IX.0 Systems Analysis Sub-Program Overview

INTRODUCTION

Systems Analysis supports the decision-making of the Fuel Cell Technologies Office (FCTO) by providing a greater understanding of technology gaps, options, and risks. The Systems Analysis sub-program analyzes the contribution of individual technology components and systems to overall pathways. For example, the team provides techno-economic analysis of fuel production on a lifecycle basis for light-, medium-, and heavy-duty fuel cell electric vehicles (FCEVs). Analysis is also conducted to assess cross-cutting issues, such as integration of hydrogen and fuel cells with the electric grid for energy storage and grid services.

Systems Analysis made several significant contributions to the Hydrogen and Fuel Cells Program in Fiscal Year (FY) 2017. The hydrogen financial analysis scenario tool (H2FAST) was expanded to provide in-depth financial and stochastic analysis of hydrogen refueling stations. The sub-program also studied how increasing fuel cell efficiency would impact the costs of fuel cells and hydrogen storage systems and the performance of FCEVs. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET®) model continues to be enhanced for the analysis of petroleum use, greenhouse gas (GHG) emissions, criteria pollutants, and water consumption for multiple hydrogen pathways for light-, medium-, and heavy-duty vehicles on a lifecycle basis.

GOAL

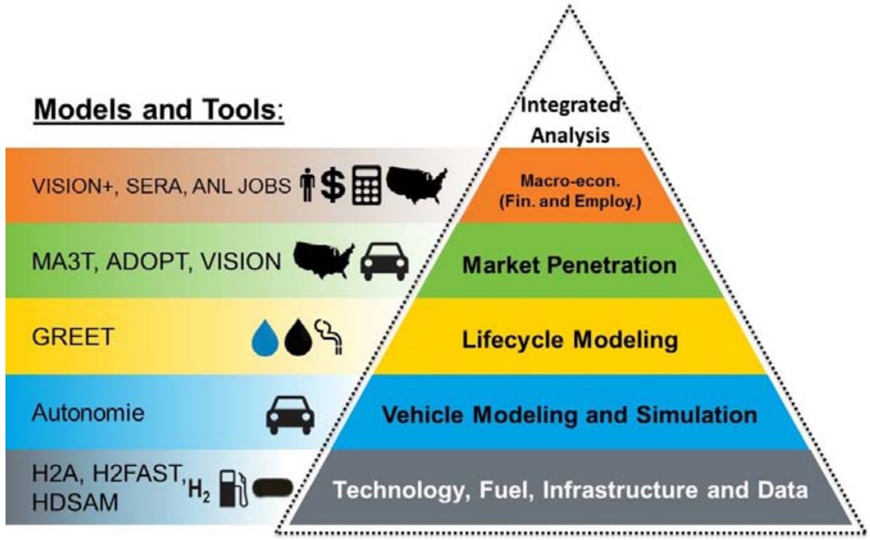
The goal of the Systems Analysis sub-program is to provide system-level analysis to support hydrogen and fuel cell technology development and technology readiness by evaluating technologies and pathways, including resource requirements, to guide the selection of research and development (R&D) projects and estimate the potential value of specific R&D efforts.

OBJECTIVES

- By 2018, complete an assessment of fuel cell cost and power requirements for multiple medium- and heavy-duty truck applications.
- By 2018, update the risk analysis process for FCTO-supported technologies, prepare a risk analysis plan for FCTO, and apply the process to at least one FCTO sub-program.
- By 2018, complete a preliminary resource analysis supporting the H2@Scale initiative and identify excess hydrogen generation capacity available for hydrogen fueling or other applications.
- By 2019, complete a sustainability analysis of FCTO metrics and develop a method of incorporating metrics in sub-program targets.
- By 2019, complete an analysis of the potential for hydrogen, stationary fuel cells, FCEVs, and other fuel cell applications such as grid services. The analysis will address necessary resources, hydrogen production, and performance of stationary fuel cells and vehicles.
- Provide milestone-based analysis, including risk analysis and independent reviews, to support the fuel cell technologies' needs prior to technology readiness.
- Periodically update the lifecycle energy and petroleum use analysis for technologies and pathways for fuel cell technologies to include technological advances or changes.

FY 2017 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

The Systems Analysis sub-program focuses on examining the economics, benefits, opportunities, and impacts of fuel cells and renewable fuels with a consistent, comprehensive analytical framework. Analysis conducted in FY 2017 included analysis of socio-economic impacts such as employment impacts from the penetration of hydrogen and FCEVs, enhancement of the H2FAST tool, analysis of the reduction of fuel cell and storage system costs as a result of improved fuel cell efficiency, lifecycle analysis of petroleum use and GHG emissions for medium- and heavy-duty trucks, and lifecycle analysis of water use and criteria emissions for multiple hydrogen and conventional light-duty fuel/vehicle pathways. Systems Analysis leverages the key models shown in Figure 1. These models have been developed in prior years for critical sub-program analyses.



Model Description Fact Sheets: http://www.energy.gov/eere/fuelcells/systems-analysis

FIGURE 1. Systems Analysis Models and Tools

Develop and Maintain Models and Systems Integration

Lifecycle Analysis of Air Pollutants for Hydrogen Production from Steam Methane Reforming (SMR)

The GREET model has been updated to assess the lifecycle emissions impact of FCEVs relative to baseline petroleum fuels usage in internal combustion engine vehicles (ICEVs). The model update methodology included developing criteria air pollutants emission factors for hydrogen production via SMR process. These factors were calibrated to air pollutant emissions from U.S. standalone SMR units and aggregated to the national level. The model simulations show that use of SMR hydrogen in FCEVs can reduce most criteria pollutant emissions from 35%–97% when compared to gasoline ICEVs.

The comparison of criteria pollutants emissions for various fuel-vehicle technologies is provided in Table 1 on grams per million British thermal units (g/mmBtu) and grams per mile bases. As shown, the hydrogen FCEV has significantly lower per-mile well-to-wheel (WTW) emissions than ICEVs for most pollutants, but SOx emissions are an exception. The higher WTW SOx emissions are attributed to the emissions associated with electricity generation for hydrogen compression, which is required for both hydrogen delivery and FCEV refueling. As the future grid electricity generation mix is projected to have a reduced share of coal-based generation, the WTW SOx emissions for FCEVs is expected to be proportionally reduced.

Lifecycle Analysis of Fuel Cell Applications for Medium- and Heavy-Duty Trucks

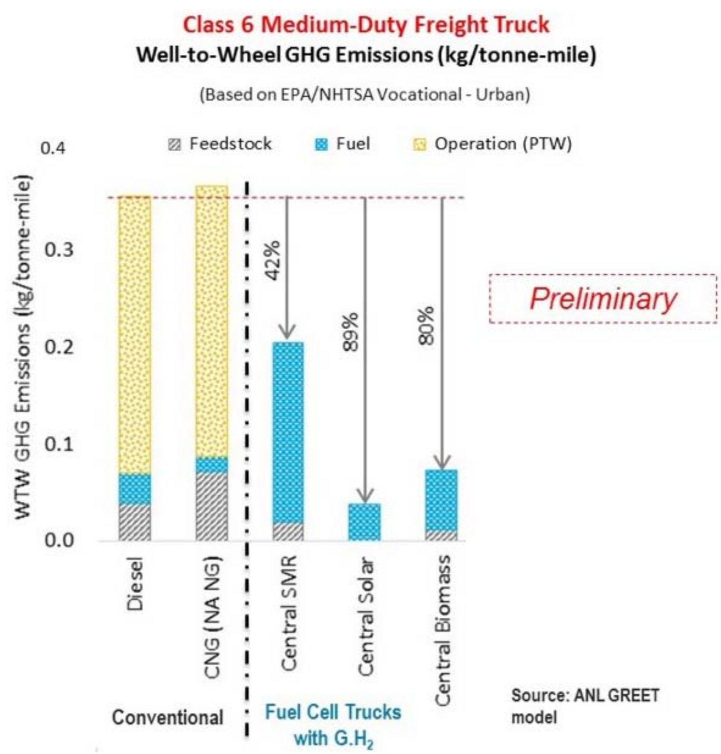
Medium- and heavy-duty vehicles (MHDVs), particularly trucks, are the second-largest and fastest-growing petroleum consumers and GHG emitters in the U.S. transportation sector. The significance of MHDVs is even greater for local air quality management in some areas. FCEVs can play an important role, as they create zero tailpipe emissions and do not consume petroleum fuels. The main goal of this project is to quantify and examine the WTW petroleum energy use and emissions of hydrogen fuel cell MHDVs in comparison with conventional diesel ICEVs by expanding the GREET model by adding FCEVs to the existing MHDV technology portfolio.

Simulation results show that medium- and heavy-duty FCEVs generally achieve 1.7 times better fuel economy (miles per diesel gallon equivalent) compared to conventional diesel vehicles, resulting in a significant reduction in petroleum use and GHG emissions. An example of the potential GHG emissions reduction for a Class 6 FCEV compared to a conventional medium-duty truck is provided in Figure 2.

TABLE 1. Lifecycle Emissions for Various Fuel–Vehicle Technologies

(g/mmBtu basis)	VOC	CO	NOx	SOx	PM10	PM2.5
Gasoline ICEV	84.7	645	65.3	21.3	8.89	4.58
Diesel ICEV	42.3	796	67.0	14.4	8.58	4.42
LPG ICEV	59.2	645	56.4	21.5	6.82	3.36
H_2 FCEV	13.7	33.6	51.8	61.0	13.2	6.35
(g/mile basis)						
Gasoline ICEV	0.364	2.78	0.281	0.091	0.038	0.020
Diesel ICEV	0.152	2.86	0.240	0.051	0.031	0.016
LPG ICEV	0.255	2.77	0.243	0.092	0.029	0.014
H_2 FCEV	0.028	0.069	0.106	0.125	0.027	0.013

Source: Argonne National Laboratory (ANL)
LPG – liquefied petroleum gas; VOC – volatile organic compound; CO – carbon monoxide; NOx – oxides of nitrogen; SOx – sulfur oxides; PM10 – particulate matter with diameter 10 mm or smaller; PM2.5 – particulate matter with diameter 2.5 mm or smaller



EPA – U.S. Environmental Protection Agency; NHTSA –National Highway Traffic Safety Administration of the U.S. Department of Transportation; PTW – pump-to-wheel; CNG – compressed natural gas; NA NG – North American natural gas; G.H_2 – gaseous hydrogen

FIGURE 2. Well-to-Wheel GHG emissions of hydrogen fuel cell truck pathway

The Hydrogen Financial Analysis Scenario Tool (H2FAST)

The H2FAST tool has been enhanced to provide in-depth financial analysis for hydrogen fueling stations to facilitate investments in hydrogen stations, improve policy design decisions to support early station and FCEV deployment, and examine the associated financial risks. Features added to the model include additional fixed operating costs (e.g., electrical demand charges), more detailed hydrogen demand ramp-up, and the ability to provide custom feedstock and retail price profiles. The expanded version also enables risk analysis for input parameters; assessment of incentives and policies, take-or-pay contract implications, and additional feedstocks for hydrogen production; and analysis of scenarios with a number of larger stations.

The tool was thoroughly peer-reviewed and issued to the public through the following website: http://www.nrel.gov/hydrogen/h2fast.

Studies and Analysis

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

The impact of different fuel cell targets on vehicle energy consumption and cost was studied using the Autonomie model to evaluate the incremental impacts and benefits of improving onboard hydrogen fuel storage and fuel cell technologies through FCTO-supported R&D. Figure 3 exhibits fuel and vehicle cost savings as a result of improvements in hydrogen storage and fuel cell technologies. These improvements include hydrogen storage changes to reduce tank costs and design changes for increased fuel cell efficiency. The largest savings for the individual technologies is achieved when the fuel cell targets are achieved; if the ultimate fuel cell and storage targets are both met, cost reduction could reach approximately $4,000 per vehicle. The results of this work will be published in an ANL report. Future work will continue to focus on examining the marginal benefits of improved fuel cell efficiency and onboard storage versus the marginal cost.

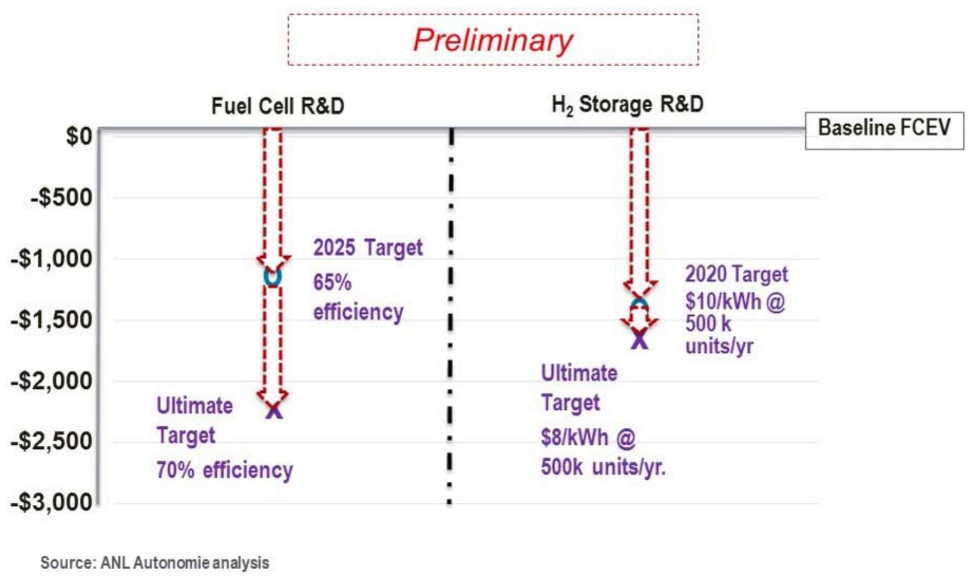


FIGURE 3. Impact of FCTO targets on fuel savings and vehicle cost reduction

Analysis of Sub-Program Benefits

Scenarios were developed and analyzed to estimate petroleum use reduction benefits as a result of the successful deployment of FCEVs. The successful development of hydrogen and fuel cell technologies as a result of DOE-funded R&D was compared to a base case without government-funded R&D. As shown in Figure 4, these advances could improve the fuel economy of the light-duty vehicle stock by 25% to 30% and reduce projected petroleum consumption by 0.3 million to ~1 million barrels per day. The results of this analysis will be published in an ANL report.

Employment Study

ANL, with assistance from RCF Economic and Financial Consulting, is analyzing the economic impacts associated with the development of FCEV technology and the associated hydrogen infrastructure technology achieved through DOE R&D funding. Scenario analysis will be used to identify fuel cell markets and regions that are most likely to experience employment and economic gains from the technology advancement. A reference (“core multi market”) scenario of FCEV deployment in five U.S. regions was developed, and initial estimates of gross employment under two manufacturing assumptions were generated. Under this scenario, approximately 260,000 jobs (100,000 associated with manufacturing and 160,000 associated with distribution and sale of 3.7 million FCEV cars and light trucks) were estimated nationally in 2050, as shown in Figure 5. This work builds on the 2008 DOE Report to

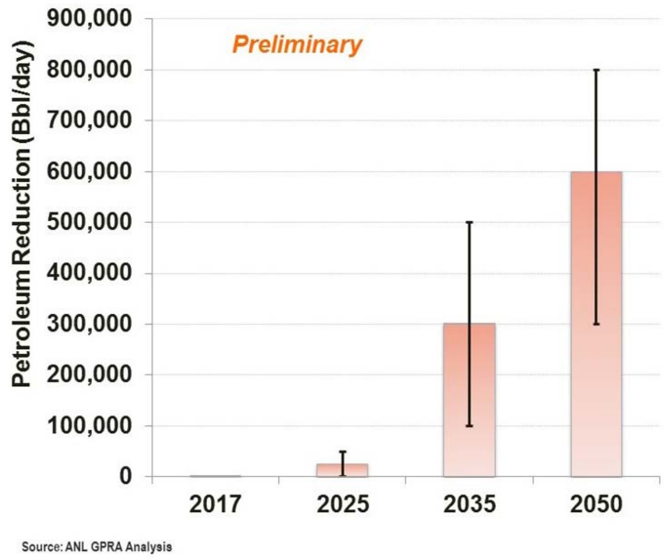
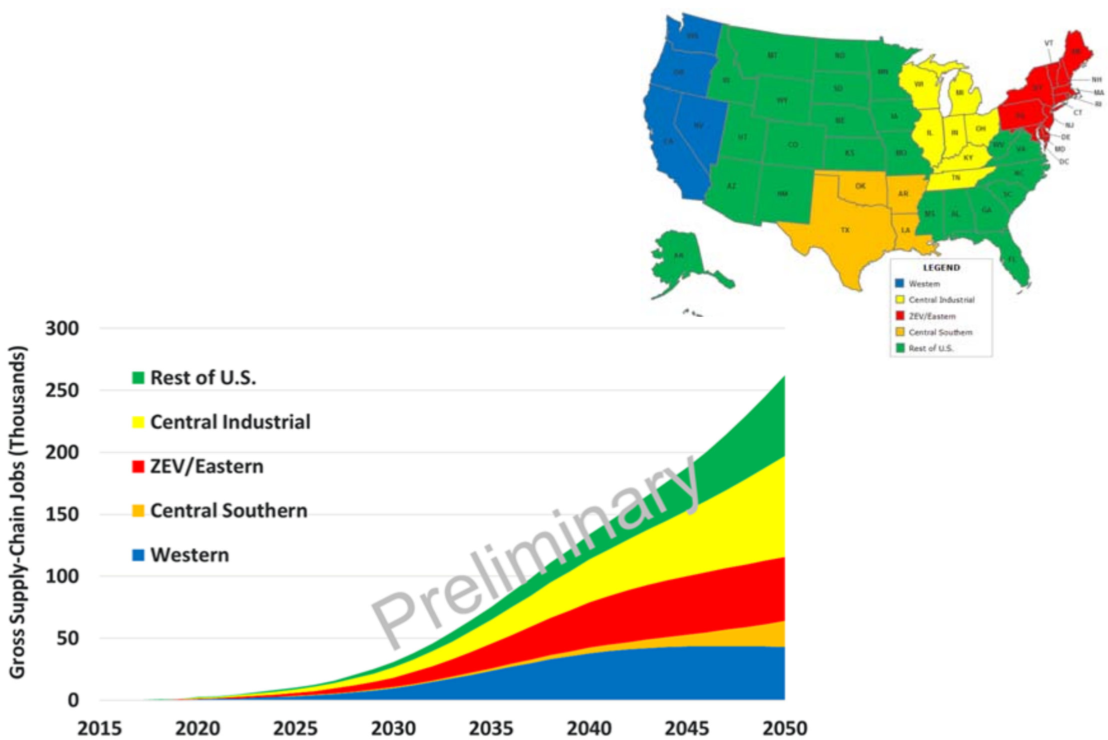


FIGURE 4. Energy security benefit – petroleum reduction attributed to FCEV market penetration



ZEV – zero emission vehicle; NE – Northeast

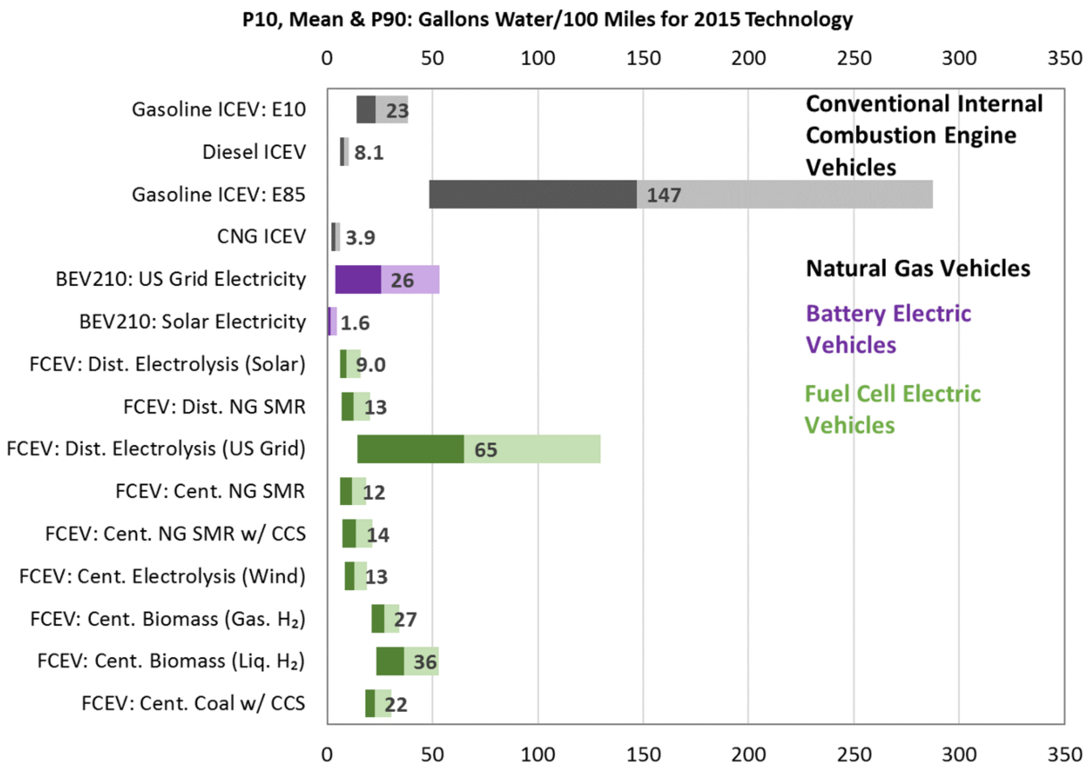
FIGURE 5. Employment impacts from FCEV penetration

Congress (*Effects of a Transition to a Hydrogen Economy on Employment in the United States*), estimating job creation and expanding that analysis to include insights gained from FCTO R&D and market developments. An ANL report will be issued on the study results.

Future work may include expanding the "core" scenario to include heavy-duty trucks and buses; analyzing hydrogen production, distribution, and sale to all FCEVs (light- and heavy-duty); and analyzing sensitivities and workforce development needs.

Water Lifecycle Analysis

The lifecycle freshwater consumption associated with various transportation fuels for light-duty vehicles in the United States was analyzed by ANL using the water module of the GREET model. The results of the analysis show that lifecycle water consumption for FCEVs can be comparable to that for conventional gasoline vehicles for certain fuel pathways, as illustrated in Figure 6. The values range from roughly 9 to 65 gal of water per 100 mi driven depending on the pathway for hydrogen production, delivery, storage, and dispensing. The baseline lifecycle water consumption for conventional gasoline vehicles (with 10% ethanol) is roughly 23 gal per 100 mi driven. The results of the analysis will be documented in a DOE Hydrogen and Fuel Cells Program record.



Source: ANL

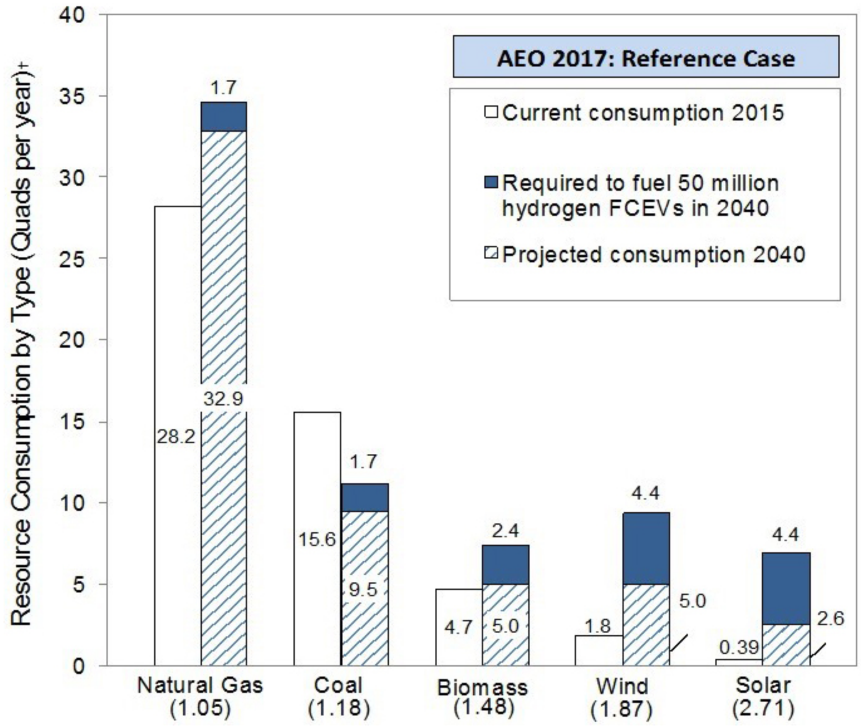
E10 – fuel mixture with 90% gasoline and 10% ethanol; E85 – fuel mixture with 15% gasoline and 85% ethanol; CNG – compressed natural gas; BEV210 – battery electric vehicle with 210 mile electric-only range; Dist. – distributed; NG – natural gas; CCS – carbon capture and storage; Cent. – central; Gas. H2 – gaseous hydrogen; Liq. H2 – liquid hydrogen; w/ – with

FIGURE 6. Lifecycle water consumption per 100 miles driven

Resource Availability for Hydrogen Production

Over the long term, the widespread deployment of FCEVs will require hydrogen produced from a diverse array of low-carbon domestic energy resources, such as coal (with carbon capture and storage), nuclear, biomass, wind, and solar energy. This analysis focused on (1) estimating the hydrogen production required to meet potential future FCEV demand and (2) providing updated estimates of total hydrogen production potential from domestic energy resources. The analysis considered resource requirements for hydrogen in a future without significant FCEV market growth (i.e., from the U.S. Energy Information Administration's [EIA's] *Annual Energy Outlook* [AEO]) and with significant market growth (i.e., 50 million FCEVs deployed by 2040). The spatial resource availability was determined on a per-kilogram-of-hydrogen basis.

Figure 7 shows the updated comparison of current (2015) and future (2040) total hydrogen consumption for the AEO 2017 Reference Case. The ratio of projected 2040 consumption to additional resources needed to supply 50 million FCEVs is shown as a factor in parenthesis below each resource label. These numbers indicate how much more of a particular resource would be needed to fuel 50 million FCEVs. The percentage increases are relatively low for natural gas (5%), coal (18%), and biomass (48%), and highest for wind (87%) and solar (171%). These results will be published in a National Renewable Energy Laboratory report.



Source: National Renewable Energy Laboratory

FIGURE 7. Resource requirements for hydrogen production

Patents Resulting from DOE-Sponsored R&D

The commercial impact of FCTO funding continues to be analyzed by tracking the patents resulting from FCTO-funded R&D projects. As shown in Figure 8, the number of patents issued has continued to grow. Over 650 patents were awarded by 2016 as a result of research funded by FCTO in the areas of storage, production, delivery, and fuel cells. This work, completed by Pacific Northwest National Laboratory, will be highlighted in the 2016 Pathways to Commercial Success Report.

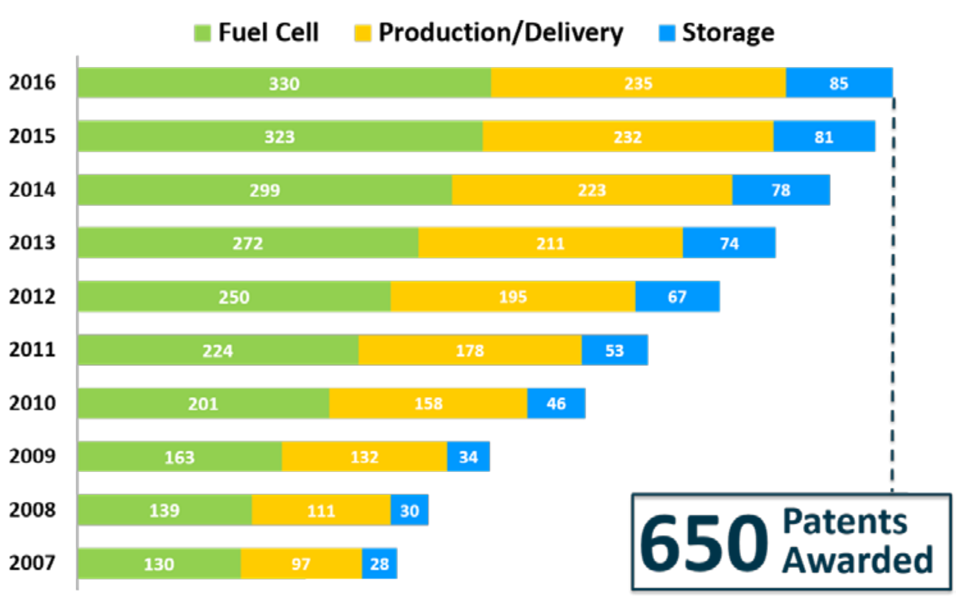


Figure 8. Cumulative number of patents awarded

BUDGET

The FY 2017 appropriation for the Systems Analysis sub-program was $3 million.

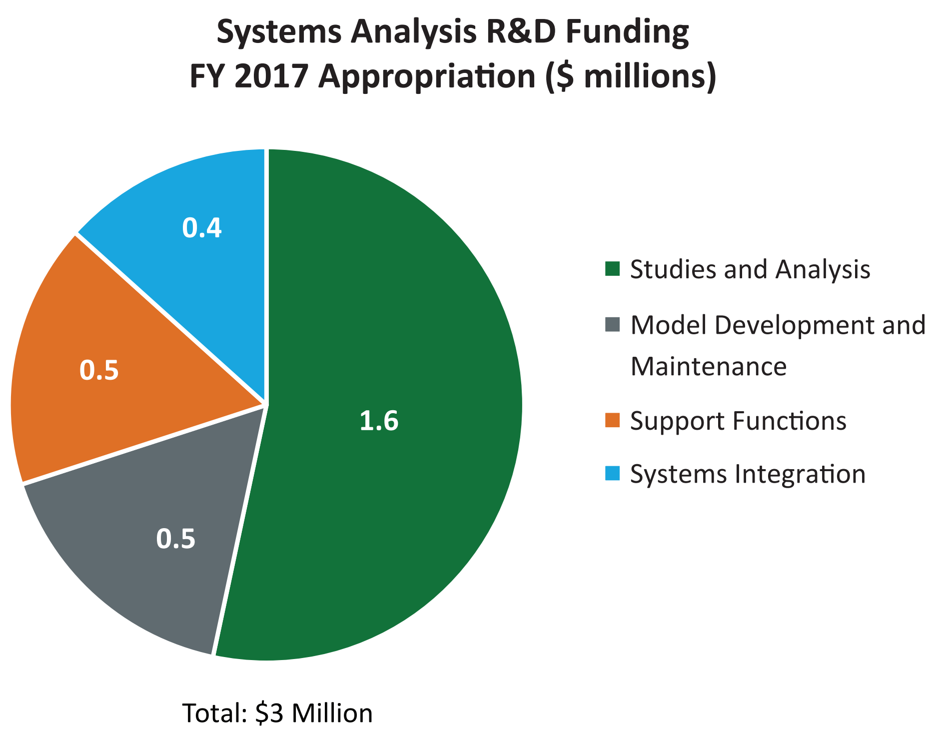


FIGURE 9. FY 2017 Systems Analysis appropriation

UPCOMING ACTIVITIES AND PLANS

Funding continues to be allocated to conduct analysis using the models developed by the sub-program. In particular, analysis projects are concentrated on:

- Market adoption of fuel cells
- Lifecycle analysis of criteria emissions and water use for hydrogen production technology pathways for light-duty vehicles
- Quantifying employment impacts of hydrogen and fuel cell technologies
- Calculating the cost of onboard hydrogen storage options
- Estimating GHG emissions and petroleum use in medium- and heavy-duty trucks based on various hydrogen pathways
- Estimating the hydrogen production (from diverse domestic energy resources such as natural gas, coal, uranium, biomass, wind, and solar) required to meet potential future FCEV demand
- Performing hydrogen fueling station business assessments
- Investigating hydrogen use as an energy carrier with applications across sectors (e.g., industrial, grid services, vehicles) supporting the H2@Scale initiative.

Future activities are subject to appropriations.

Fred Joseck
Systems Analysis Program Manager
Fuel Cell Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585-0121
Phone: (202) 586-7932
Email: Fred.Joseck@ee.doe.gov