XI.0 Systems Analysis Program Overview

INTRODUCTION

The Systems Analysis program supports decision-making 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 with the electrical sector and use of renewable fuels. Particular emphasis is given to assessing onboard storage options and infrastructure implications.

The Systems Analysis program made several significant contributions to the program during Fiscal Year (FY) 2013. The cost of infrastructure was compared to infrastructure for other advanced fuel vehicles and opportunities of reducing the infrastructure costs were examined by using stakeholder input and exploring synergies with other fuels such as natural gas. The JOBS and economic impacts of Fuel Cells (JOBS FC) model continues to be enhanced by Argonne National Laboratory (ANL) and RCF Economic and Financial Consulting as they add the capability to assess employment impacts of infrastructure development. Infrastructure and early market analyses were conducted to better understand hurdles such as cash flow and station utilization, and supply and demand issues. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model is being enhanced to evaluate greenhouse gas emissions and petroleum on a well-to-wheels basis for hydrogen pathways with various onboard storage options, and to incorporate water consumption analysis capability to conduct life-cycle analysis of various hydrogen production pathways.

GOAL

The program's goal is to provide system-level analysis to support hydrogen and fuel cell development and technology readiness by evaluating systems and pathways including resources and infrastructure issues to help guide the selection and estimate potential value of research, development, and deployment projects and efforts.

OBJECTIVES

- By 2014, complete environmental studies that are necessary for technology readiness.
- 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 electric vehicles (FCEVs) 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 FCEVs, and the system effects resulting from the growth of fuel cell market share in the various sectors of the economy.
- Provide milestone-based analysis, including risk analysis, independent reviews, financial evaluations, and environmental analysis to support the program's needs prior to technology readiness.
- Periodically update the life-cycle energy, petroleum use, greenhouse gas, and criteria emissions analysis for technologies and pathways for the program to include technological advances or changes.

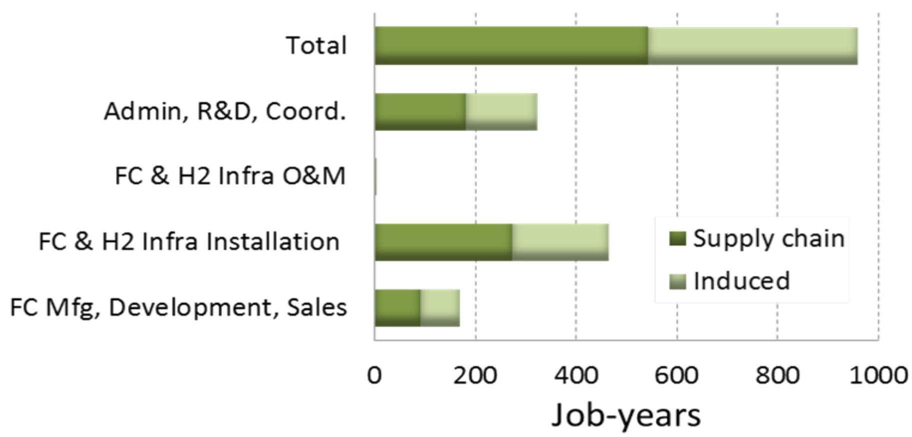
FY 2013 STATUS

The Systems Analysis 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 2013 included socio-economic impacts such as increased employment from fuel cell deployment, life-cycle cost of various vehicle platforms including FCEVs with the Vehicle Technologies Office, renewable biogas resources for hydrogen production, potential benefits of emerging onboard storage options, life-cycle impacts of water use in hydrogen production pathways, identification of early markets for fuel cells and opportunities to reduce cost through various mechanisms, and options to reduce infrastructure cost. The Systems Analysis program has transitioned from developing key models to completing critical program analyses. As evidenced by the completed and ongoing analysis activities, the initial strategy of the Systems Analysis program was effective in enabling the completion of a portfolio of analytical projects.

FY 2013 ACCOMPLISHMENTS

Develop and Maintain Models and Systems Integration

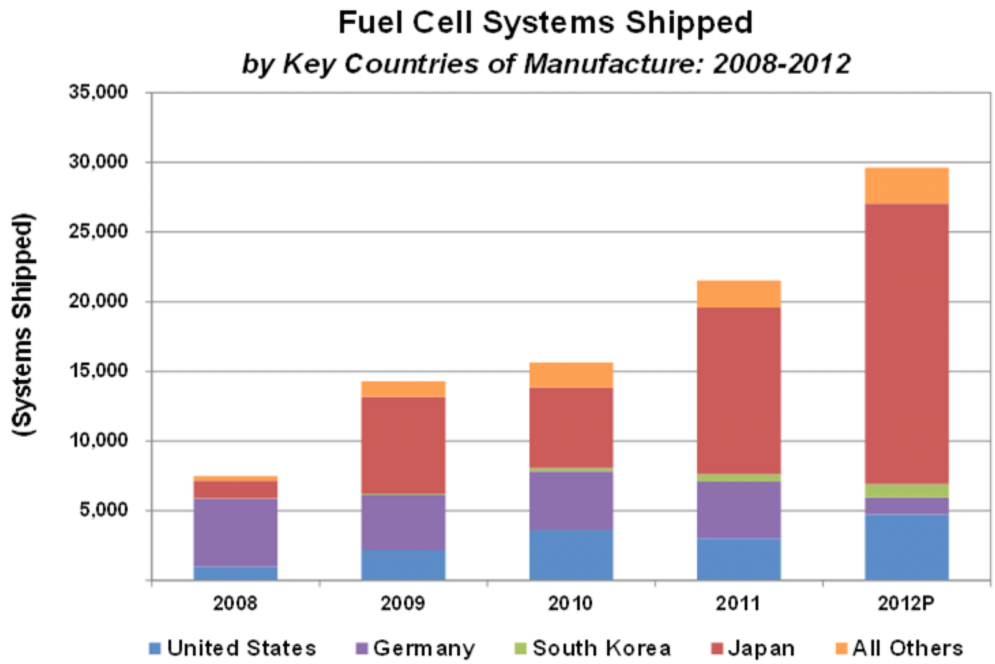
- ANL, with assistance from RCF, continues to estimate job creation as a result of program projects and enhance the JOBS FC model to estimate employment and revenue impacts of infrastructure development. JOBS FC uses an input-output methodology to estimate changes in industry expenditures as a result of fuel cell deployment and calculates the effects of those changes throughout the economy. Version 1.0 of the model was released for public use in May 2012 and includes forklift and backup power applications of polymer electrolyte membrane fuel cells and prime power applications of phosphoric acid and molten carbonate fuel cells for user-specified analyses at the state, regional, or national level. It is available for download at www.jobsfc.es.anl.gov.
- The model is being used to continue to assess the employment impacts of the American Reinvestment and Recovery Act of 2009 (Recovery Act) funding for fuel cell deployments for backup power. The figure below illustrates that Recovery Act created or retained approximately 950 job-years of employment during the 2009 to 2012 timeframe. Note that a job-year is one year of work by one person (e.g., 5 job-years can be 5 years of work by 1 person, 1 year of work by 5 persons).



FC – fuel cell; H2 – hydrogen; O&M – operations and maintenance; Infra – infrastructure; Mfg - manufacturing
Source: Argonne National Laboratory

Market Analysis

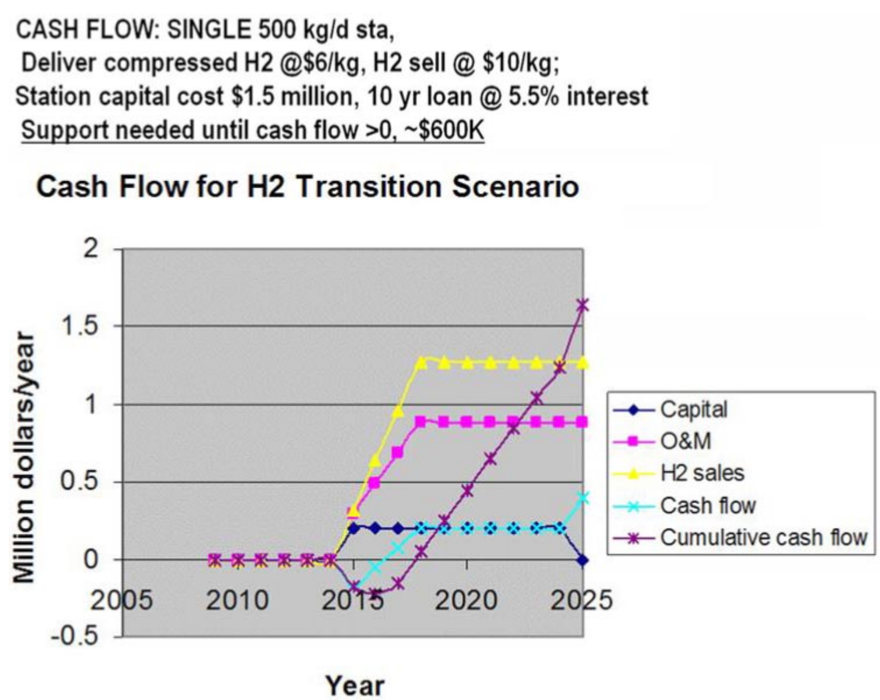
- Navigant Research continues to assess global and domestic market analysis of the fuel cell markets for portable, stationary power, and transportation applications. The analysis identified increased growth in the fuel cell market in the domestic and international markets as shown in the following figure. As exhibited, the fuel cell market remains strong with over ~30,000 systems shipped in 2012, an increase of greater than 35% over 2011.



2012P – 2012 projected
Sources: Navigant Research and DOE 2012 Fuel Cell Technologies Market Report

Infrastructure Analysis

- The University of California at Davis assessed alternative strategies for introducing FCEVs and hydrogen infrastructure in Southern California over the next decade to satisfy the zero emission vehicle regulation while taking into consideration station placement, quantity, size, and type. The analysis studies infrastructure economics from multiple perspectives including network, station owner, and consumer. The project analyzed rollout strategies for FCEVs and hydrogen infrastructure including station cash flow in Southern California over

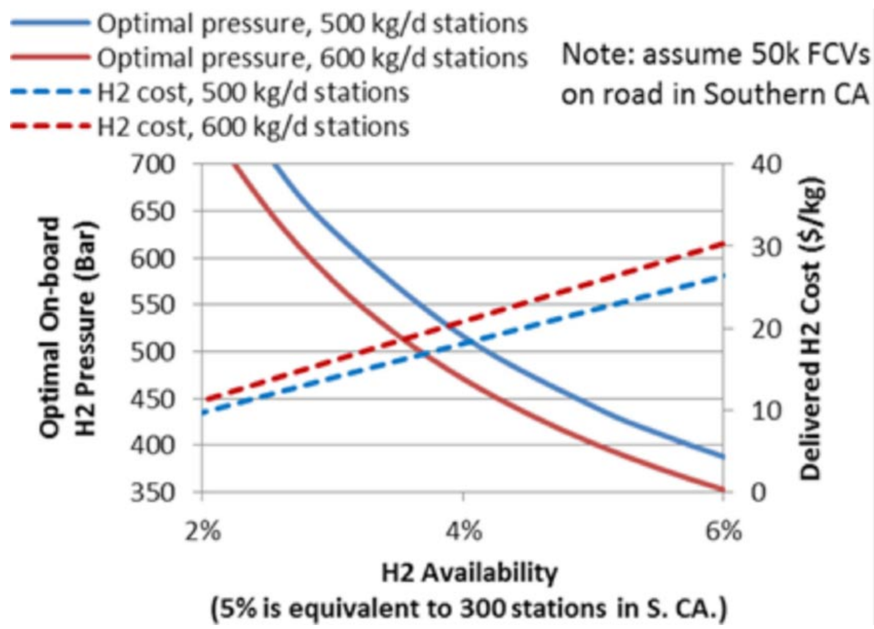


Source: University of California, Davis

the next decade through input and discussion with stakeholders in the auto industry, energy industry, industrial gas industry, state agencies, and national labs. The analysis showed that a single 500 kg/d station costing $1.5 million has a positive cash flow within a few years, once the hydrogen demand for the station increases to the station capacity. The station could experience a negative cash flow totaling ~$400K-700K in the early stages.

Fueling Pressure Analysis

- Oak Ridge National Laboratory (ORNL) began examining the optimal delivered hydrogen pressure for refueling FCEVs by including the values of consumer choice. The project assessed the balance between storage and delivery pressure and station quantity to determine the best deployment of infrastructure to support consumer refueling needs. The analytical framework assesses the complicated relationships between onboard hydrogen storage pressure and range, costs, consumer acceptance, and industry risks. ORNL found that the optimal pressure is most sensitive to the value that consumers place on their time, incremental cost of hydrogen, and number of FCEVs. For example, with 100 stations and 50,000 FCEVs in Southern California, 700-bar fueling offers lower combined costs than either 350 bar or 500 bar. This conclusion provides insight to the uncertainty of high-pressure incremental costs (0.2-0.6 $/kg for high-pressure upgrade) or the value of refueling travel time (25-75 $/hour).

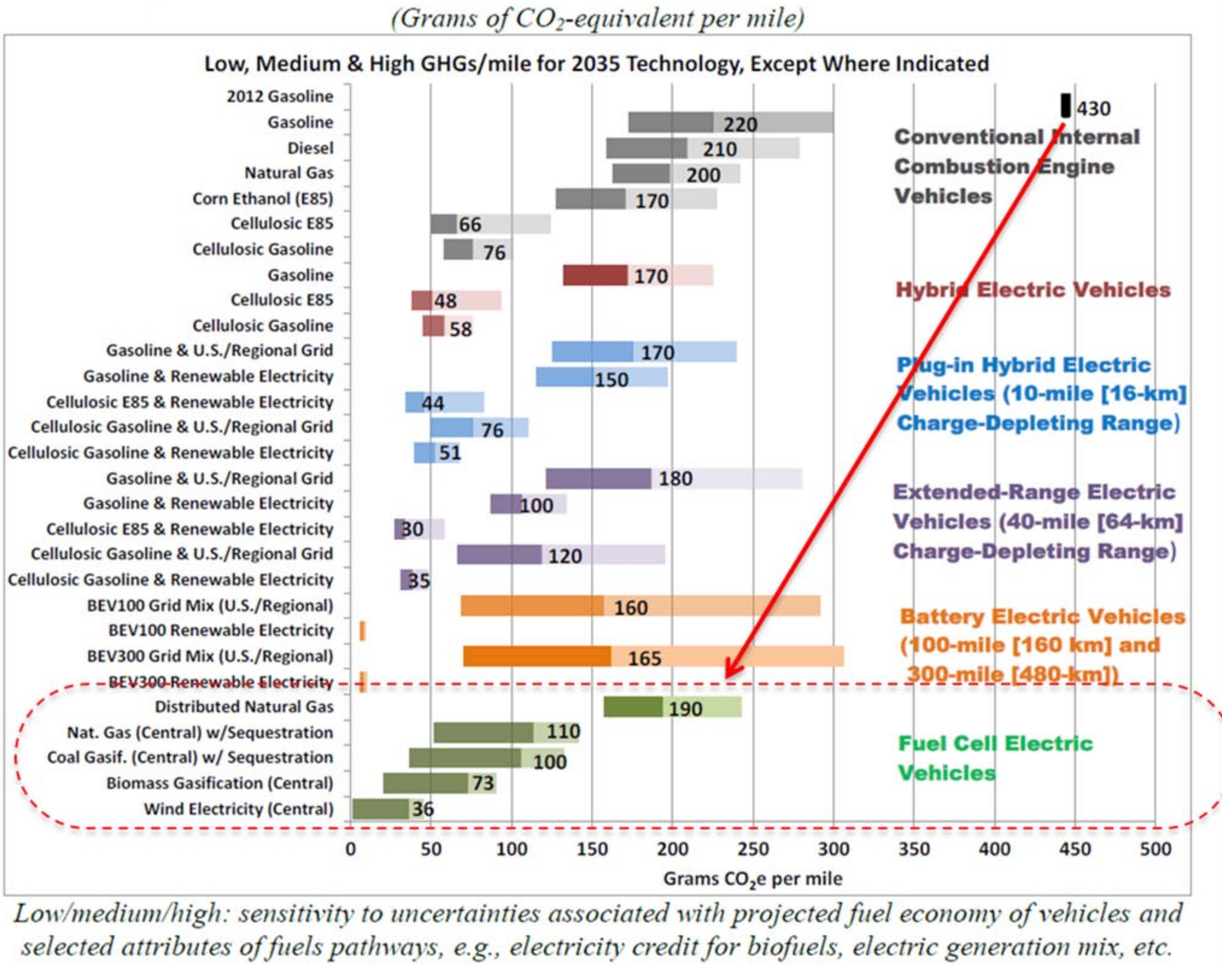


FCV – fuel cell vehicle
Source: Oak Ridge National Laboratory

Environmental Analysis

- **Vehicle Portfolio Well-to-Wheel Analysis**
Analysis was conducted in collaboration with the Bioenergy Technologies and Vehicle Technologies Offices to estimate the lifecycle greenhouse gas (GHG) emissions resulting from several fuel/vehicle pathways, for a portfolio of future mid-size cars. Major inputs to the calculation of GHG emissions included the fuel economy of each vehicle and fuel production pathway efficiency. The data and major assumptions and results are documented in a DOE record[1]. The results of the analysis show that GHG emissions could be reduced to a range of 30-190 g of CO_2e per mile compared to the current gasoline internal combustion engine of 430 g of CO_2e per mile. This reinforces the point that a portfolio of advanced vehicles and renewable fuels will be needed to reduce the GHG emissions from the current vehicle fleet to meet future reduction targets.

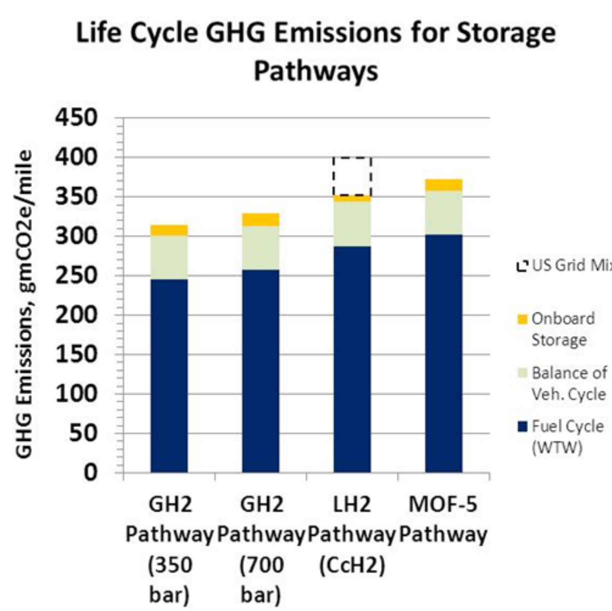
[1] http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf.



E85 – 85% ethanol 15% gasoline; BEV – battery electric vehicle
Source: http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

- **Onboard Storage Well-to-Wheel Analysis**
  ANL revised the GREET model to include new onboard storage options with a central natural gas reforming production pathway. The onboard storage options added to the model included the following:
  - Cryo-compressed storage system
  - Metal organic framework (MOF-5) sorption storage system

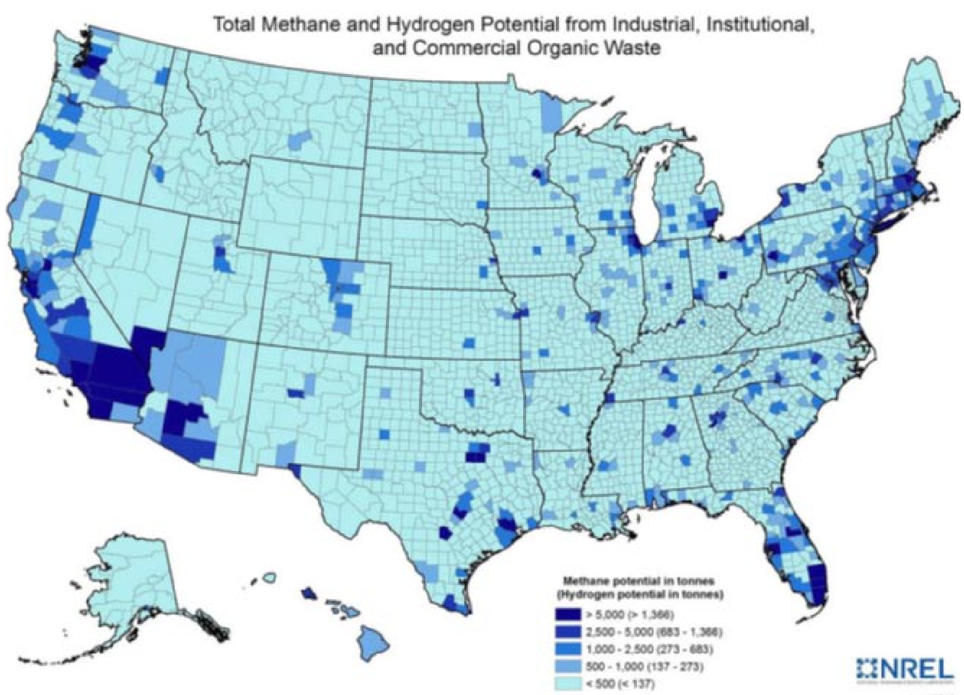
  As shown in the figure to the right, the life-cycle GHG emissions associated with 350 and 700 bar gaseous storage and the new onboard hydrogen storage systems were estimated to be between 315 and 373 g_{CO2e}/mi. Systems that require significant precooling (e.g., cryo-compressed and MOF-5) at their current technology state exhibited GHG emissions of 370 to 400 gCO_2e/mi compared with GHG emissions of 315 to 330 gCO_2e/mi from systems that require less precooling (i.e., 700-bar system) or no precooling (i.e., 350-bar system). The same methodology will be applied to evaluate the environmental impacts of other new and emerging hydrogen onboard storage systems.



GH2 – gaseous hydrogen; LH2 – liquefied hydrogen; CcH2 – cryo-compressed hydrogen; WTW – well to wheels
Source: ANL

Resource Analysis

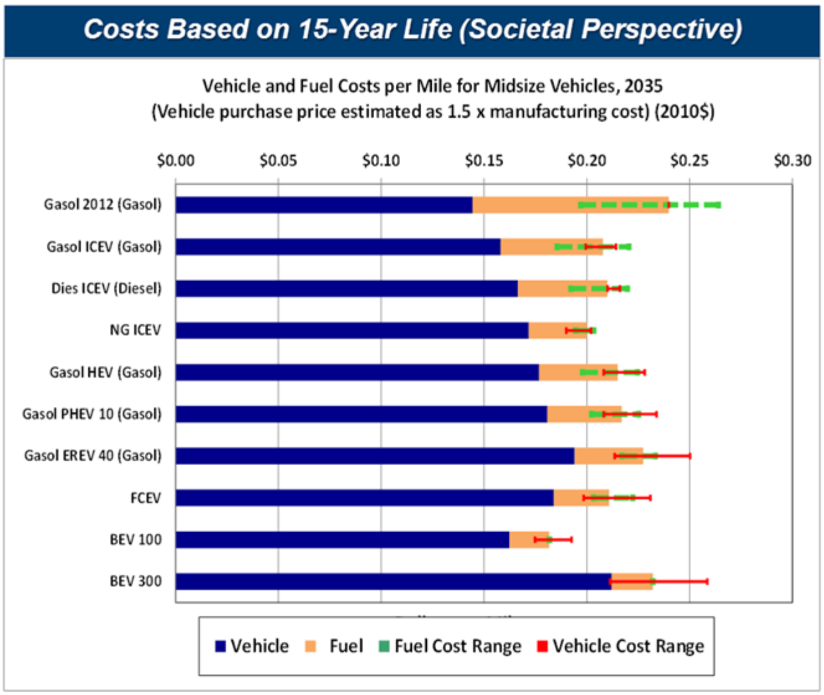
- **Water Life Cycle Analysis**
  ANL enhanced the GREET model's life cycle analysis capabilities to examine water consumption for hydrogen production and delivery pathways from natural gas. The production of energy feedstocks and fuels requires water use. Feedstocks like natural gas, crude oil, and oil sands require significant volumes of water for drilling, extraction, and conversion into energy products. Also, biofeedstocks such as corn and cellulosic sources need water for growth. Converting these conventional and new feedstocks to fuel requires additional water consumption. Similarly, water is needed for heat rejection in thermo-electric power generation cycles. Producing hydrogen from electricity (via electrolysis), natural gas (via steam methane reformation), or biomass (via gasification) requires additional use of water for the conversion process as well as for cooling. Analysis will continue to examine water consumption for other hydrogen production and delivery pathways such as coal, biogas, and nuclear feedstock sources. The analysis will include liquefaction and compression processes along these pathways, as compared to other fuel pathways on a life-cycle basis, including baseline petroleum gasoline, bioethanol, and battery electric vehicles pathways.
- **Biogas Resource Analysis**
  National Renewable Energy Laboratory examined resource availability for renewable hydrogen produced from net biogas from landfills and wastewater treatment plants, which provides alternatives to traditional sources of hydrogen, hedges against fluctuation in costs and demand for fossil fuels, and aids compliance with state policies for renewable fuels. The total methane potential from industrial, institutional and commercial organic waste is estimated to be 6.2 million tonnes per year, which, if converted to hydrogen, would yield approximately 1.6 million tonnes of hydrogen per year. The project updates prior studies on hydrogen production from methane from wastewater treatment, landfills, and manure management, and expands analysis to include methane from industrial processes and organic food waste.



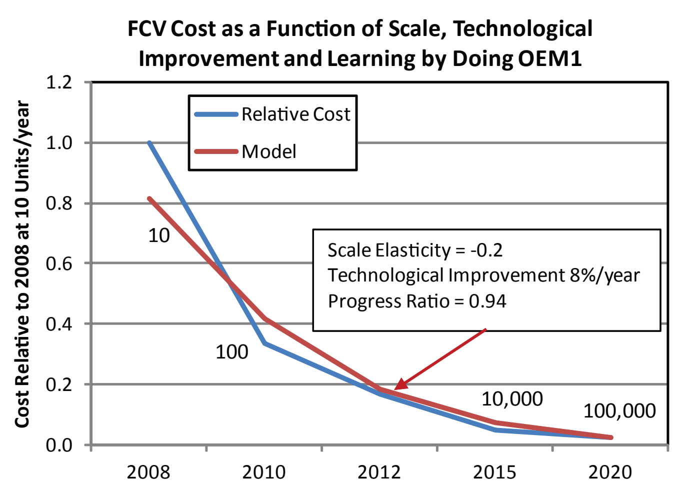
Source: National Renewable Energy Laboratory

Programmatic Analysis

- **Cost per Mile Analysis**
  Analyses were conducted in conjunction with the Vehicle Technologies Office to estimate the life-cycle costs resulting from several fuel/vehicle pathways, for a portfolio of future mid-size cars. Major inputs to the calculation of costs of ownership included the price of each vehicle and the annual fuel costs. The data and major assumptions and results are documented in a DOE record[2]. As shown below, projected R&D advances will drive future cost competitiveness between advanced vehicles and fuels.



- **Worldwide Status of Hydrogen FCEV Technology and Prospects for Commercialization**
  ORNL examined the status of FCEV technology and commercialization plans in Japan, Korea, the European Union, and the United States. Benchmark progress has been seen by original equipment manufacturers (OEMs) in the performance of FCEV technology, manufacturing costs, and the timing of commercialization. Government and industry plans for deployment of FCEVs were documented, and the data collected were used to recalibrate the market transition models. FCEV performance will be ready for commercial introduction by OEMs in 2013, 2015, 2017, and 2020, depending on the availability of refueling stations. There is general agreement that the performance of FCEVs with respect to durability, cold start, packaging, acceleration, refueling time, and range has progressed to the point where vehicles that could be brought to market in 2015 will satisfy customer expectations.

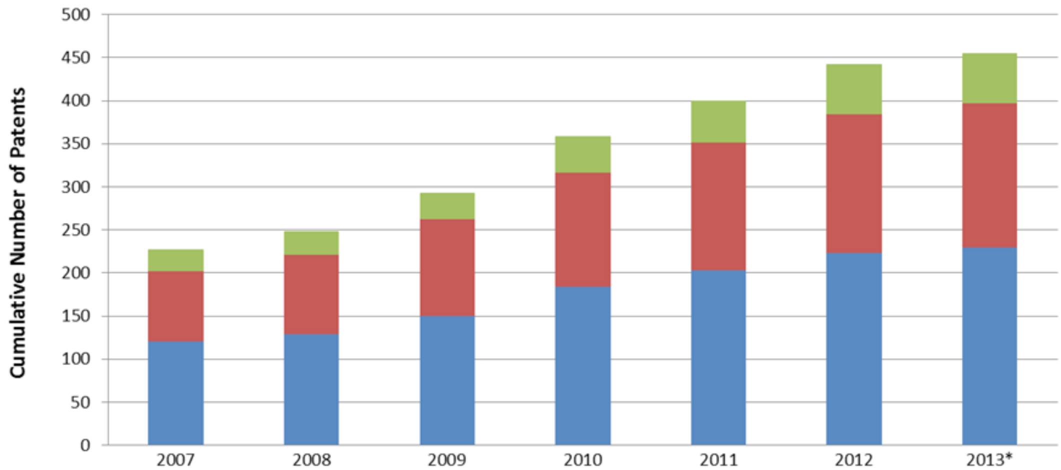


Source: Oak Ridge National Laboratory

[2] http://hydrogen.energy.gov/pdfs/13006_ldv_life_cycle_costs.pdf.

- **Commercial Products and Patents Resulting from DOE Sponsored R&D**
  Pacific Northwest National Laboratory continues to analyze the commercial benefits of the program by tracking the commercial products and technologies, and patents developed from the Energy Efficiency and Renewable Energy Office (EERE) funding. The benefits of EERE-funded projects continue to grow as illustrated in the figures below. Over 450 patents were awarded and 41 products were commercialized by 2013 as a result of research funded by EERE in the areas of storage, production, delivery, and fuel cells which will be highlighted in the FY 2013 Pathways to Commercial Success Report[3].

Cumulative Number of Patents Awarded

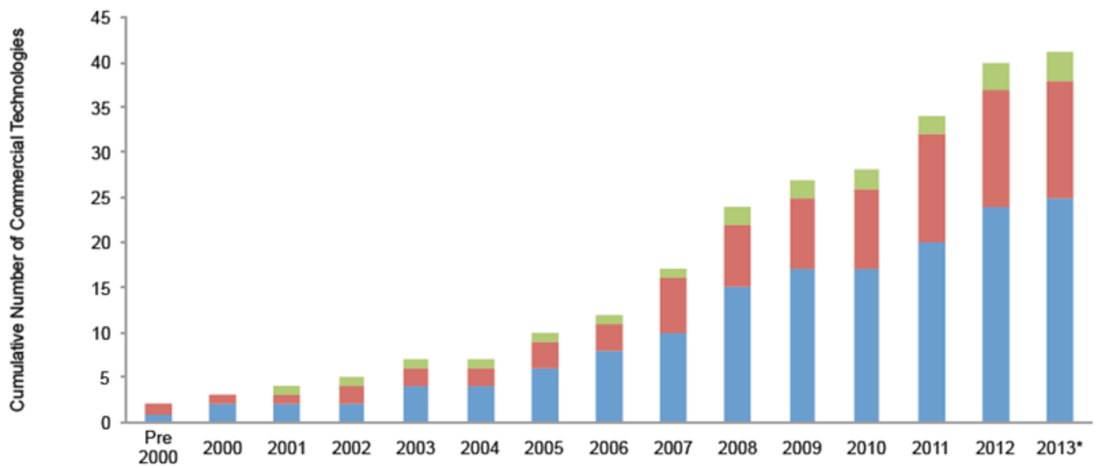


	2007	2008	2009	2010	2011	2012	2013*
Storage	24	26	30	41	47	57	58
Production/Delivery	82	93	112	132	148	161	167
Fuel Cell	121	129	151	185	204	224	230
Total	227	248	293	358	399	442	455

*Partial data for 2013

Source: Pacific Northwest National Laboratory

Cumulative Number of Commercial Products Entering the Market



	Pre 2000	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013*
Storage	0	0	1	1	1	1	1	1	1	2	2	2	2	3	3
Production/Delivery	1	1	1	2	2	2	3	3	6	7	8	9	12	13	13
Fuel Cell	1	2	2	2	4	4	6	8	10	15	17	17	20	24	25
Total	2	3	4	5	7	7	10	12	17	24	27	28	34	40	41

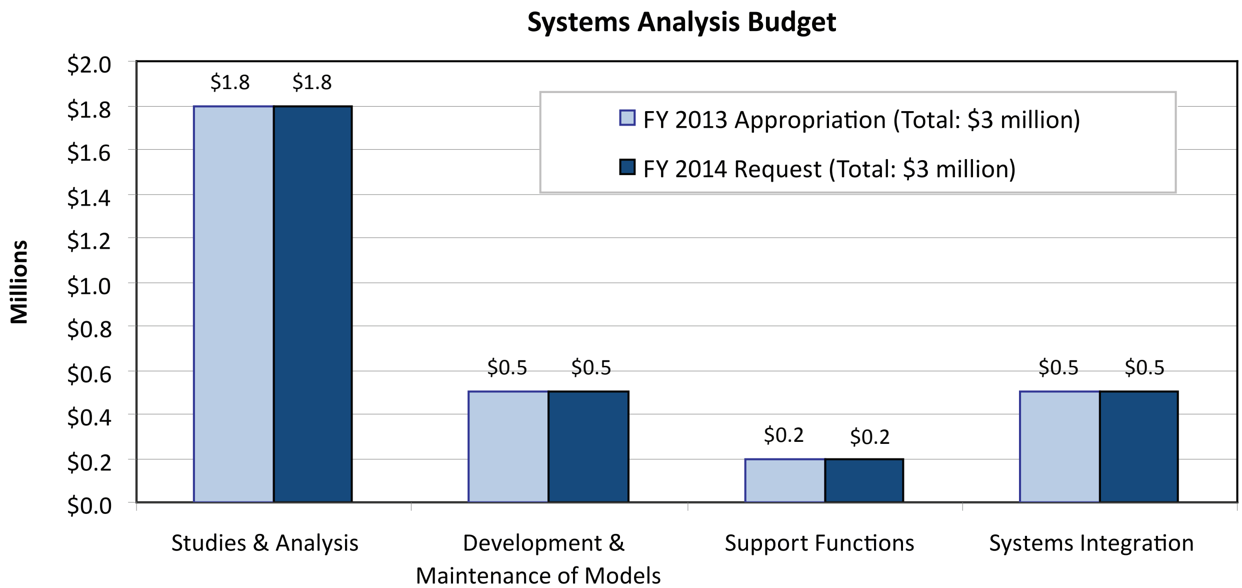
*Partial data for 2013.

Source: Pacific Northwest National Laboratory

[3] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2013.pdf.

BUDGET

The budget for the Systems Analysis program is consistent with the goals and objectives of the program and is responsive to assessing fuel cell applications for energy storage, stationary power generation, specialty applications, and light duty transportation. The FY 2014 budget request includes funding for early fuel cell and hydrogen market and infrastructure analysis, as well as renewable resource evaluation, environmental and resource life cycle analysis, overall program analysis, socio-economic analysis of fuel cell and hydrogen market growth, modeling, and systems integration. New fuel cell opportunities for energy storage and integration with existing energy supply networks such as natural gas transmission will continue to be evaluated.



FY 2014 PLANS

The Systems Analysis activity for FY 2014 will focus on conducting analyses to determine technology gaps for fuel cell systems and infrastructure for different applications, benefits, and opportunities for new onboard storage options and utilizing fuel cells for energy storage and transport. Analyses will be focused on understanding the tradeoffs and regional impacts of fuel cells with other alternative fuels, light-duty vehicle life cycle costs for multiple platforms, socio-economic impacts of job creation based on hydrogen supply infrastructure development and other fuel cell technologies, and the synergies of linking stationary fuel cell power generation and hydrogen generation from combined heat, hydrogen and power applications with early market power and light-duty vehicle electricity and hydrogen demands. The FY 2013 appropriation included $3 million for Systems Analysis; the FY 2014 request is also $3 million. The budget request for FY 2014 reflects the focus on early market analysis, fuel cell technology evaluations, and renewable fuel benefits, as well as biogas and water resource and infrastructure analysis.

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