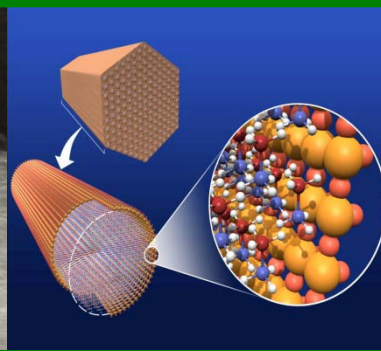




U.S. DEPARTMENT OF
ENERGY



Systems Analysis

Fred Joseck

*2011 Annual Merit Review and Peer Evaluation Meeting
May 9, 2011*

GOAL: Provide system-level analysis to support infrastructure development and technology readiness by evaluating technologies and pathways, guiding the selection of RD&D technology approaches/options, and estimating the potential value of RD&D efforts

OBJECTIVES

- Assess the Life Cycle Analysis benefits of hydrogen and fuel cells for diverse applications
- Quantify the benefits of integrating hydrogen fuel production with stationary fuel cell power generation
 - Evaluate the potential for biogas, landfill gas, and stranded hydrogen streams
- Evaluate fueling station costs for early vehicle penetration
- Evaluate the use of hydrogen for energy storage and as an energy carrier
- Evaluate socio-economic benefits of the Program such as job creation

Market complexities and data inconsistency present challenges

Future Market Behavior

- Understanding of drivers of fuel and vehicle markets needed for long-term projections.
- Models need to adequately address interactions - hydrogen/vehicle supply and demand.

Inconsistent Data, Assumptions & Guidelines

- Analysis results depend on data sets and assumptions used.
- Large number of stakeholders and breadth of technologies - difficult to establish consistency.

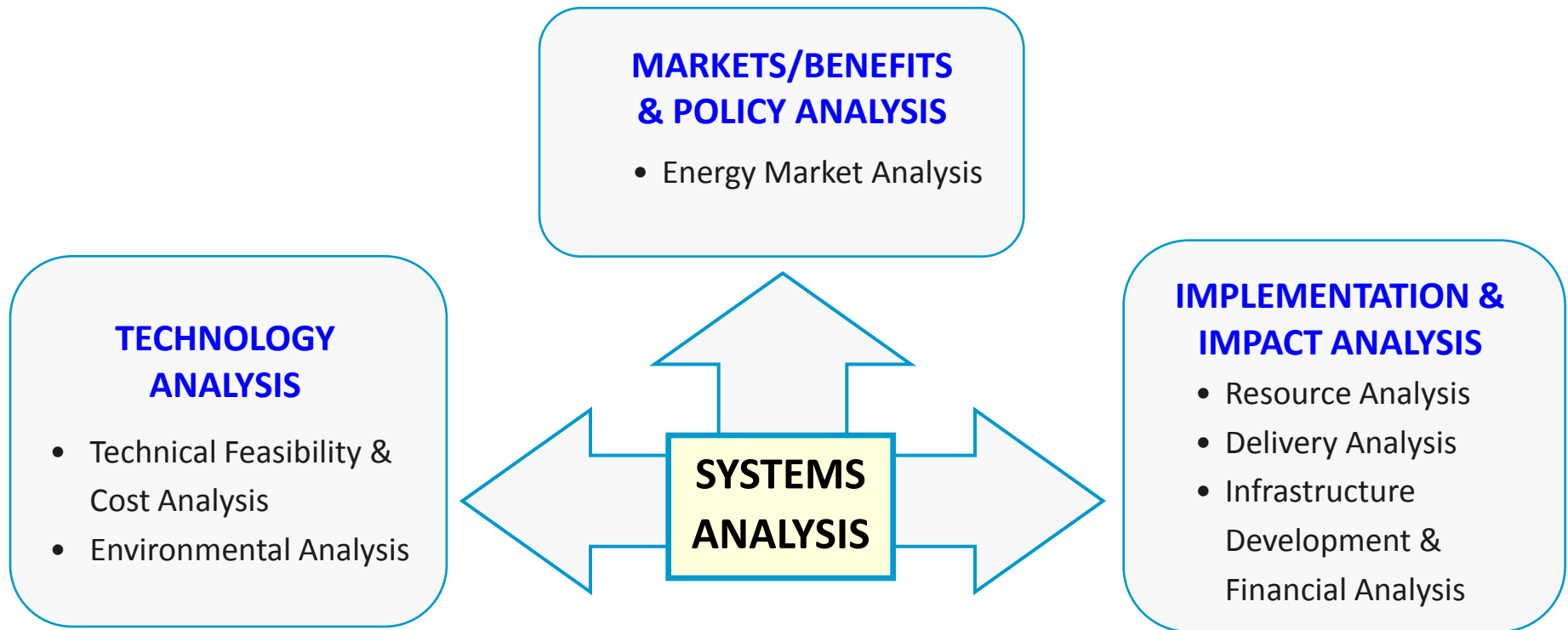
Coordination of Analytical Capability

- Analytical capabilities segmented by Program element, organizationally by DOE office, and by performers/analysts.

The screenshot shows the 'Hydrogen Program Analysis Repository' page. The header includes the U.S. Department of Energy logo and the text 'Hydrogen Program Analysis Repository'. Below the header, there are several navigation links: 'Analysis Projects', 'Modeling Projects', 'Projects by Title', 'Projects by Performing Organization', 'Projects by Principal Investigator', and 'Projects by Date'. A main text block explains that the repository is a compilation of analyses and analytical models relevant to assessing hydrogen fuel. A bulleted list follows, detailing the types of data and models included: hydrogen production, delivery, storage, fuel cells, and hydrogen vehicle technology; hydrogen production feedstock cost and availability; electricity production, central and distributed; and energy resource estimation and forecasting. At the bottom, a note states that the U.S. Department of Energy created this repository to help analysts, policy makers, businesses, government agencies, and others quickly.

The screenshot shows the 'Hydrogen Analysis Resource Center' website. The header features the 'energy.gov' logo. Below the header, there is a search bar with 'SEARCH: All Media' and a 'FOR:' dropdown menu. A 'BROWSE: Select a Topic' dropdown menu is also present. The main content area is titled 'Welcome to the Hydrogen Analysis Resource Center' and contains a detailed introductory paragraph about the center's mission and the types of data and tools available. A sidebar on the right contains two sections: 'NEW MATERIALS' with a link to 'Latest fuel price projections from EIA' and 'Hydrogen Properties', and 'POPULAR RESOURCES' with links to 'Transportation Energy Data Book' and 'DOE Hydrogen Production Cost Estimates'.

A variety of analysis methodologies are used in combination to provide a sound understanding of hydrogen and fuel cell systems and developing markets, as well as quantifying benefits, impacts, and risks of different hydrogen and fuel cell systems.

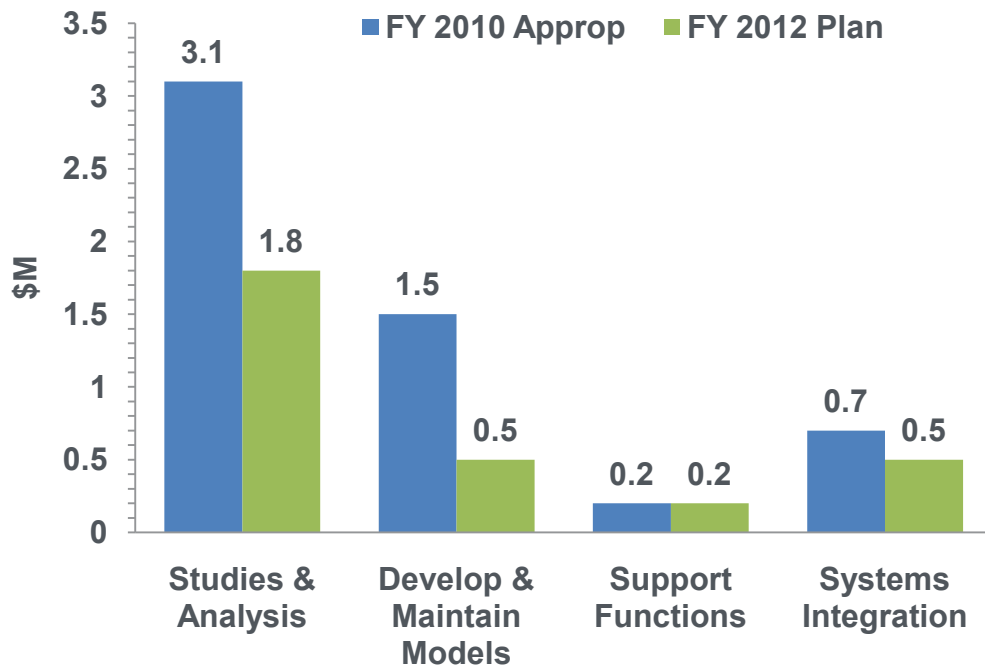


Systems Analysis Budget

Determine technology gaps, economic/jobs potential, and quantify 2012 technology advancement

FY 2012 Request = \$3.00 M

FY 2010 Appropriation = \$5.41 M



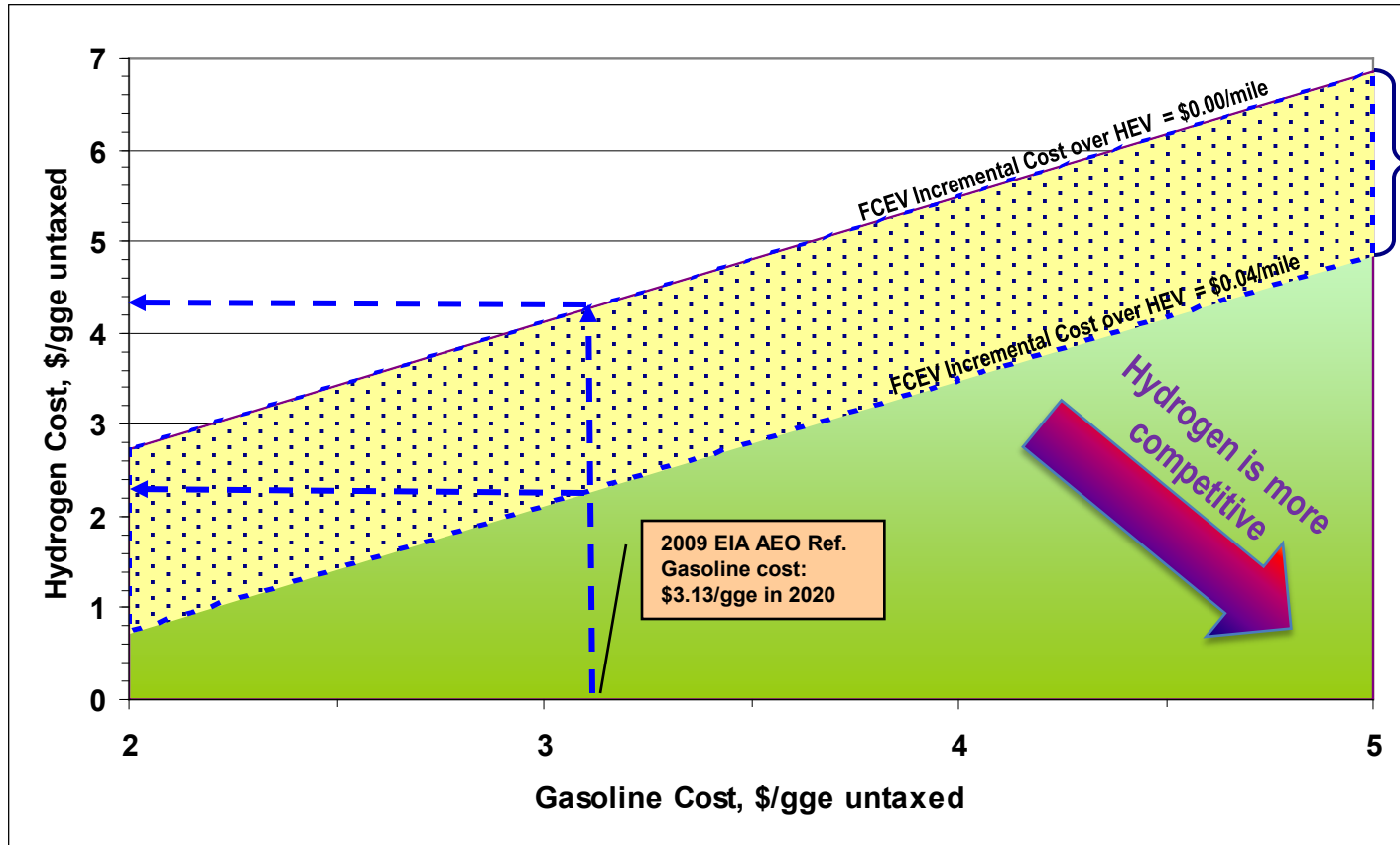
* Subject to FY11 budget

EMPHASIS

- Update models for program analysis, using cost performance and environmental information.
- Assess market penetration, job creation, and opportunities for fuel cell applications in the near term.
- Assess gaps and drivers for early market infrastructure cost for transportation and power generation applications
- Assess business cases of biogas applications, infrastructure applications and integration in a domestic fueling network, and fuel cell Combined Heat and Power (CHP) applications for Federal facilities.

Programmatic Analysis: Hydrogen Threshold Cost

*Competitive cost of hydrogen compared to gasoline HEV is
~\$2.00–\$4.00/gge*



Range includes diverse technologies, fuel economies and incremental vehicle cost assumptions.

- H₂ Threshold Cost includes vehicle incremental cost
- H₂ Threshold Cost will be applied across the Program
 - Target setting
 - Subprogram R&D progress gauge

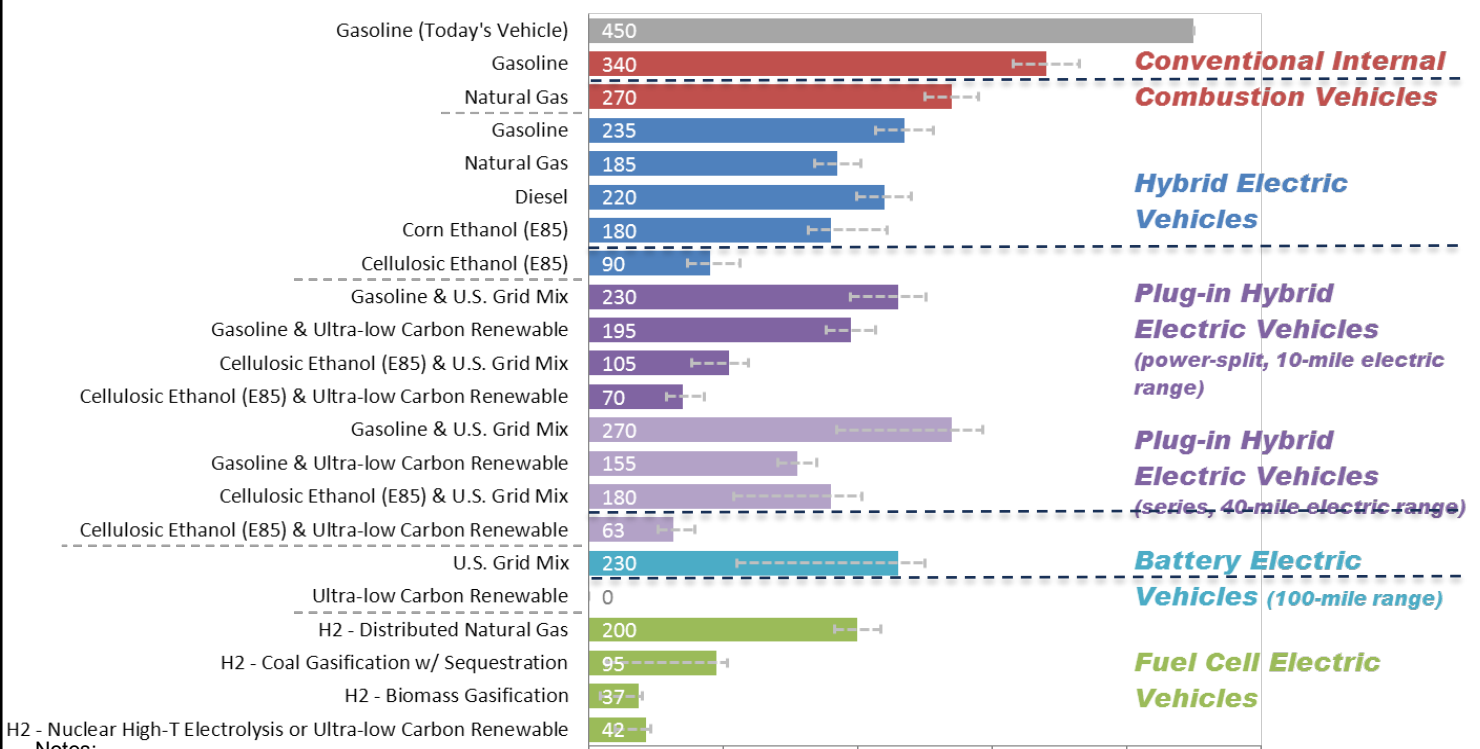
• The fuel cost per mile for a hydrogen fuel cell vehicle is set equivalent to the price of the competing vehicle on a “per mile” basis.

$$\text{\$/gge H}_2 = \left[\left(\frac{\text{Gasoline HEV cost, \$/gge}}{\text{HEV fuel economy, miles/gge}} \right) - \text{FCEV incremental vehicle cost, \$/mile} \right] \times \text{FCEV fuel economy, miles/gge}$$

Programmatic Analysis: Well-to-Wheels Analysis Updates

DOE is pursuing a portfolio of technologies with the potential to significantly reduce emissions of greenhouse gases from light-duty vehicles.

Well-to-Wheels Greenhouse Gases Emissions Future Mid-Size Car (Grams of CO2-equivalent per mile)



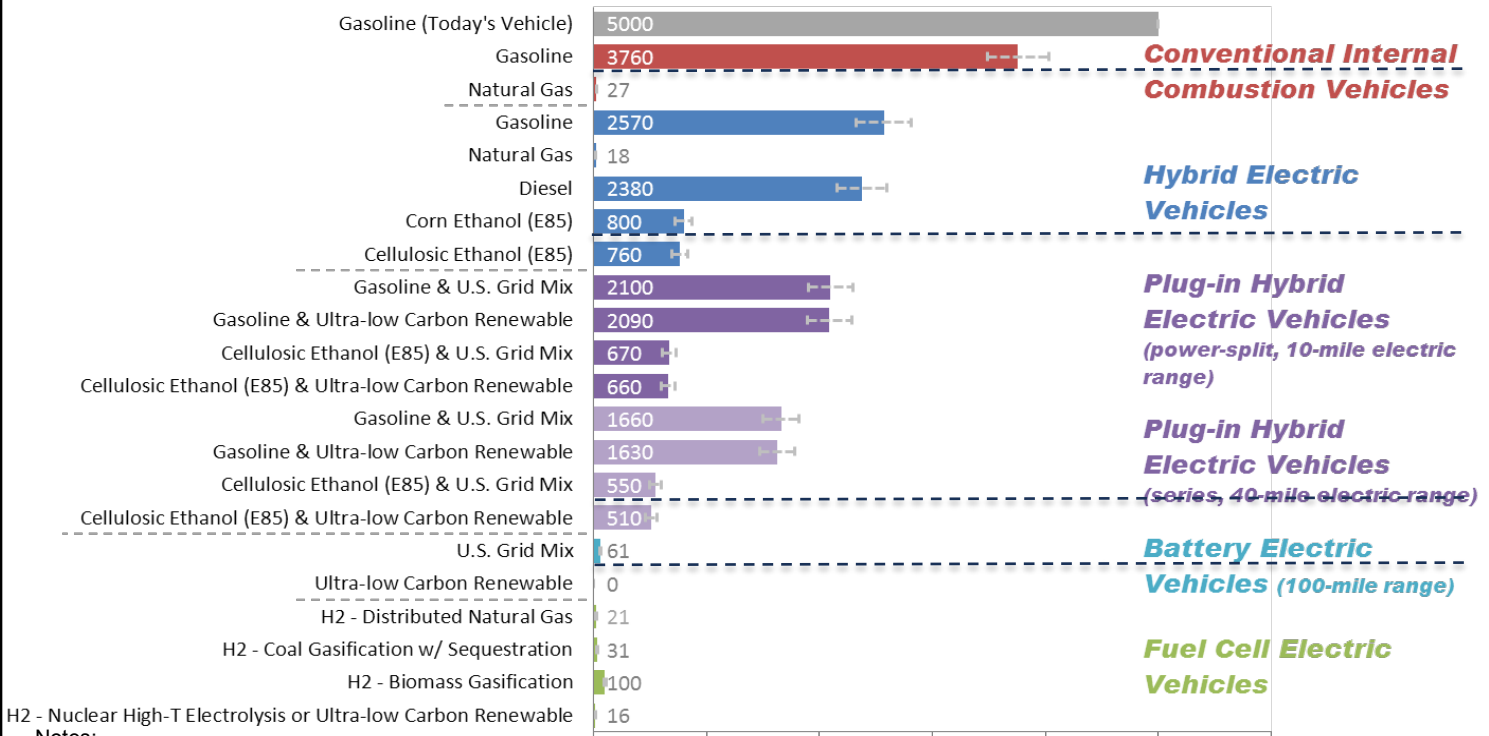
Notes:
 For a projected state of technologies in 2035-2045.
 Ultra-low carbon renewable electricity includes wind, solar, etc.
 Does not include the life-cycle effects of vehicle manufacturing and infrastructure construction/decommissioning.

- Multi- Program analysis with consistent assumptions and transparent approach
- Analysis included Vehicles Technologies and Biomass Programs, and ANL and NREL
- Analysis illustrates need for portfolio approach to reduce greenhouse gas emissions from conventional vehicle fleet

Programmatic Analysis: Well-to-Wheels Analysis Updates

DOE is pursuing a portfolio of technologies with the potential to significantly reduce the consumption of petroleum by light-duty vehicles.

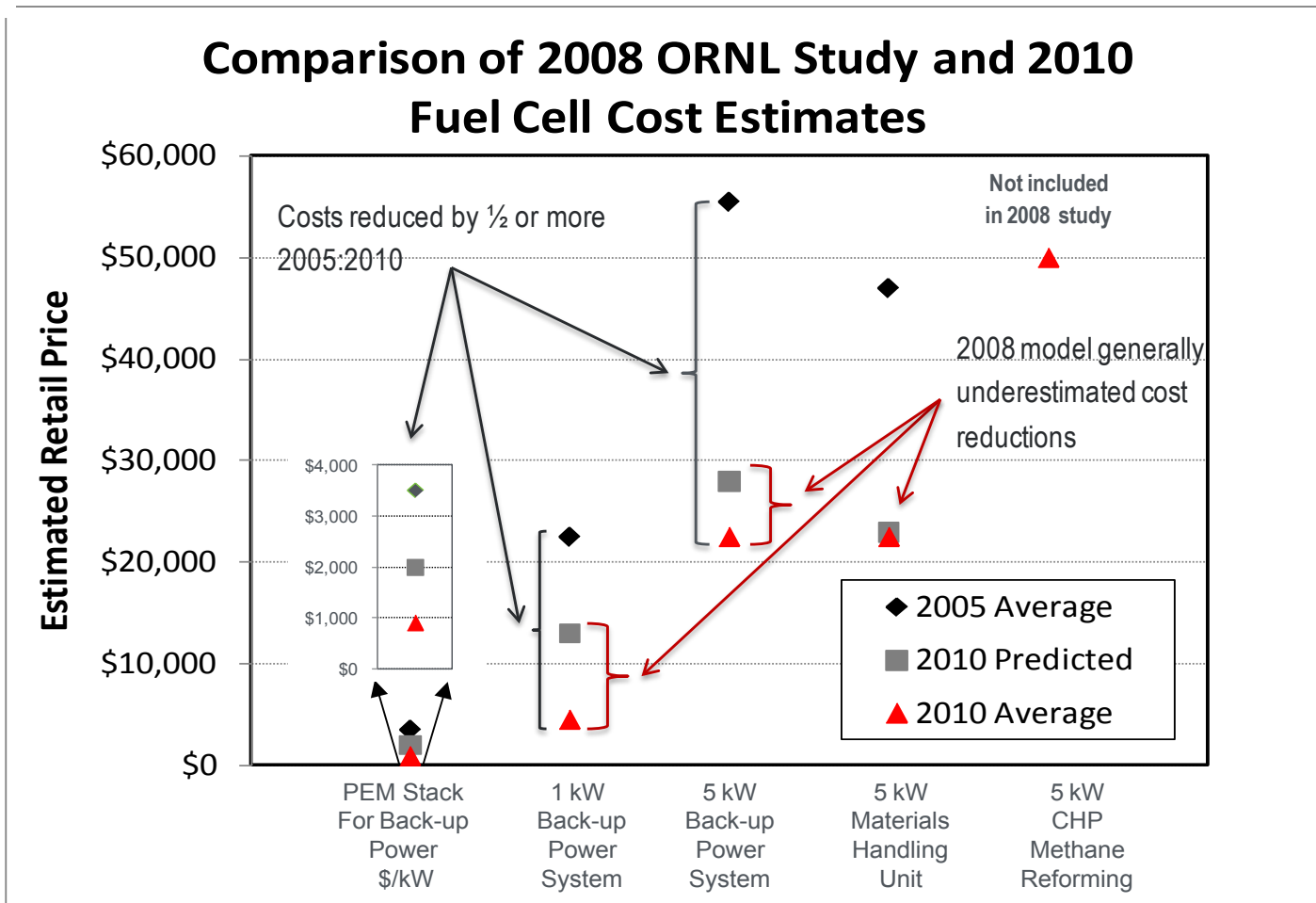
Well-to-Wheels Petroleum Energy Use for Future Mid-Size Car (BTUs per mile)



Notes:
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- Multi-Program analysis with consistent assumptions and transparent approach
- Illustrates need for portfolio approach to reduce petroleum use from conventional vehicle fleet

Oak Ridge National Laboratory model provided projections of the benefits from purchases to help reduce the fuel cell costs.



- Fuel cell cost for multiple applications have decreased from 2005 to 2010 as a result of purchases and programs such as ARRA and investment tax credits.
- ORNL model provides a method to estimate the impact of purchases.

2005 and 2010 averages based on estimates supplied by OEMs. 2010 predicted assumed government procurements of 2,175 units per year, total for all market segments. Predictions assumed a progress ratio of 0.9 and scale elasticity of -0.2.

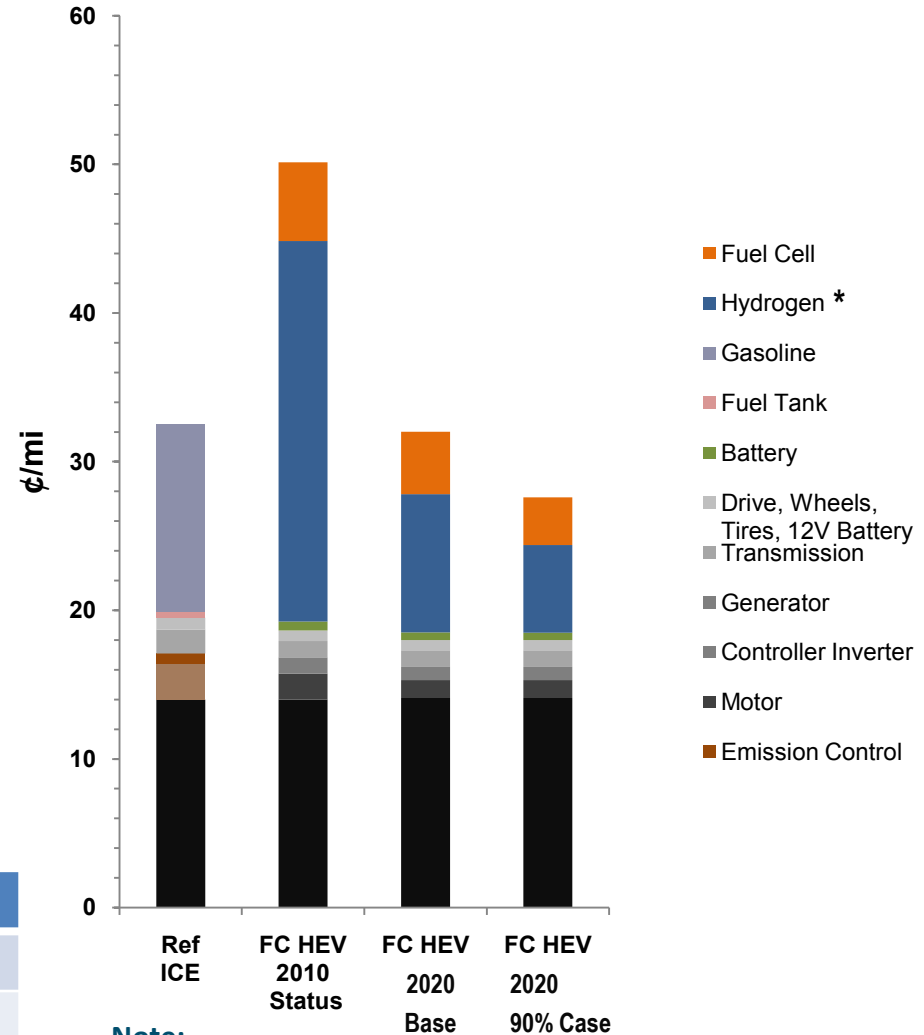
Technical Analysis: Vehicle Lifecycle Cost Breakdown Analysis

Reducing the cost of hydrogen fuel is a key requirement for fuel cell electric vehicles to compete with conventional ICEs on a lifecycle cost basis.

Preliminary Analysis - Vehicle Cost, ¢/mi

¢/mi	2010	2010	2020	2020
	Ref ICE	FC HEV 2010 Status	FC HEV 2020 Base	FC HEV 2020 90% Case
Fuel Cell		5	4	3
Hydrogen		26	9	6
Other Vehicle	33	19	19	19
Gasoline (\$3.08/gal.)	13	N/A	N/A	N/A
Fuel Tank	0	N/A	N/A	N/A
Battery	0	1	1	1
Drive, Wheels, Tires, 12V Battery	1	1	1	1
Transmission	2	1	1	1
Generator	0	0	0	0
Controller Inverter	0	1	1	1
Motor	0	2	1	1
Emission Control	1	0	0	0
ICE	2	0	0	0
Glider	14	14	14	14
Carbon Cost	0	0	0	0
Total	33	50	32	28

Assumptions	Ref ICE	2010	2020	2020
H ₂ cost	NA	\$9.50	\$3.50	\$3.00
H ₂ Storage cost	NA	\$5,050	\$2,100	\$1,050
Fuel Cell cost (80 kW)	NA	\$4,000	\$3,200	\$2,400
Vehicle Fuel Economy	25	50	54	67



Note:
*Hydrogen: Includes production, delivery, and on-board storage

Technical Analysis: Lifecycle Costs for Light Duty Vehicles

Conclusion: Meeting subprogram targets is key to enabling fuel cell vehicles to compete with other vehicle platforms.

Preliminary Analysis

2020

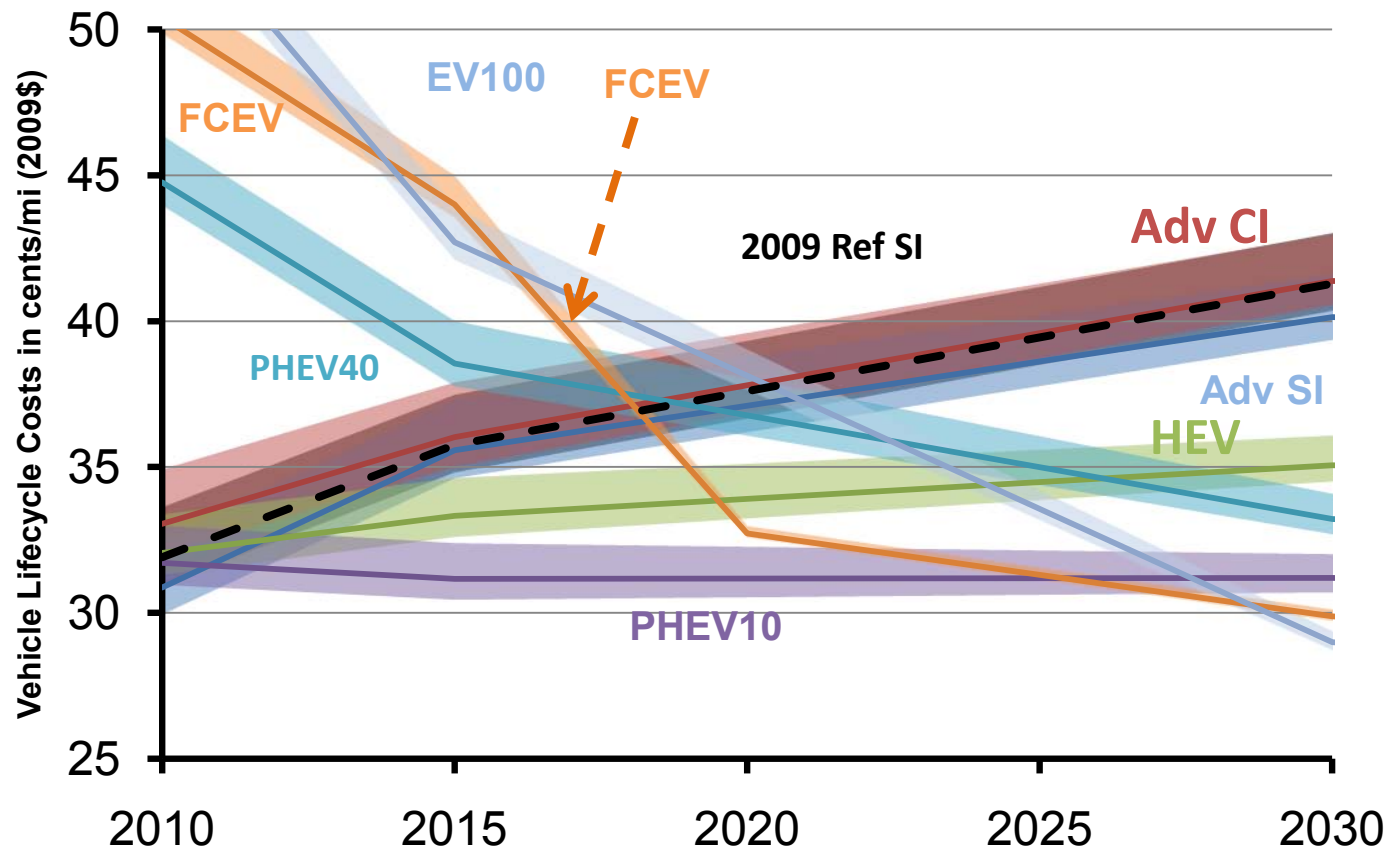
- Fuel cell vehicles become competitive with gasoline-based vehicles

2030

- Fuel cell vehicles are competitive with other alternate fuel vehicles

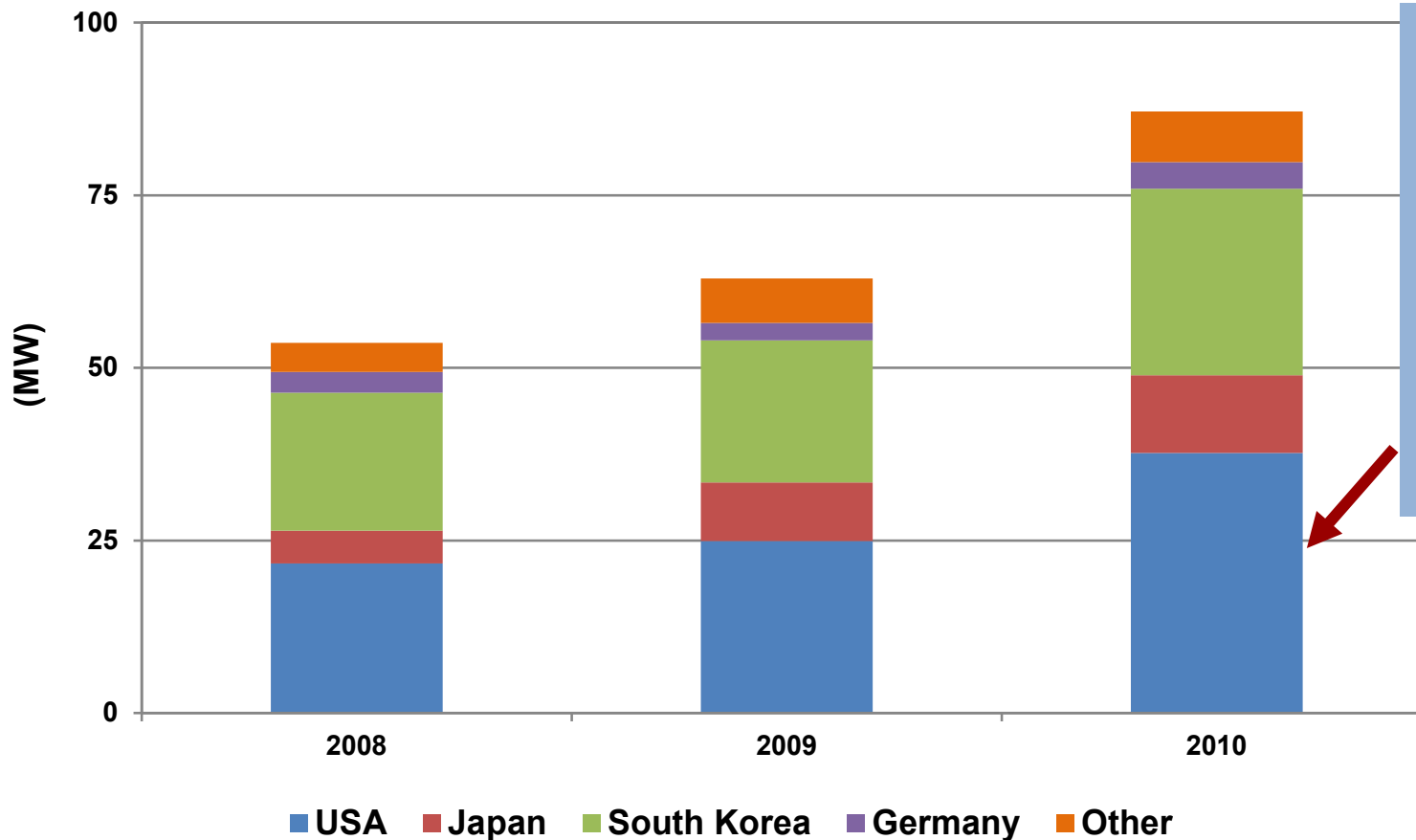
Analysis includes FCTP, OBP, VTP, and ANL.

Advanced Light Duty Vehicle Technologies (Mid-Size)



* No state, local or utility incentives are included. Federal subsidy policies (e.g., Recovery Act 09 credits for PHEVs) are also excluded. Fuel prices follow AEO09 high oil projections (gases rises from \$3.07 in 2010 to \$5.47 in 2030; diesel increases from \$3.02 in 2010 to \$5.57 in 2030); fuel taxes are included in EIA estimates. The vehicle cost range represents a range of potential carbon prices, from \$0 to \$56 (the centerline is plotted at a carbon price of \$20). Technology costs are estimated based on a 50% ("average") likelihood of achieving program goals.

Fuel Cell System Shipments in Megawatts 2008-2010



Significant increase in megawatts of fuel cell systems shipped by US companies from 2009 to 2010 year: **>50% market growth in just one year**

Early Market Analysis: Infrastructure Requirements

Infrastructure workshop with multiple stakeholders provided valuable insight for cost reduction and gaps to assess.

Workshop Summary

Objectives

Identify:

- Cost reduction opportunities from
 - Economies of scale (e.g., station standardization, number and size of installations)
 - Learning-by-doing resulting from growth in material handling equipment (MHE), backup power, transit bus, and light-duty vehicle markets.
- Cost reduction opportunities from focused R&D.

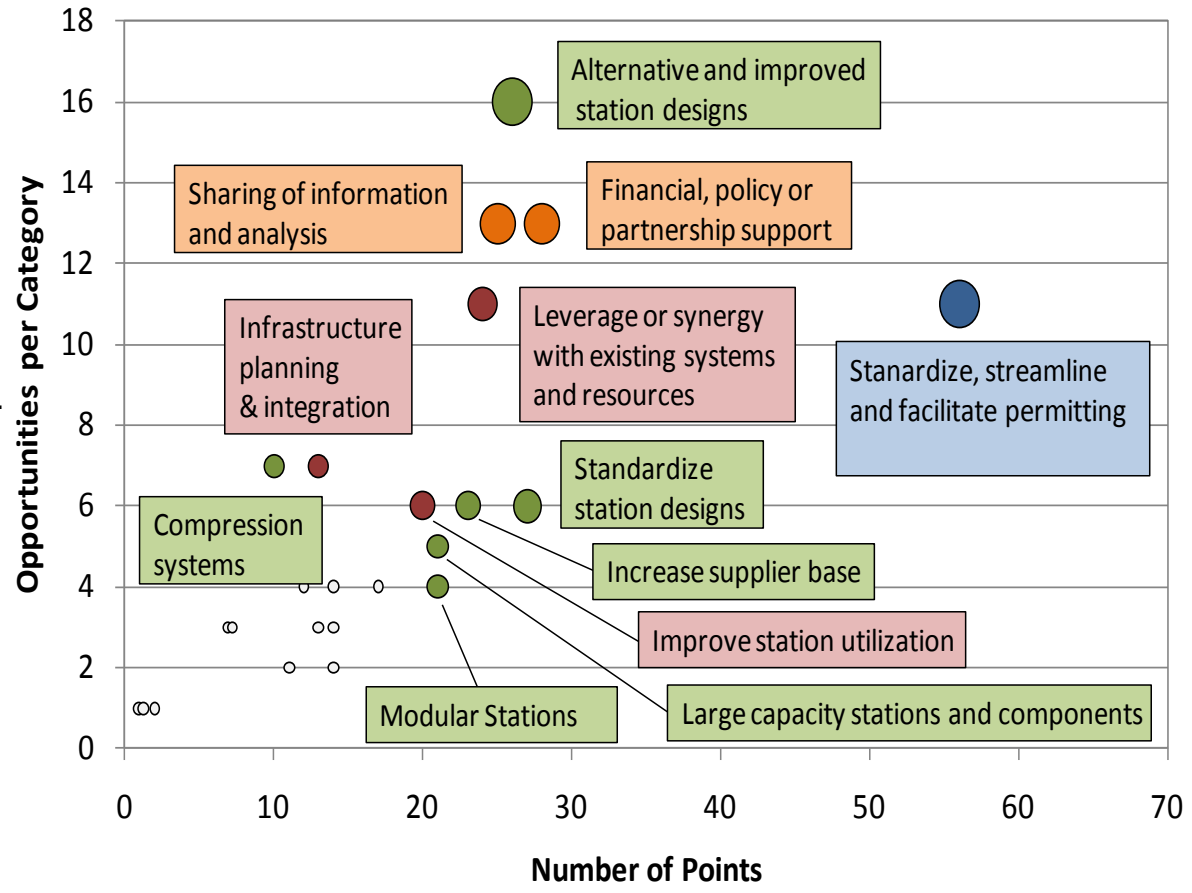
Participants included:

- **Countries**

US	Germany
Japan	Norway
- **Companies**

GM	Toyota	Nissan
Honda	Linde	StatOil
Shell	Sprint	Plug
ReliOn	Nuvera	Proton
Air Products	Air Liquide	Daimler
Chevron		

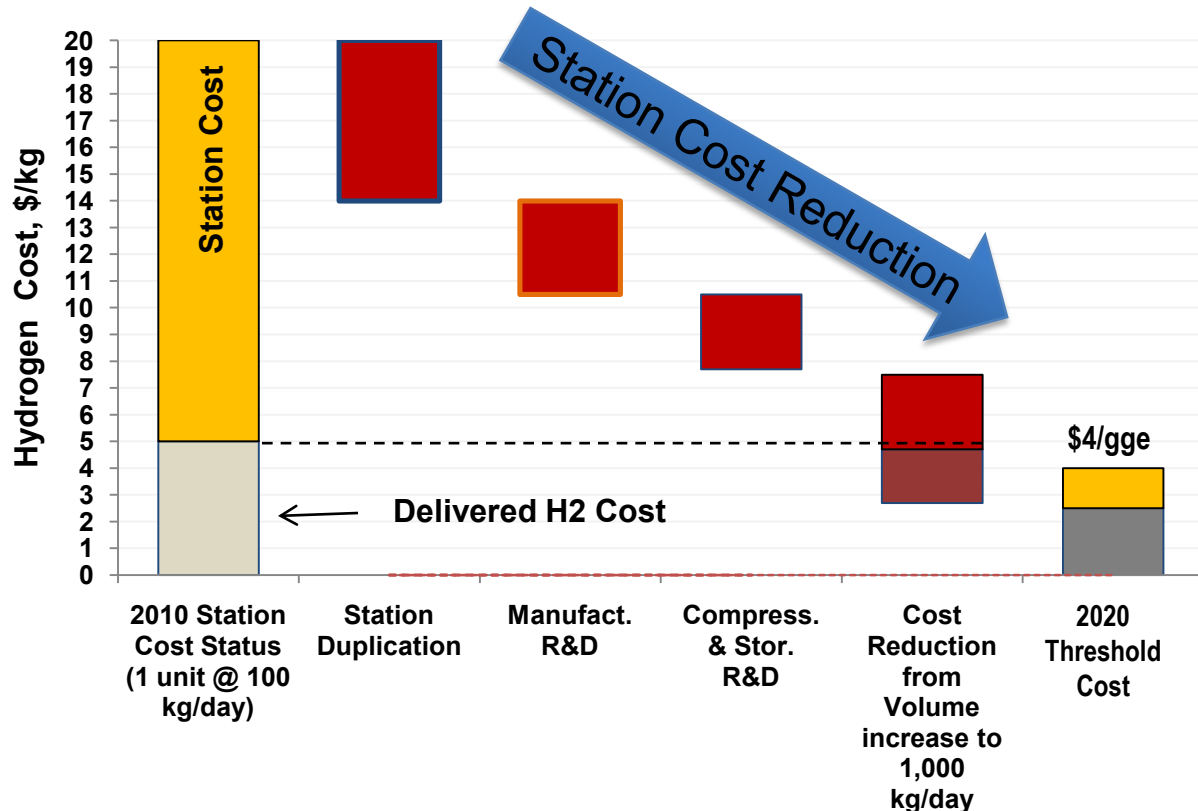
Preliminary Summary of Workshop Results



Source: NREL from Infrastructure Workshop 2011

Developed cost reduction opportunity assessment

Preliminary Analysis: Cost Reductions for Stations



Preliminary results of Infrastructure Workshop highlighted current station costs can be reduced through

- Economies of scale
- Standardized station design
- Multiple station installations
- Continued R&D of manufacturing station components, compressors and hydrogen storage
- Increase the number of station installers and component suppliers

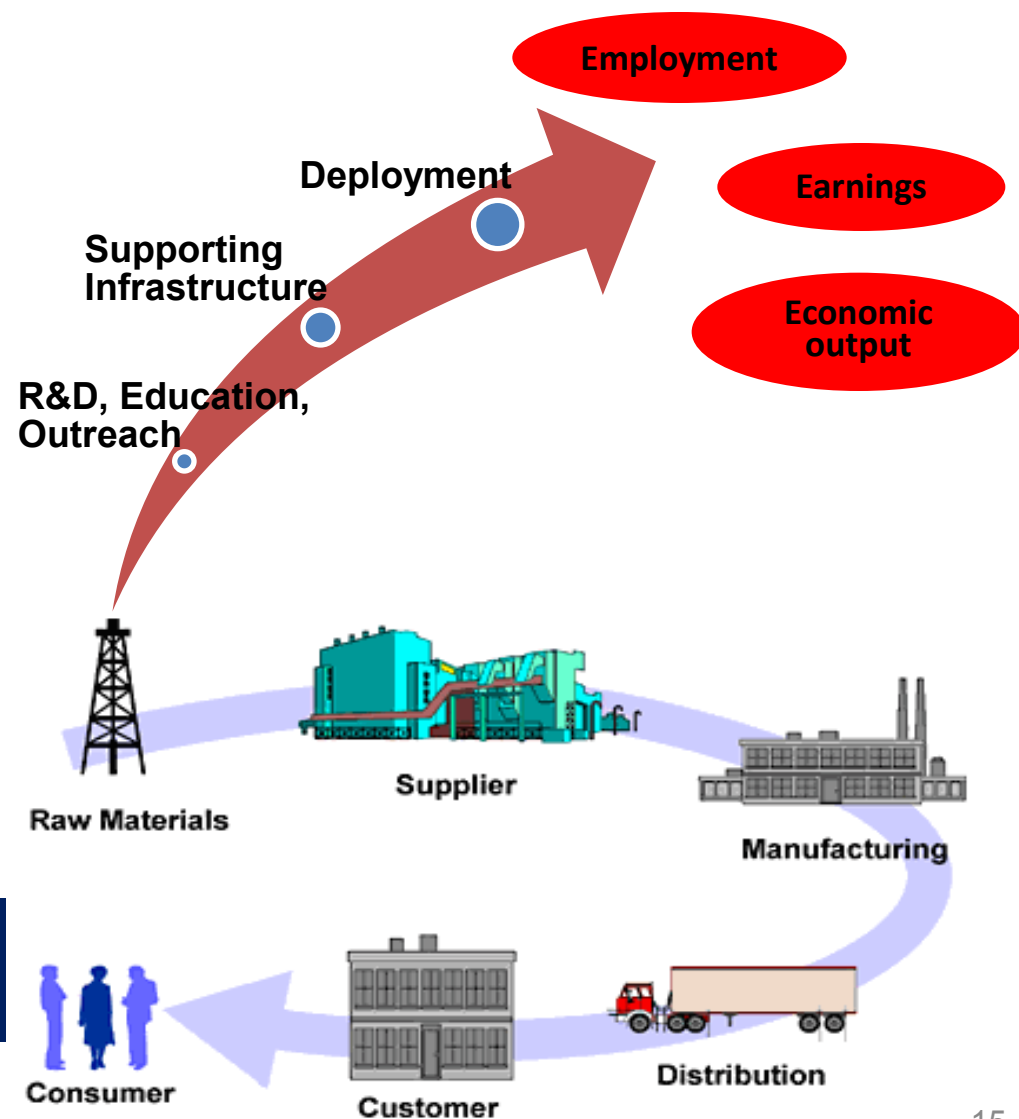
1. Cost reduction from station duplication will required ~120 stations and was based on 3% reduction for a doubling of capacity. Reference: "A portfolio of power-trains for Europe: a fact-based analysis" by McKinsey & Co.
2. Cost of hydrogen delivered to station is ~\$5/kg based on TTC Hydrogen Market Study 2009.
3. Station cost reductions based on ANL Hydrogen Delivery Systems Analysis Model (HDSAM).
4. The current station cost is based on costs from the current California state funded stations. The capital cost for the station was assumed to be \$2.5 million.
5. The starting station capacity is 100 kg/day.

Socio-Economic Analysis: Fuel Cell Industry Impact on Employment

Developed employment model for job creation potential for states and regions

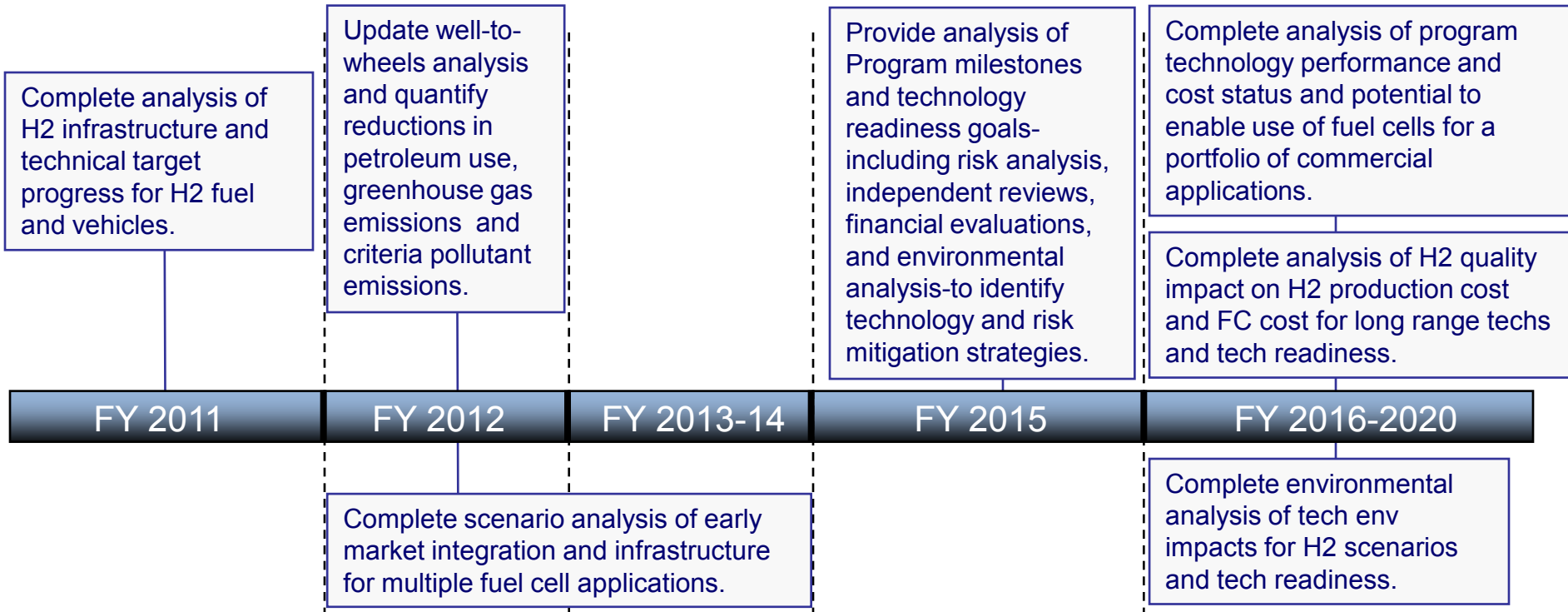
- ANL-RCF developing employment and economic impact tool to estimate stationary FC industry impacts:
 - Production (PEMFC, PAFC and MCFC) in target applications
 - Installation of FCs and required infrastructure
 - O&M including fuel
 - Construction/expansion of manufacturing capacity
- State, regional and national level analyses including supply chain impacts
- Applications included forklifts, back-up power, specialty vehicles, etc.

Systems Analysis and Education Subprograms are collaborating on the model development and analysis

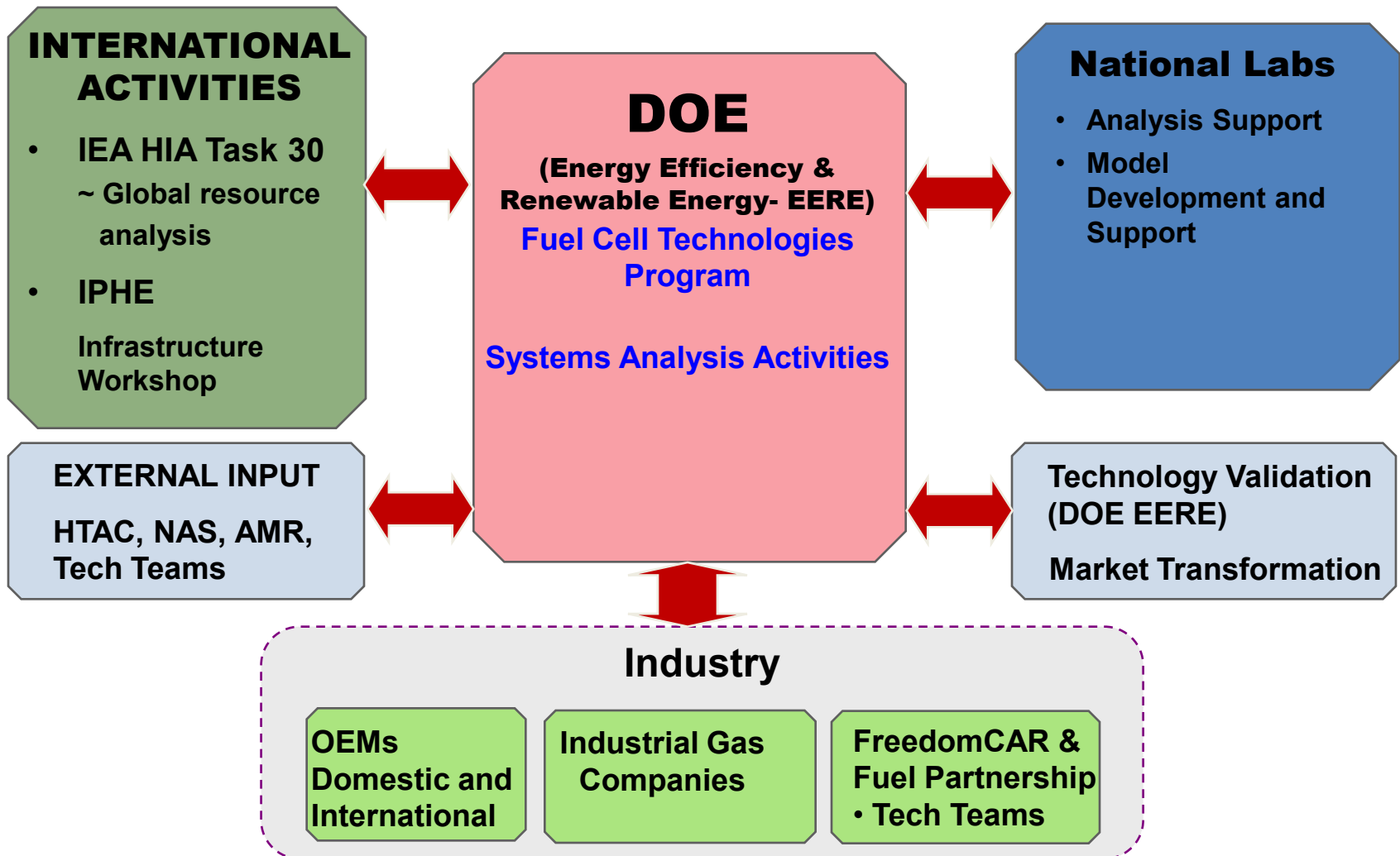


Key Milestones & Future Plans

- Diverse portfolio and expanded capability of models developed by the Systems Analysis sub-program are enabling analysts to address barriers to technology development and commercialization.
- Emphasis on *early market and infrastructure analysis* :
 - Focus on utilizing biogas as a resource for an alternative fuel.
 - Comprehensive approach to evaluate a portfolio of fuel cell applications for light duty transportation, stationary generation, backup power and material handling equipment, and the electric sector to realize economic, environmental and social benefits.
- Plans continue to enhance existing models and expand analyses.



Analysis and peer review input coordinated among national and international organizations



Systems Analysis is an integral component of EERE and the Fuel Cell Technologies Program.

- Continue to provide program guidance and support by reviewing and updating programmatic targets
- Identify gaps and opportunities for continued program R&D through analysis and input from multiple sources such as the early market infrastructure analysis
- Confirm through transparent analysis and peer review the impact of the FCT Program on market penetration and product development such as the ORNL report, Fuel Cells 2000 and Pike Research Market report and the PNNL Commercial Product report
- Assess the impact of Government policies on industry and market introduction and technology growth
- Provide transparent analysis and illustrations of the climate, economic and socio-economic benefits of fuel cell applications for transportation, stationary power generation, material handling equipment and other markets

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