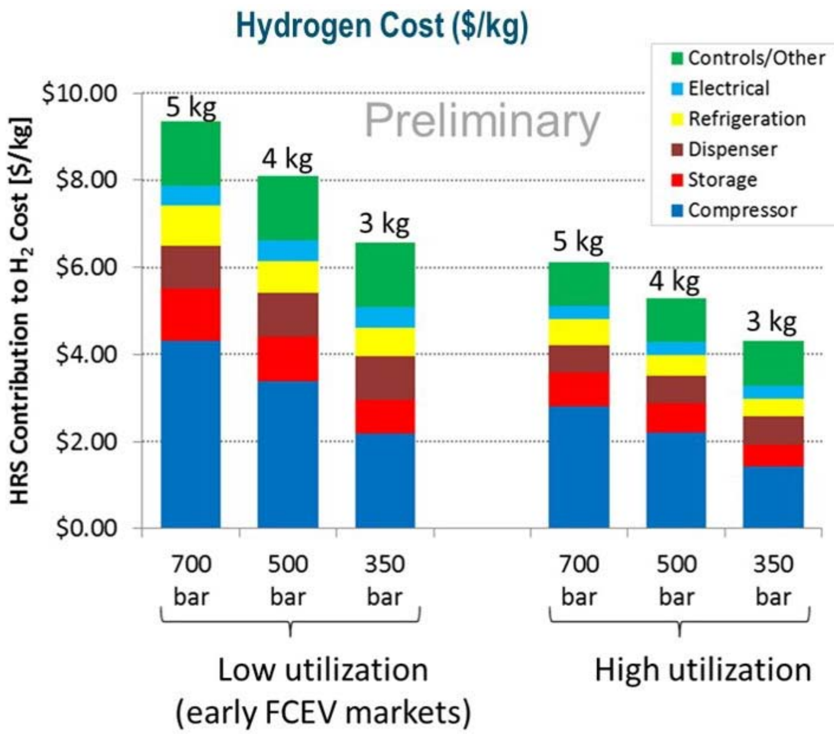
Fueling Pressure Analysis

ANL evaluated the cost of multiple delivered hydrogen pressures (350 bar, 500 bar, and 700 bar) for refueling FCEVs. The project assessed the performance of the refueling system and the impact of fueling pressure and precooling requirements on the tank fill time and refueling cost. Also, the refueling costs for stations with high and low utilization factors with a capacity of 200 kg/d were evaluated, as exhibited in Figure 5. The refueling cost savings with the lower fueling pressures is much greater as a result of the reduced compressor needs and smaller storage equipment costs. (ANL)

Environmental Analysis

Well-to-Wheels (WTW) GHG Emissions for Methanol-to-Hydrogen Pathways

The methanol hydrogen fuel cell vehicle and direct methanol fuel cell (DMFC) vehicle pathways were estimated to have 30% to 35% less GHG emissions as compared to today's gasoline ICEV. In comparison, the natural gas hydrogen fuel cell vehicle pathways have 45% to 50% less GHG emissions as compared to today's gasoline ICEV. The analysis



Source: Argonne National Laboratory
HRS – hydrogen refueling station

FIGURE 5. Impact of fueling pressure on hydrogen refueling cost

was carried out by expanding and modifying the 2014 version of the GREET model. Figure 6 compares the GHG emissions associated with the production and use of hydrogen in FCEVs and of methanol (MeOH) in DMFC vehicles to the GHG emissions associated with the production and use of petroleum gasoline and CNG in ICEVs and hybrid electric vehicles (HEVs). Figure 6 also shows a renewable pathway for hydrogen production via electrolysis using electricity generated from wind power. The small GHG emissions associated with that pathway are due to compression energy at refueling stations using a United States average generation mix. Note that gasoline is a mix of 10%

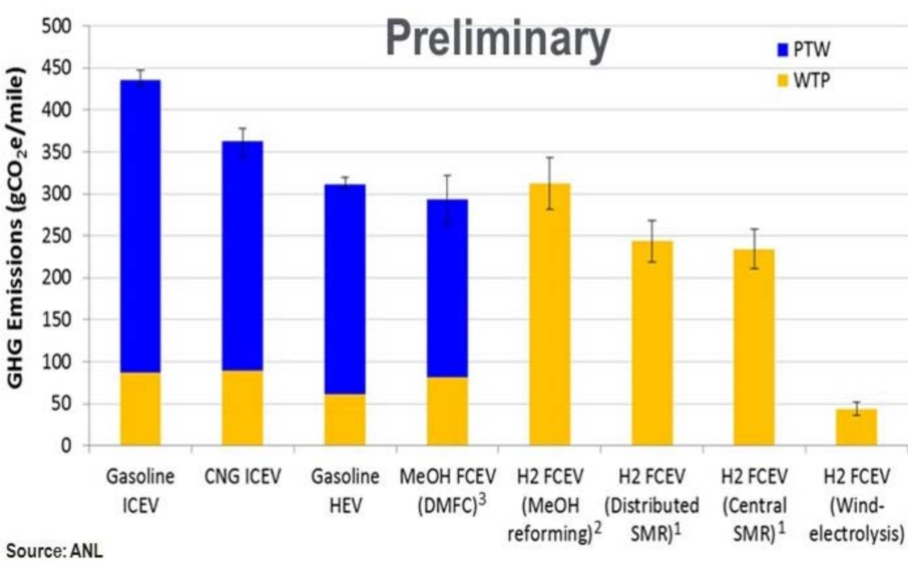


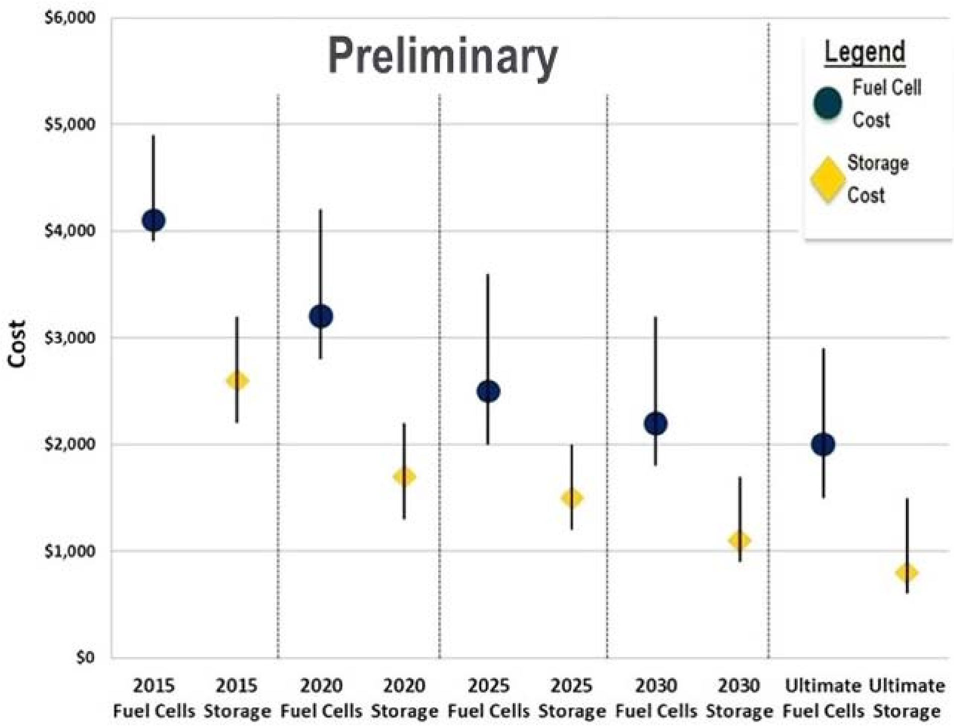
FIGURE 6. WTW GHG emissions of hydrogen FCEV pathways compared to gasoline and CNG ICEV pathways

corn-based ethanol and 90% gasoline blendstock by volume (also known as E10). The figure shows two main stages for the WTW GHG emissions: well-to-pump (WTP) and pump-to-wheels (PTW). (ANL)

Programmatic Analysis

Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost

ANL studied the impact of different fuel cell targets on the vehicle energy consumption and cost using the Autonomie model and compared the energy consumption and cost to those of conventional gasoline internal combustion powertrains. In addition, the impact of fuel cell system improvements on the potential onboard storage requirements and cost was analyzed. The findings of the study indicate the fuel economy of the FCEV could be improved by 10–14% by increasing the fuel cell peak efficiency from 60% to 68%. When the FCEV improvements are compared to conventional vehicles, the FCEV's fuel economy is found to be five times higher than that of the conventional vehicle in the 2030 timeframe. The fuel economy improvements for the FCEV are illustrated in Figure 7. (ANL)



Source: Argonne National Laboratory

FIGURE 7. Improvement in fuel economy and onboard fuel storage costs for FCEVs over time

Interim Cost Target

An early market cost target was developed to guide and prioritize R&D for FCTO. The early market hydrogen cost target, a pathway independent target to guide R&D for production and delivery technologies for hydrogen fuel, is set at $7/gge, untaxed and dispensed at the pump. This target is based on a "top-down" analysis of the cost at which hydrogen fuel for FCEVs is projected to be competitive on a cost per mile basis with gasoline fuel for gasoline ICEVs in the early market timeframe of 2015 to 2020, as exhibited in Figure 8. The target considers a range of vehicle technologies, performance, fuel economy values (for both FCEVs and the competing ICEVs), and the federal and regional incentives currently in place, as well as the gasoline market prices in the regions analyzed. DOE record #14013 was developed, peer reviewed, and issued. http://hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf

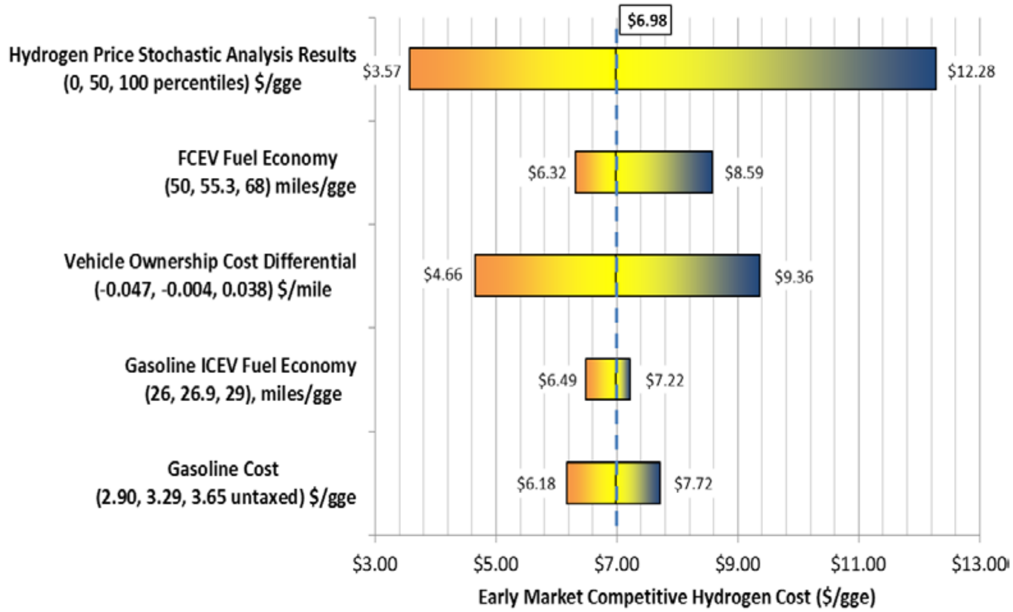
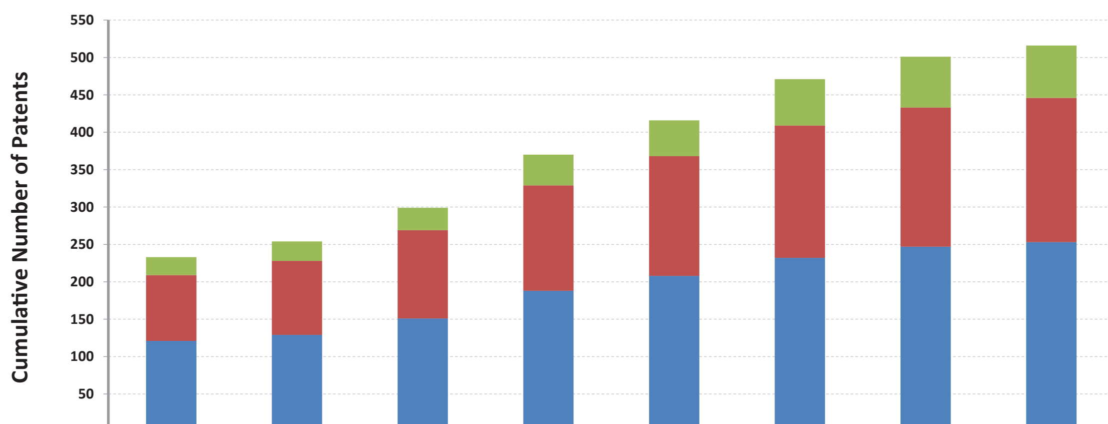


FIGURE 8. Sensitivity of the early market hydrogen cost (untaxed) to gasoline cost, vehicle ownership cost differential, and vehicle fuel economy

Commercial Products and Patents Resulting from DOE-Sponsored R&D

Pacific Northwest National Laboratory (PNNL) continues to analyze the commercial benefits of FCTO by tracking the commercial products and technologies, and patents developed from FCTO R&D funding. The benefits of DOE-funded projects continue to grow, as illustrated in Figures 9 and 10. Over 510 patents were awarded and 40 products were commercialized by 2015 as a result of research funded by FCTO in the areas of storage, production, delivery, and fuel cells, which will be highlighted in the FY 2015 Pathways to Commercial Success report. (PNNL)

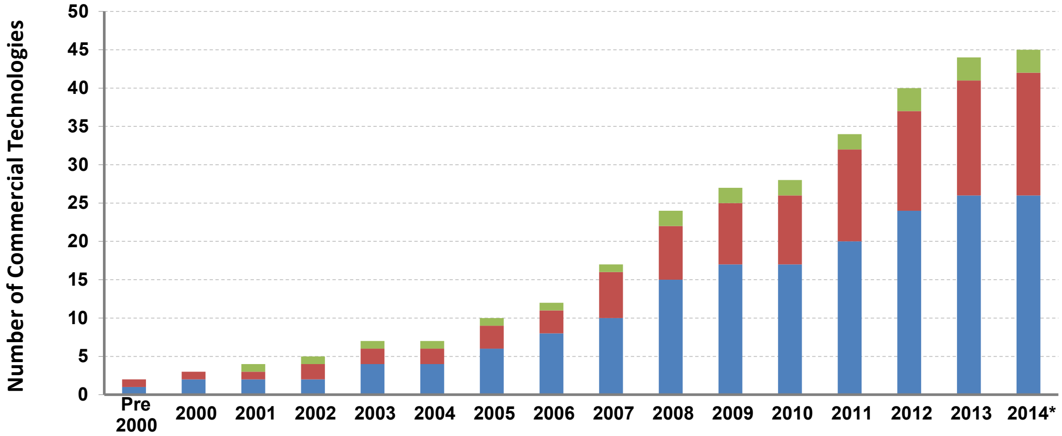


	2007	2008	2009	2010	2011	2012	2013	2014*
Storage	24	26	30	41	48	62	68	70
Production/Delivery	88	99	118	141	160	177	186	193
Fuel Cell	121	129	151	188	208	232	247	253
Total	233	254	299	370	416	471	501	516

*Partial data for 2014

Source: Pacific Northwest National Laboratory

FIGURE 9. Cumulative number of patents awarded for FCTO-funded projects



	Pre 2000	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Storage	0	0	1	1	1	1	1	1	1	2	2	2	2	3	3	3
Production/Delivery	1	1	1	2	2	2	3	3	6	7	8	9	12	13	15	16
Fuel Cell	1	2	2	2	4	4	6	8	10	15	17	17	20	24	26	26
Total	2	3	4	5	7	7	10	12	17	24	27	28	34	40	44	45

*Partial data for 2014

Source: Pacific Northwest National Laboratory

FIGURE 10. Cumulative number of commercial products entering the market from FCTO-funded projects

BUDGET

The budget for the Systems Analysis sub-program is consistent with the goals and objectives of FCTO and is responsive to assessing hydrogen and fuel cell applications for energy storage, stationary power generation, specialty applications, and light-duty transportation. The FY 2015 appropriation for the Systems Analysis sub-program was $3 million (Figure 11). Funding for the sub-program continues to focus on conducting analysis using the models developed by the program. In particular, projects are concentrated on analysis of hydrogen for energy storage and transmission, analysis of early market adoption of fuel cells, continued life-cycle analysis of water use for advanced

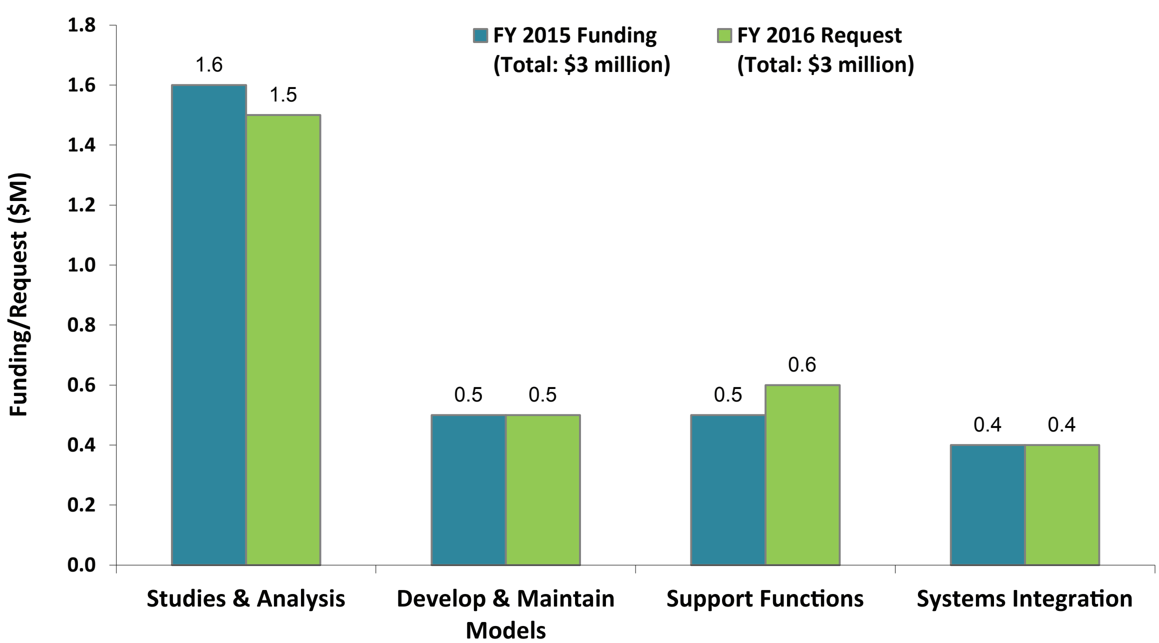


FIGURE 11. Systems Analysis R&D Funding. Subject to appropriations, project go/no-go decisions, and competitive selections. Exact amounts will be determined based on research and development progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements.

hydrogen production technology pathways, analysis of the levelized cost of hydrogen from emerging hydrogen production pathways, assessment of the impacts of consumer behavior, analysis of the cost of onboard hydrogen storage options and associated greenhouse gas emissions and petroleum use, and hydrogen fueling station business assessment.

FY 2016 PLANS

The FY 2016 request of $3 million, subject to congressional appropriation, provides greater emphasis on analysis of employment impacts of hydrogen and fuel cell technologies, sustainability, early market adoption of fuel cells, life-cycle analysis of GHG emissions and petroleum use for future hydrogen production technology pathways such as photoelectrochemical and solar thermal chemical hydrogen production, levelized cost of hydrogen from emerging hydrogen production pathways, and impacts of consumer behavior.

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