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## XI.0 Systems Analysis Sub-Program Overview

Systems Analysis supports decision-making by providing a greater understanding of technology gaps, opportunities and risks, the contribution of individual technology components to the overall system (i.e., from fuel production to utilization), and the interaction of the components within the system. Analysis is also conducted to assess issues that cut across all the various aspects of hydrogen and fuel cell technologies—for example, examining how hydrogen and fuel cells can be integrated with the electrical sector and with other renewable fuels. Particular emphasis is given to assessing stationary fuel cell applications, the impact of fuel quality on fuel cell performance, and potential options for hydrogen infrastructure.

The Systems Analysis sub-program made several significant contributions to the Program during Fiscal Year (FY) 2011. The sub-program developed the hydrogen threshold cost, which represents the cost at which hydrogen fuel cell electric vehicles (FCEVs) are projected to become competitive on a cost per mile basis with the competing fuel-and-vehicle combination—gasoline in hybrid-electric vehicles (HEVs). This cost was determined to be \$2–\$4/gasoline gallon equivalent (gge, untaxed). Analytical tools, including HyDRA and the Macro-System Model, were updated and peer reviewed to support the analytical process. Infrastructure and early market analyses were conducted to better understand the supply and demand issues involved. A cost model was developed to evaluate the cost of removing impurities from the resource streams for hydrogen production. In addition, a study was initiated to evaluate the impact of biogas impurities on fuel cell performance and durability. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model was modified to enable greenhouse gas emissions to be evaluated on a well-to-wheels basis for hydrogen energy storage from renewable electricity generation.

### Goal

Provide system-level analysis to support the development of hydrogen and fuel cell technologies by: evaluating technologies and pathways, including resource and infrastructure issues; guiding the selection of RD&D projects; and estimating the potential value of RD&D efforts.

### Objectives

- By 2011, enhance the Macro-System Model by including stationary electrical generation and infrastructure for long-term applications analysis.
- By 2011, complete a study comparing combined-heat-and-power (CHP) fuel cell systems with other CHP technologies.
- By 2012, evaluate the use of hydrogen for energy storage and as an energy carrier to supplement the energy and electrical infrastructure.
- By 2012, evaluate fueling station costs for early FCEV penetration to determine the cost of different hydrogen fueling pathways for low and moderate demand rates.
- By 2014, complete environmental studies needed for technology readiness of FCEVs—including analyses of potential greenhouse gas and criteria pollutant emissions reductions from the penetration of FCEVs in the light-duty vehicle fleet.
- By 2015, analyze the ultimate potential for hydrogen, stationary fuel cells, and FCEVs. (This 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 hydrogen's market shares in the various sectors of the economy.)
- By 2018, complete analysis of Program performance, the cost status of various technologies, and the potential for use of fuel cells for a portfolio of commercial applications.
- On an ongoing basis, provide milestone-based analyses—including risk analysis, independent reviews, financial evaluations and environmental analysis—to support the Program's needs as new fuel cell applications achieve technology readiness.
- On an ongoing basis, periodically update life-cycle analyses of the energy use, petroleum use, and greenhouse gas and criteria pollutant emissions for various fuel cell applications and hydrogen production pathways. (These updates will include technological advances or changes in the underlying parameters.)

## FY 2011 Status

Analysis conducted in FY 2011 included: updating the Hydrogen Threshold Cost; working with the DOE Vehicle Technologies Program to examine the life-cycle costs of various vehicle platforms including FCEVs; and identifying early markets for fuel cells and opportunities to reduce cost through various mechanisms, such as tax credits and other legislation. The Systems Analysis sub-program has transitioned from activities focused on key model development to the application of the developed models for completing critical analyses. The sub-program’s initial strategy has been effective in enabling the completion of a portfolio of analytical projects; several of these are discussed in the following section, “FY 2011 Accomplishments.”

## FY 2011 Accomplishments

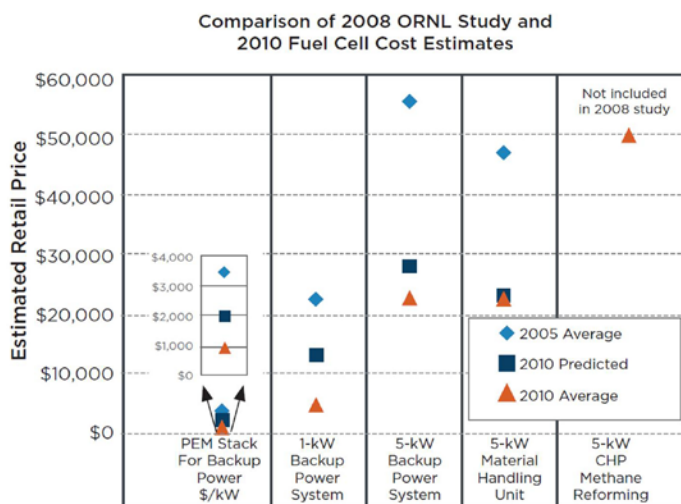
### Development and Maintenance of Models

- The Macro-System Model, a dynamic engineering transition model, was updated to enable evaluation of the impacts of stationary fuel cells on electricity distribution. The Macro-System Model is used to simulate of the performance, cost, and the potential for reducing emissions and petroleum use by hydrogen and fuel cell technologies. The model uses a distributed architecture to link existing and emerging models for system components. Stationary fuel cell analysis capabilities were made possible by adding the National Renewable Energy Laboratory’s (NREL’s) Fuel Cell Power Model to the Macro-System Model.

### Studies and Analysis

#### Market Analysis

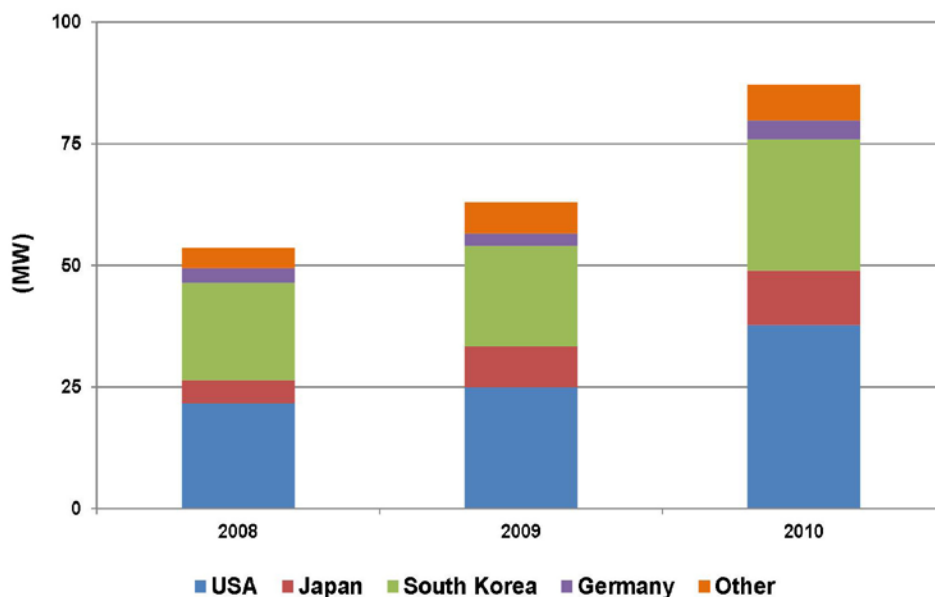
- Oak Ridge National Laboratory analyzed the status and outlook for the U.S. non-automotive fuel cell industry by examining the impacts of government policies and funding. They found that fuel cell manufacturers have been able to achieve large cost reductions of ~50% over the last two to five years, as shown in Figure 1; and, they found that government funding and incentives have been key elements in enabling these cost reductions. They also found that continuation or enhancement of current policies, such as the investment tax credit and government procurement, combined with progress by industry will be necessary to establish a viable domestic fuel cell industry.
- Pike Research completed global and domestic analyses and studies of the fuel cell markets for material handling equipment, stationary power, and portable power. The studies identified increased growth for fuel cells in the domestic and international markets, as shown in Figure 2. In particular, the U.S. market grew more than 50% from 2008 to 2010 in terms of megawatts of fuel cell systems shipped.



**FIGURE 1. Cost Reductions in Early Market Fuel Cells.** A 2008 study<sup>1</sup> by Oak Ridge National Laboratory assessed the average cost (in 2005) of fuel cells for early markets and then predicted what these costs would be in 2010, based on a model that included economies of scale and technology progress. An updated 2011 study<sup>2</sup> by the same group has estimated the average 2010 cost, which was shown to be equal to or even lower than the predictions. 2005 and 2010 averages based on estimates supplied by original equipment manufacturers. Predicted 2010 costs assumed total government procurements of 2,175 units per year, across all market segments. These predictions also assumed a progress ratio of 0.9 and scale elasticity of -0.2.

<sup>1</sup> David Greene and K.G. Duleep, “Bootstrapping a Sustainable North American PEM Fuel Cell Industry: Could a Federal Acquisition Program Make a Difference?” Oak Ridge National Laboratory, October 2008, [http://cta.ornl.gov/cta/Publications/Reports/ORNL\\_TM\\_2008\\_183.pdf](http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_183.pdf).

<sup>2</sup> David Greene, et al., “Status and Outlook for the U.S. Non-automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities,” Oak Ridge National Laboratory, May 2011, [http://cta.ornl.gov/cta/Publications/Reports/ORNL\\_TM2011\\_101\\_FINAL.pdf](http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM2011_101_FINAL.pdf).



**FIGURE 2. Megawatts of Fuel Cells Shipped.**<sup>3</sup> Fuel cell shipments, in terms of megawatts, continue to increase (~36% in 2010). U.S. shipments grew by more than 50% in 2010.

### Infrastructure Analysis

- Infrastructure analysis conducted by NREL with the Scenario Evaluation and Regionalization Analysis model and Sandia National Laboratories revealed that synergies between fuel cells for stationary power generation and transportation could be realized in the early phases of market adoption of hydrogen for FCEVs. Widespread deployment of stationary fuel cell systems that co-produce power, heat, and hydrogen (“combined-heat-hydrogen-and-power” or CHHP systems) could reduce the problem of hydrogen availability in the early stages of transition to FCEVs. Model results indicate that the production of hydrogen from CHHP could result in smaller stations with higher capital utilization and lower hydrogen cost. Hydrogen produced this way could supplement hydrogen supplied from distributed natural gas-based steam methane reforming, particularly for the early years of FCEV penetration, when hydrogen demand and station sizes will be small. The analysis shows that hydrogen costs from CHHP units drop from \$7–\$9/gge in the early years when demand is low to \$5–\$7/gge in the later years when demand is higher.
- NREL examined cost reduction opportunities for components of hydrogen infrastructure by conducting a workshop on February 16–17, 2011, with a diverse group of stakeholders and through infrastructure cost assessment with a cost calculator of early market fueling stations. Stakeholders identified potential cost reductions of 50% through standardization and modular approaches of station design. They found that station costs could be reduced by an additional 20–30% by adopting a uniform permitting process. The results of the stakeholder input from the workshop and cost calculator will be published by the end of 2011.

### Environmental Analysis

- Argonne National Laboratory analyzed the impact of feedstock quality on stationary fuel cell performance; identified contaminate removal solutions for sulfur, halogen and silica compounds; and estimated the costs associated with meeting the required feedstock quality specifications. The feedstocks primarily assessed included natural gas and biogas (from landfills and anaerobic digestion of wastewater). The key impurity analysis shows sulfur, siloxanes (organo-silica compounds), and halides are detrimental to the fuel cell

<sup>3</sup> 2010 Fuel Cell Technologies Market Report, U.S. Department of Energy, June 2011, [http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/2010\\_market\\_report.pdf](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/2010_market_report.pdf).

anode. The level of impurities was found to vary among feedstocks. For example, halogens were found to be higher in landfill gas, while siloxane compounds are typically higher in biogas produced from wastewater treatment, as shown in Figure 3. Ammonia, CO, and hydrocarbons are less damaging for higher temperature fuel cells such as solid oxide and molten carbonate fuel cells. The costs of contaminant removal will be determined for different removal schemes.

Energy Storage Analysis

- NREL analyzed the potential of utilizing renewable electricity generation from various wind farm locations combined with hydrogen production and storage systems to provide renewable hydrogen for energy storage and vehicle applications. Results of the analysis exhibit the delivered cost of electricity from the capture of curtailed wind-generated electricity would range from \$0.13-\$0.29/kWh on a levelized basis, depending on the location of the wind farm. The equipment cost, including the electrolyzer cost, was found to be one of the key drivers for the electricity cost delivered from hydrogen energy storage systems.

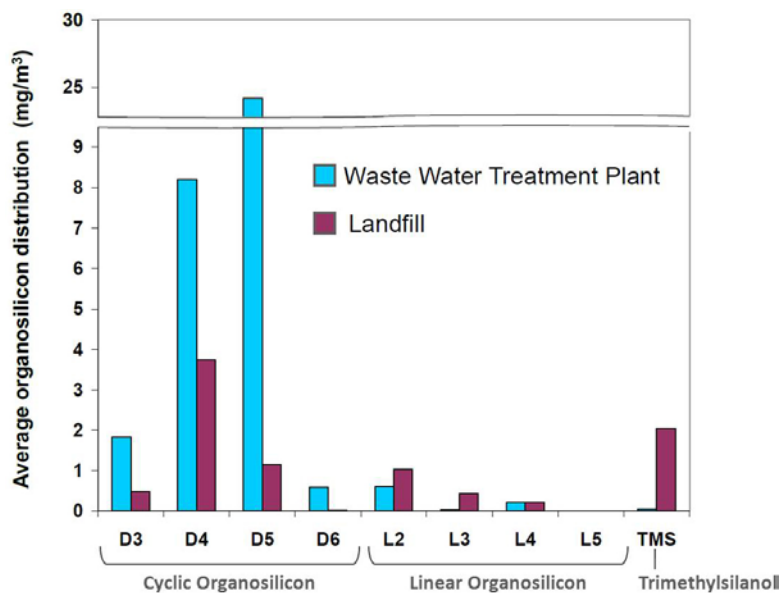


FIGURE 3. Impurities in Biogas Streams<sup>4</sup>

Programmatic Analysis

- A cost threshold for hydrogen was developed to assist DOE in focusing and prioritizing research and development (R&D) options. The cost threshold represents the cost of hydrogen at which FCEVs are projected to become competitive on a cost per mile basis with the competing fuel/vehicle combination—gasoline in HEVs. Its calculation includes projected vehicle fuel economies for HEVs and FCEVs, projected costs of gasoline, and projected incremental costs of FCEVs on a per-mile basis. Due to the uncertainty in all the parameters, both single-value and stochastic sensitivities were performed. The resulting hydrogen threshold cost is in the range of \$2-\$4/gge (in 2007 dollars). A graphical representation of the hydrogen threshold cost is shown in Figure 4.
- Pacific Northwest National Laboratory analyzed the commercial benefits of the DOE Fuel Cell Technologies (FCT) Program by tracking the commercial products, technologies, and patents developed from FCT R&D funding. The results show that more than 300 patents had been awarded and 30 products had been commercialized by 2011 as a result of research funded by FCT in the areas of fuel cells and hydrogen storage, production, and delivery (see Figure 5). These findings have been highlighted in the 2011 *Pathways to Commercial Success*<sup>5</sup> report.

<sup>4</sup> D. Papadias, et al., “Fuel Quality Effects on Stationary Fuel Cell Systems,” 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, May 2011, [http://hydrogen.energy.gov/pdfs/review11/an010\\_ahmed\\_2011\\_o.pdf](http://hydrogen.energy.gov/pdfs/review11/an010_ahmed_2011_o.pdf).

<sup>5</sup> *Pathways to Commercial Success: Technologies and Products Supported by The Fuel Cell Technologies Program*, Pacific Northwest National Laboratory, September 2011, [http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways\\_2011.pdf](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf).

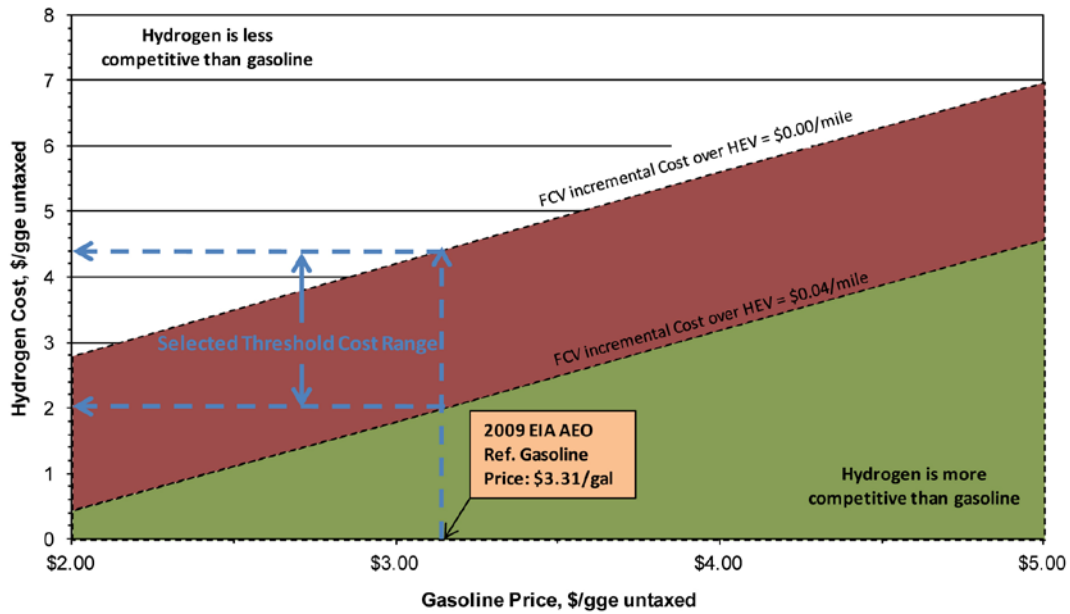


FIGURE 4. Effect of Gasoline Price on Hydrogen Threshold Cost

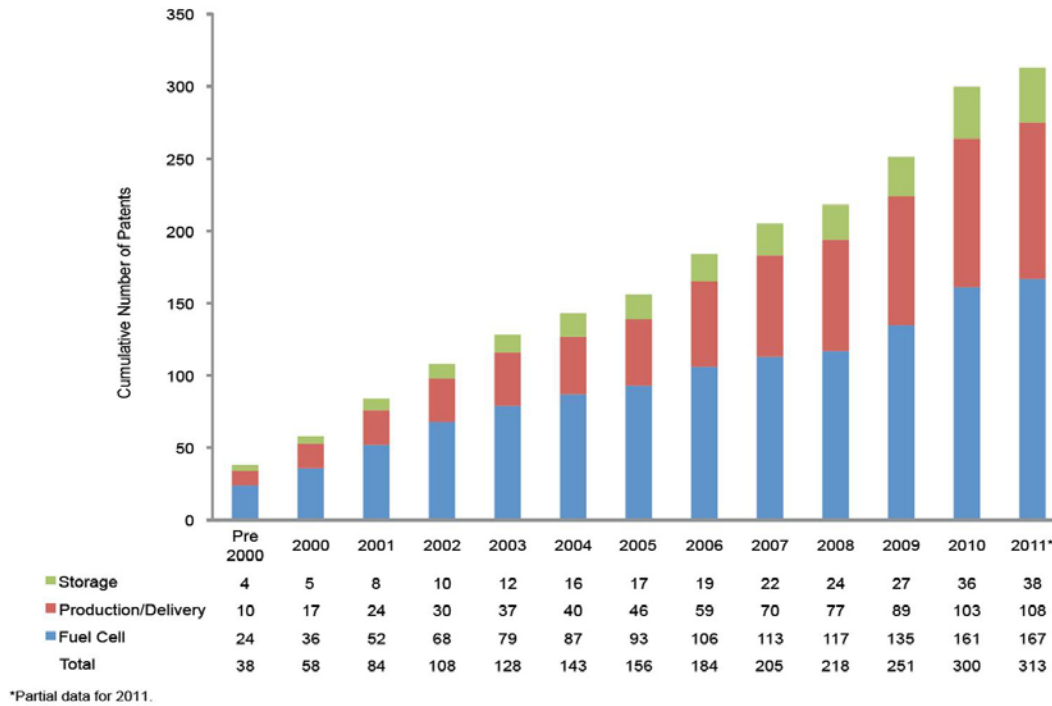
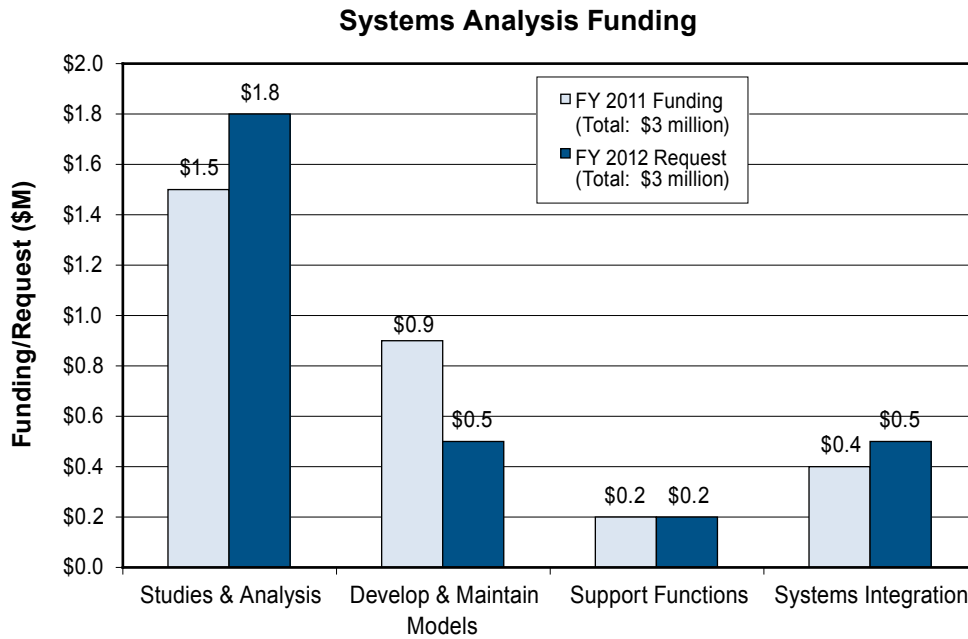


FIGURE 5. Cumulative Number of Patents Awarded as a Result of FCT Program Funding

### Budget

The FY 2011 appropriation included \$3 million for Systems Analysis, and the FY 2012 request is \$3 million. The budget for Systems Analysis is consistent with the goals and objectives of the sub-program and allows the Program to assess fuel cell applications for energy storage, stationary power generation, specialty

applications, and light-duty transportation. The FY 2012 budget request includes funding for early fuel cell and hydrogen market and infrastructure analysis, as well as fuel quality evaluation, environmental analysis, overall program analysis, modeling, and systems integration.



### FY 2012 Plans

In FY 2012, Systems Analysis will focus on conducting analyses to determine technology gaps for: fuel cell systems and infrastructure for different applications, and the use of fuel cells for energy storage and transmission. Analyses will include: assessing 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 fuel cell and hydrogen manufacturing, and the synergies of linking stationary fuel cell power generation with the electrical sector. New opportunities for using fuel cells for energy storage and integration with existing energy supply networks such as natural gas transmission will also be explored.

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