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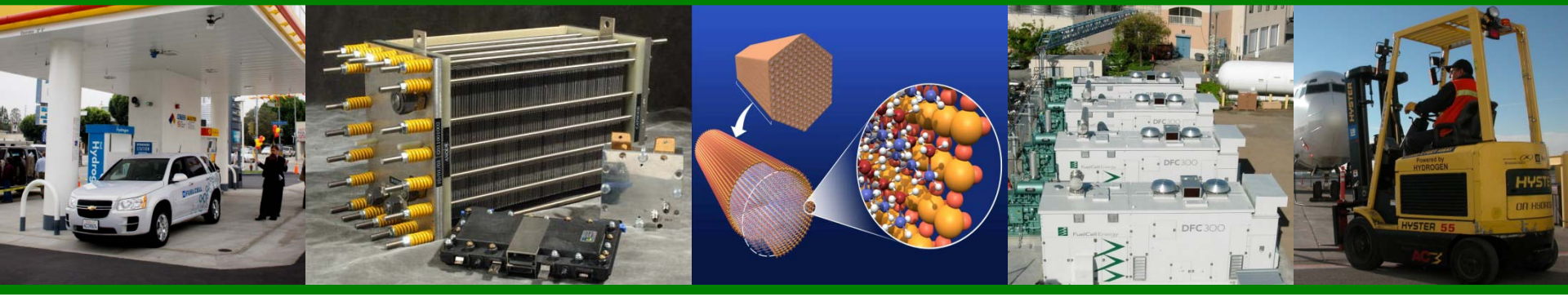

Systems Analysis Sub-program
- Session Introduction -

Fred Joseck

2011 Annual Merit Review and Peer Evaluation Meeting
May 10, 2011

Goal & Objectives

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***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

Challenges

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Market complexities and data inconsistency present challenges

Future Market Behavior

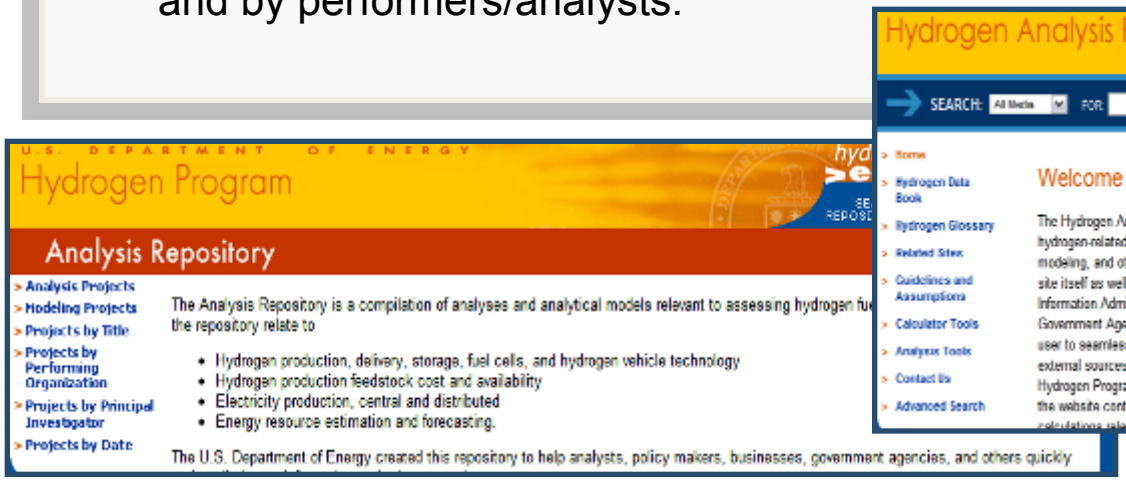
- Understanding of drivers of fuel and vehicle markets needed for long-term projections.
- Models need to adequately address interactions - hydrogen/vehicle supply and demand.

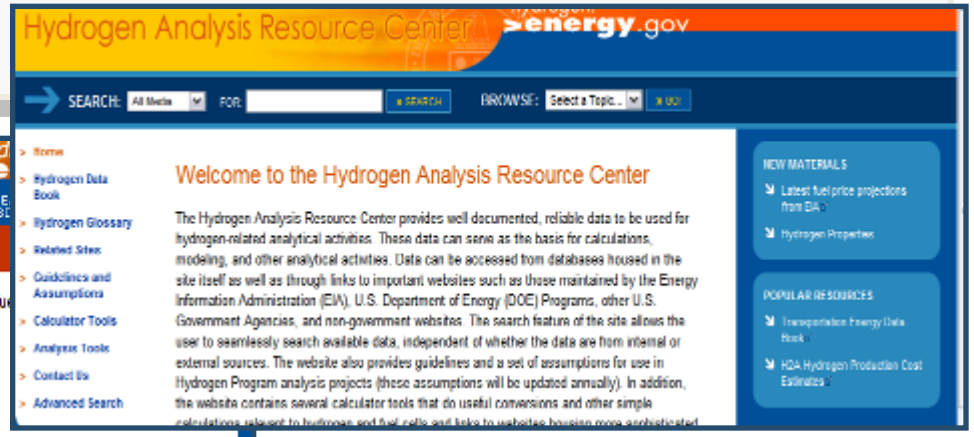
Inconsistent Data, Assumptions & Guidelines

- 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.





Analysis Portfolio

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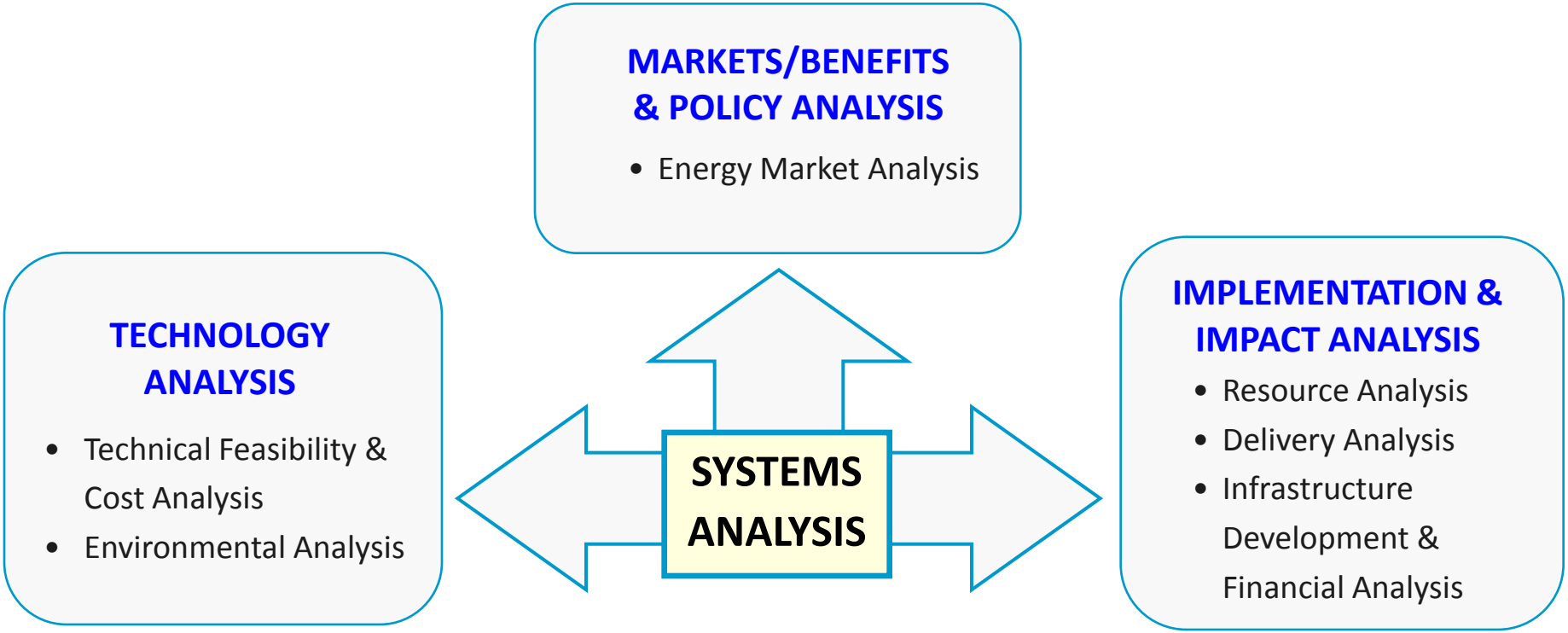
A variety of analysis methodologies are used in combination to provide a sound understanding of hydrogen and fuel cell systems and developing markets, as well as quantifying benefits, impacts, and risks of different hydrogen and fuel cell systems.



Systems Analysis Budget

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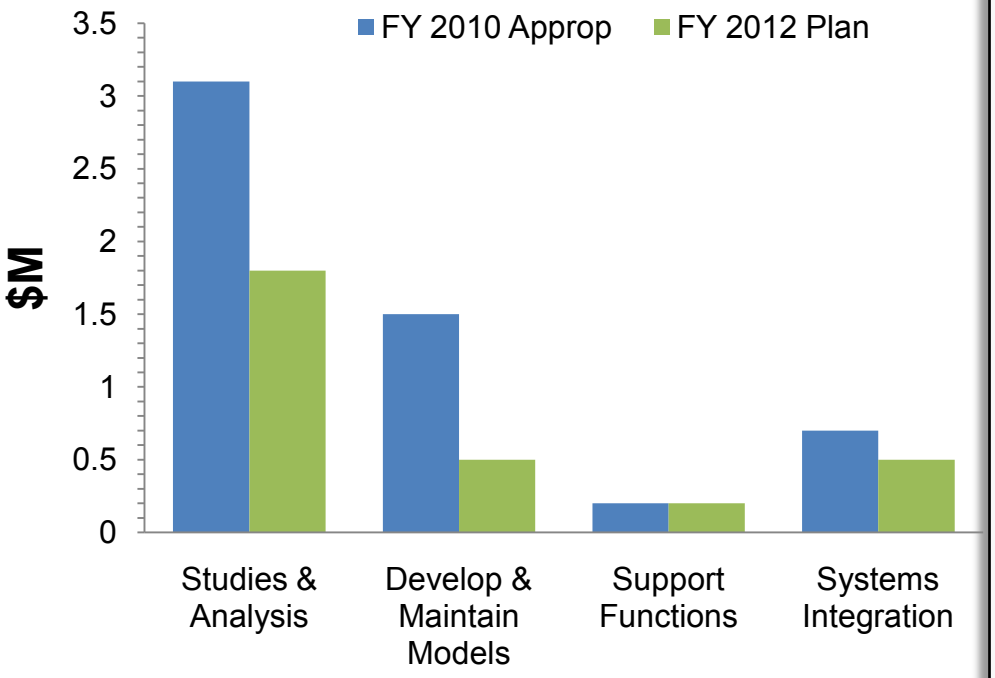
Determine technology gaps, economic/jobs potential, and quantify 2012 technology advancement

FY 2012 Request = $3.00 M

FY 2010 Appropriation = $5.41 M



FY11 Appropriation to be determined.

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

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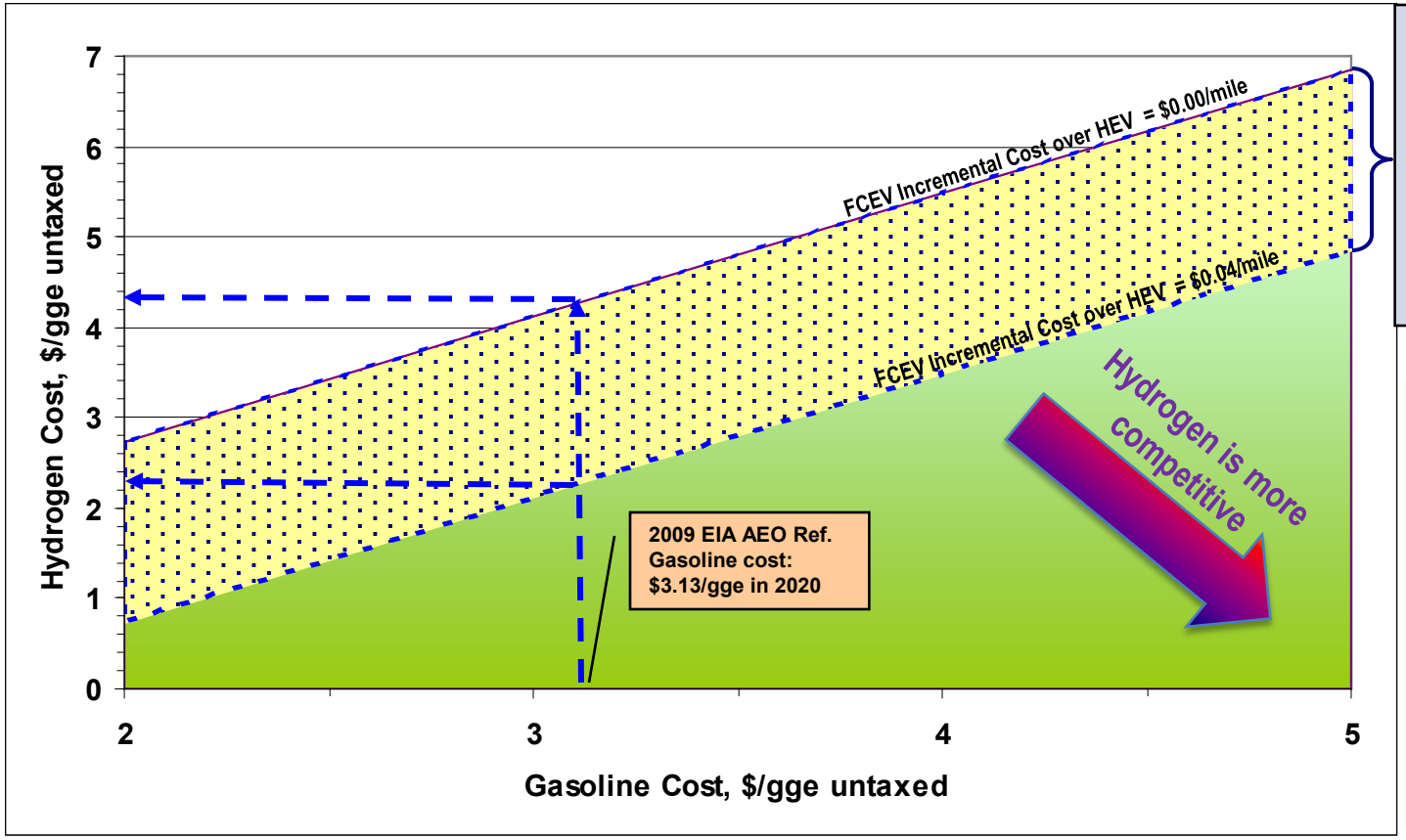
Competitive cost of hydrogen compared to gasoline HEV is ~ $2.00–$4.00/gge



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

Plans:

H_2 Threshold Cost will be applied across the Program

- Target setting
- Subprogram R&D progress assessment

- 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.

$$\$/\text{gge H2} = \left[\left(\frac{\text{Gasoline HEV cost, \$/gge}}{\text{HEV fuel economy, miles/gge}}\right) - \text{FCEV incremental vehicle cost, \$/mile}\right] \times \text{FCEV fuel economy, miles/gge}$$

See DOE Record 11001

Expert review included National Laboratories, Hydrogen Technical Advisory Committee and FreedomCAR Partnership

Programmatic Analysis: Commercialization of Technology

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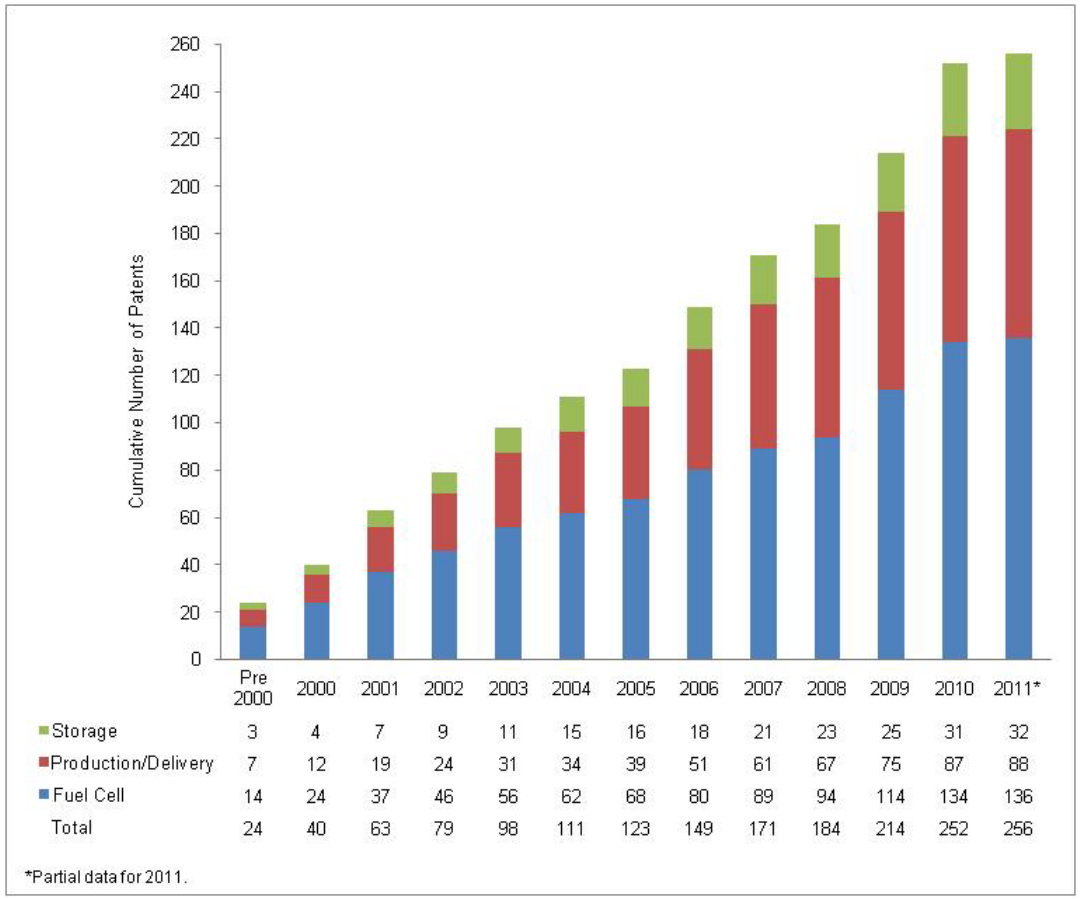
An increasing number of patents have been granted as a result of DOE Fuel Cell Technologies Program–funded R&D.

Accelerating Technology Innovation and Application

>250 PATENTS granted as a result of EERE-funded Fuel Cell Technologies R&D



	Pre 2000	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011*
Storage	3	4	7	9	11	15	16	18	21	23	25	31	32
Production/Delivery	7	12	19	24	31	34	39	51	61	67	75	87	88
Fuel Cell	14	24	37	46	56	62	68	80	89	94	114	134	136
Total	24	40	63	79	98	111	123	149	171	184	214	252	256

*Partial data for 2011.

Source: Pacific Northwest National Laboratory

Commercial Products:

EERE-funded Fuel Cell Technologies resulted in nearly 30 commercial products

256 patents resulting from EERE-funded R&D:

- 136 fuel cell
- 88 H_2 production and delivery
- 32 H_2 storage

Programmatic Analysis: Regional Benefit Analysis

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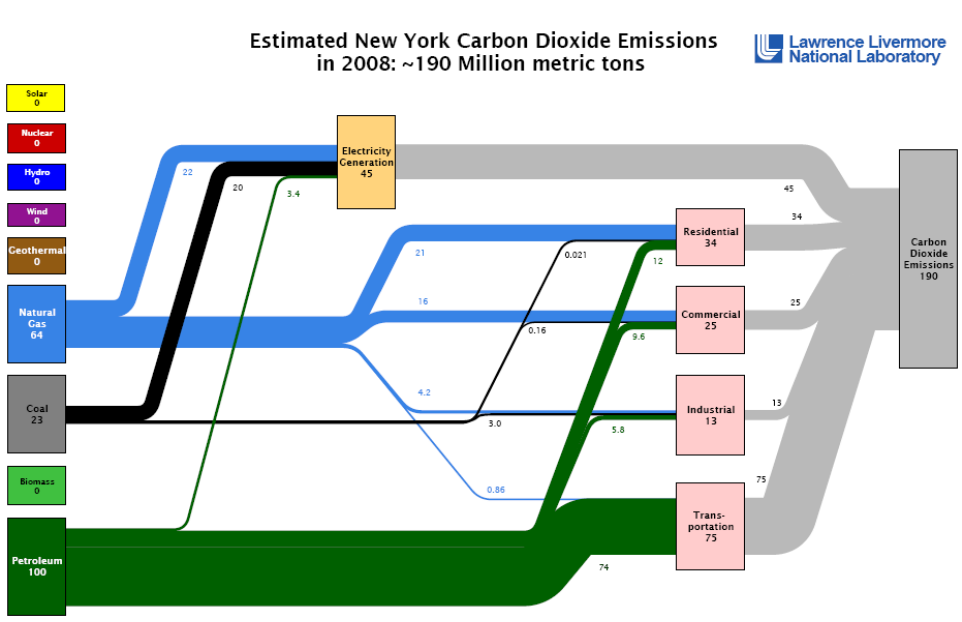

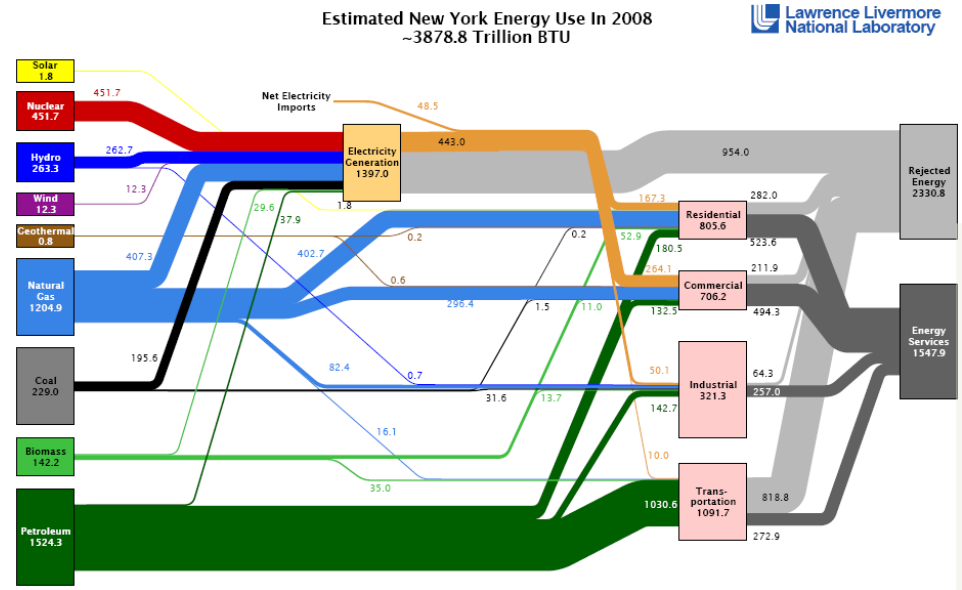

Regional and state analysis of energy use and CO_2 emissions identify key fuel cell technology applications

Analysis Results

- **Currently, residential and commercial sectors consume ~1 million b/d of petroleum for heat generation resulting in more than 120 million metric tons per year of CO2 emissions[1].**
- **Fuel cells could be utilized in states such as New York and regions in the Northeast to provide residential and commercial power and heat and result in a net petroleum reduction.**
- **The high efficiency of the fuel cell in residential and commercial combined heat and power service would reduce ghg emissions at the state and region levels.**

[1] Source: 2010 EIA AEO

Plans:

- Evaluate the greenhouse gas reduction and petroleum use reduction with the application of fuel cells for residential use
- Evaluate fuel cell costs and economic requirements for the fuel cell application
- Assess subprogram targets and policy requirements to assist fuel cell penetration into the market

Policy Analysis: Benefits of Policies and Incentives

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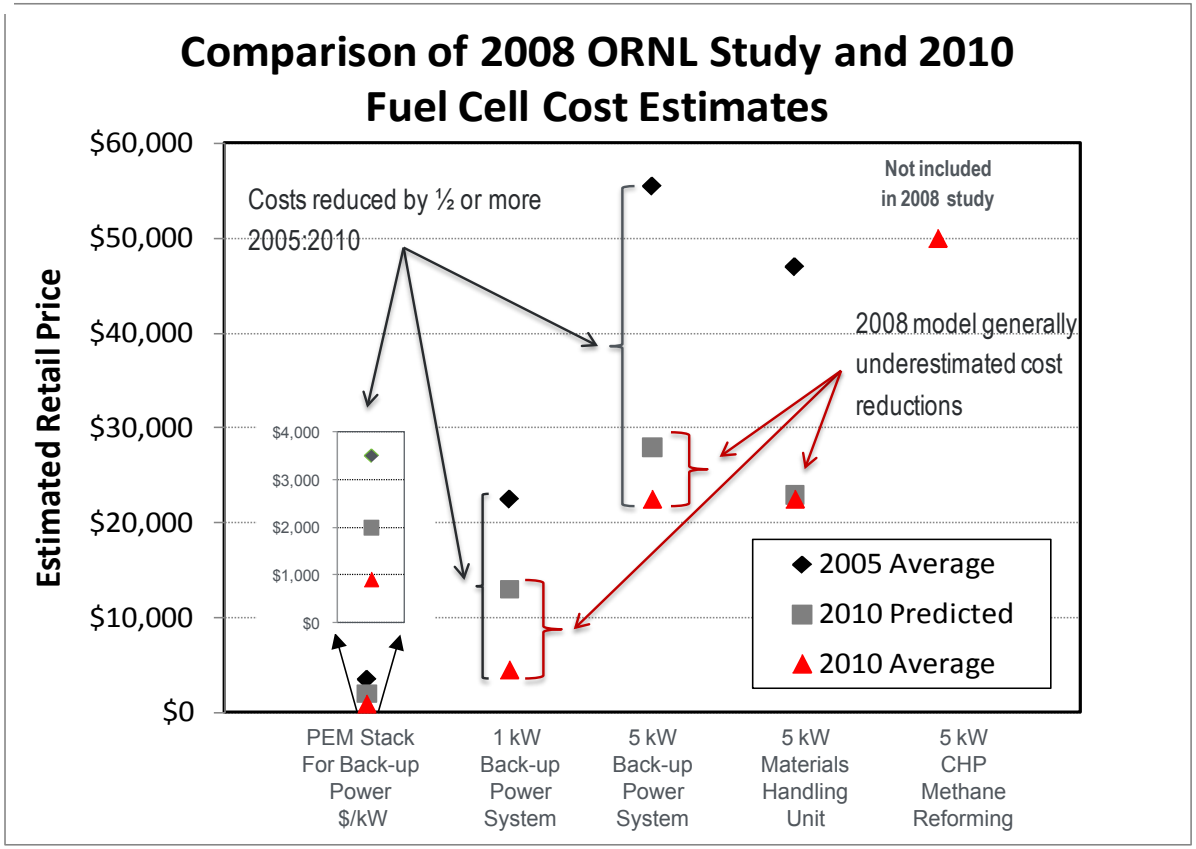
Oak Ridge National Laboratory model provided projections of the benefits from purchases to help reduce the fuel cell costs.



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.

- **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**

Early Market Analysis

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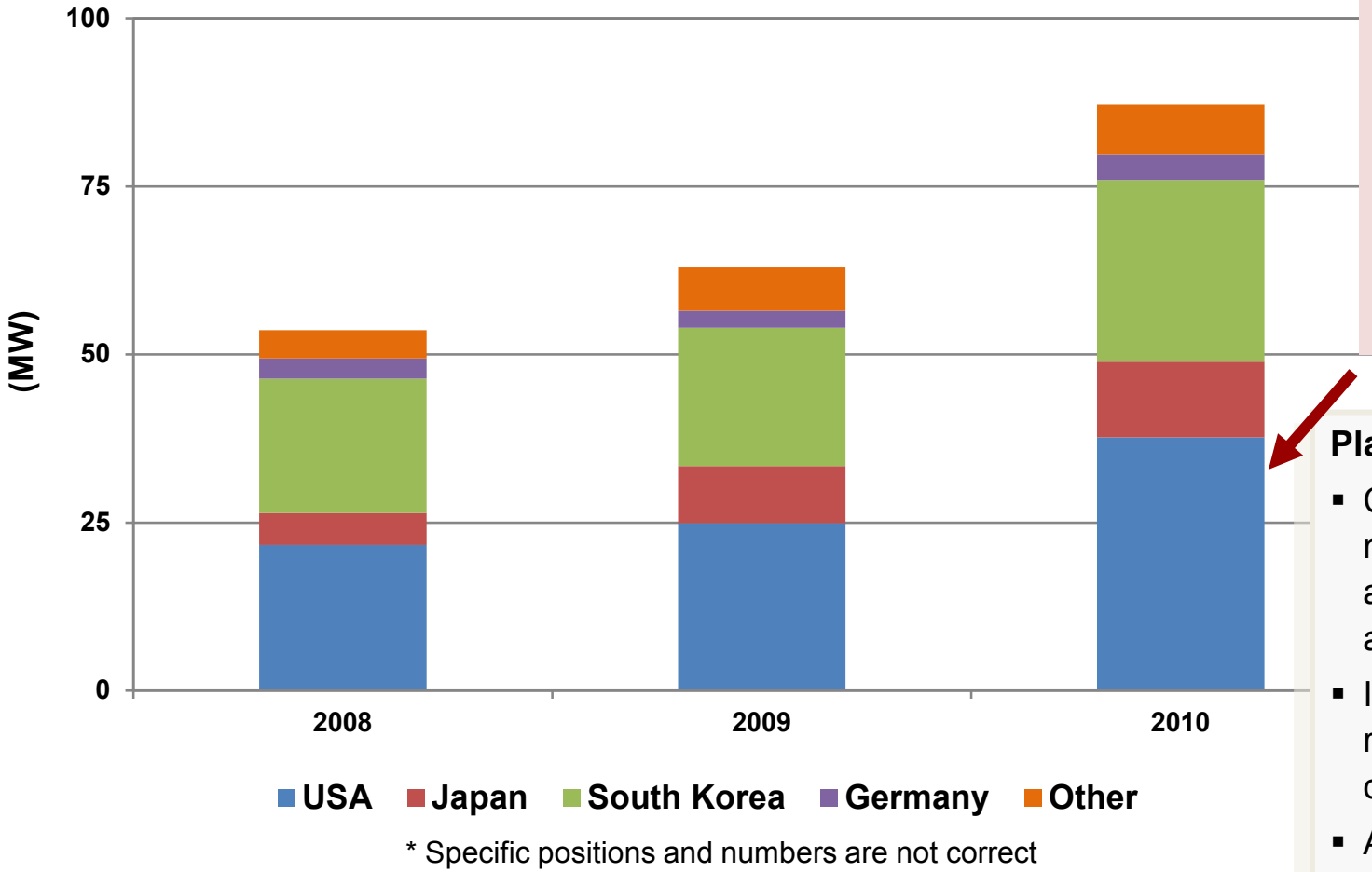
Fuel Cell System Shipments in Megawatts, 2008-2010



* Specific positions and numbers are not correct

Source: Pike Research, www.pikeresearch.com

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

Plans:

- Continue to monitor the market for fuel cells and various applications
- Identify key drivers required to sustain fuel cell market growth
- Analyze impact of policy options to stimulate and sustain the market

Early Market Analysis: Infrastructure Requirements

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Infrastructure workshop with a diverse field of stakeholders provided valuable insight for cost reduction and gaps.

Workshop Summary

Objectives

Identify:

- Cost reduction opportunities from economies of scale (e.g., station standardization, number and size of installations) and 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.

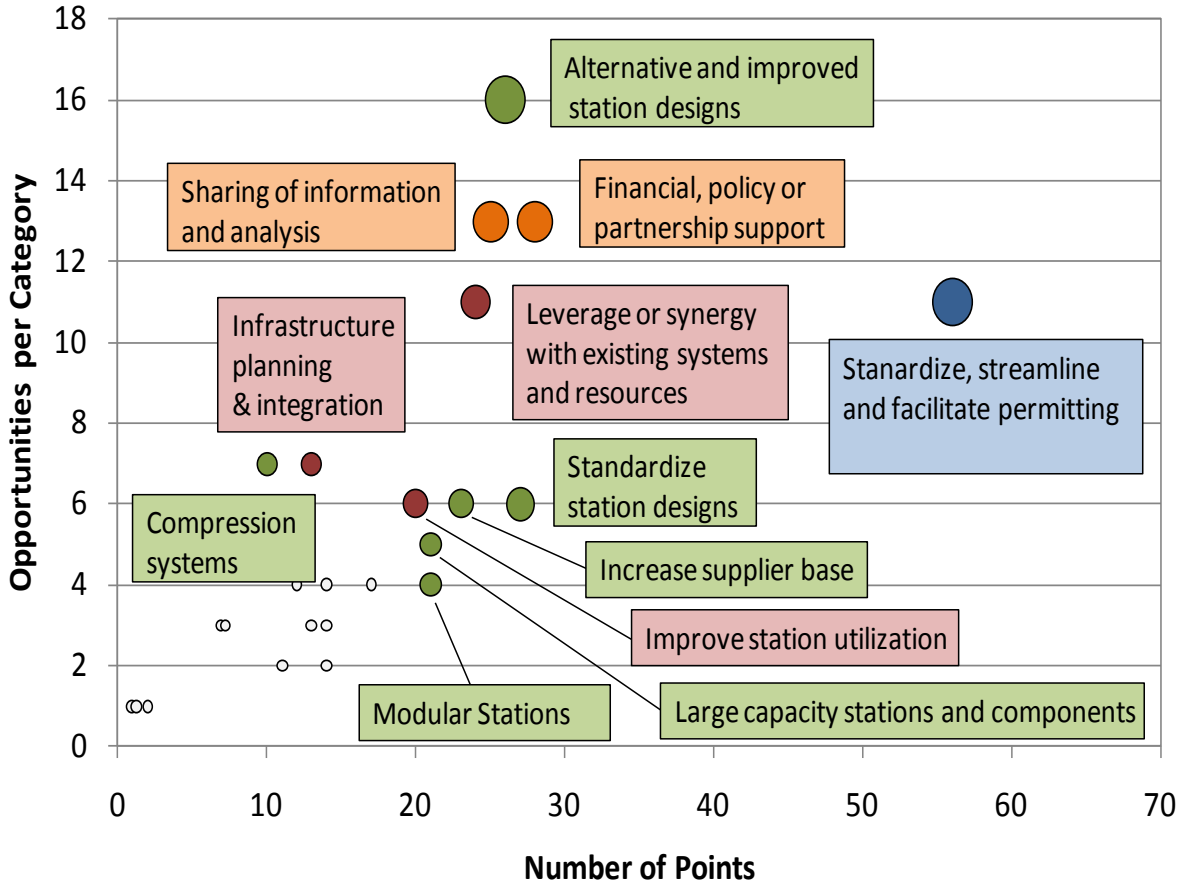
Participants included:

- ***Countries***

US	Germany
Japan	Norway

- ***Companies***

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



Early Market Analysis: Station Cost Reduction

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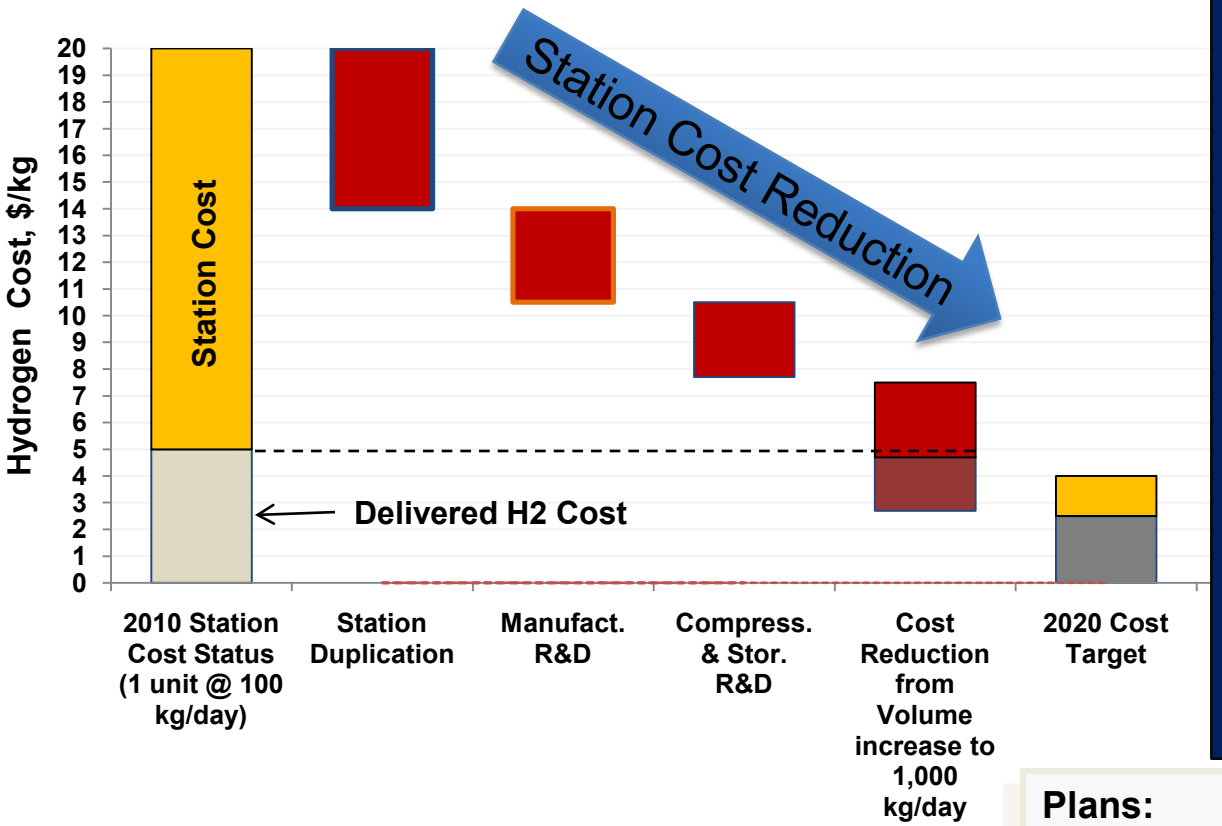
Preliminary Analysis: Cost Reductions for Stations



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.

Plans:

- Identify key drivers required to reduce the cost of early market fueling stations
- Analyze the top areas to reduce costs and have additional workshops to determine detailed barriers and opportunities to overcome the barriers

Biogas Resource: Methane from Landfills

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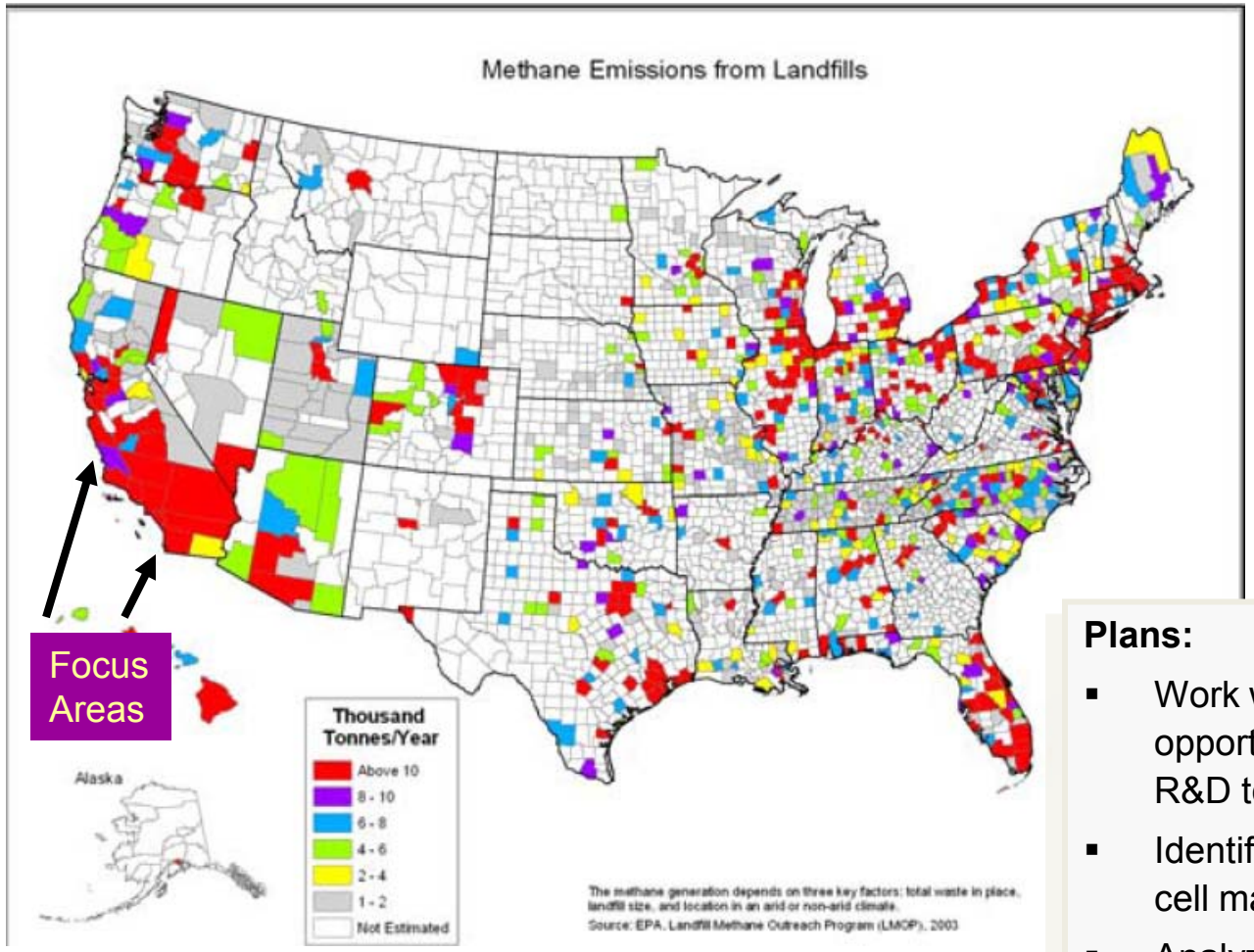
Landfill-biogas resources are located near large urban centers and could provide enough renewable hydrogen to fuel ~2–3 million fuel cell electric vehicles per day.



- 12.4 million MT per year of methane available from landfills in U.S.
- Majority of resource located near urban centers.
- If 50% of the bio-methane was available, ~8 million kg/day of renewable hydrogen could be produced from steam methane reforming.
- Renewable hydrogen is enough to fuel ~2-3 million fuel cell vehicles per day.

Plans:

- Work with the Biomass Program to identify opportunities of collaboration and joint R&D to resolve critical issues
- Identify key drivers required to sustain fuel cell market growth
- Analyze impact of policy options to stimulate and sustain the market

Source: NREL report *A Geographic Perspective on Current Biomass Resource Availability in the United States*, 2005

Socio-Economic Analysis: Fuel Cell Industry Impact on Employment

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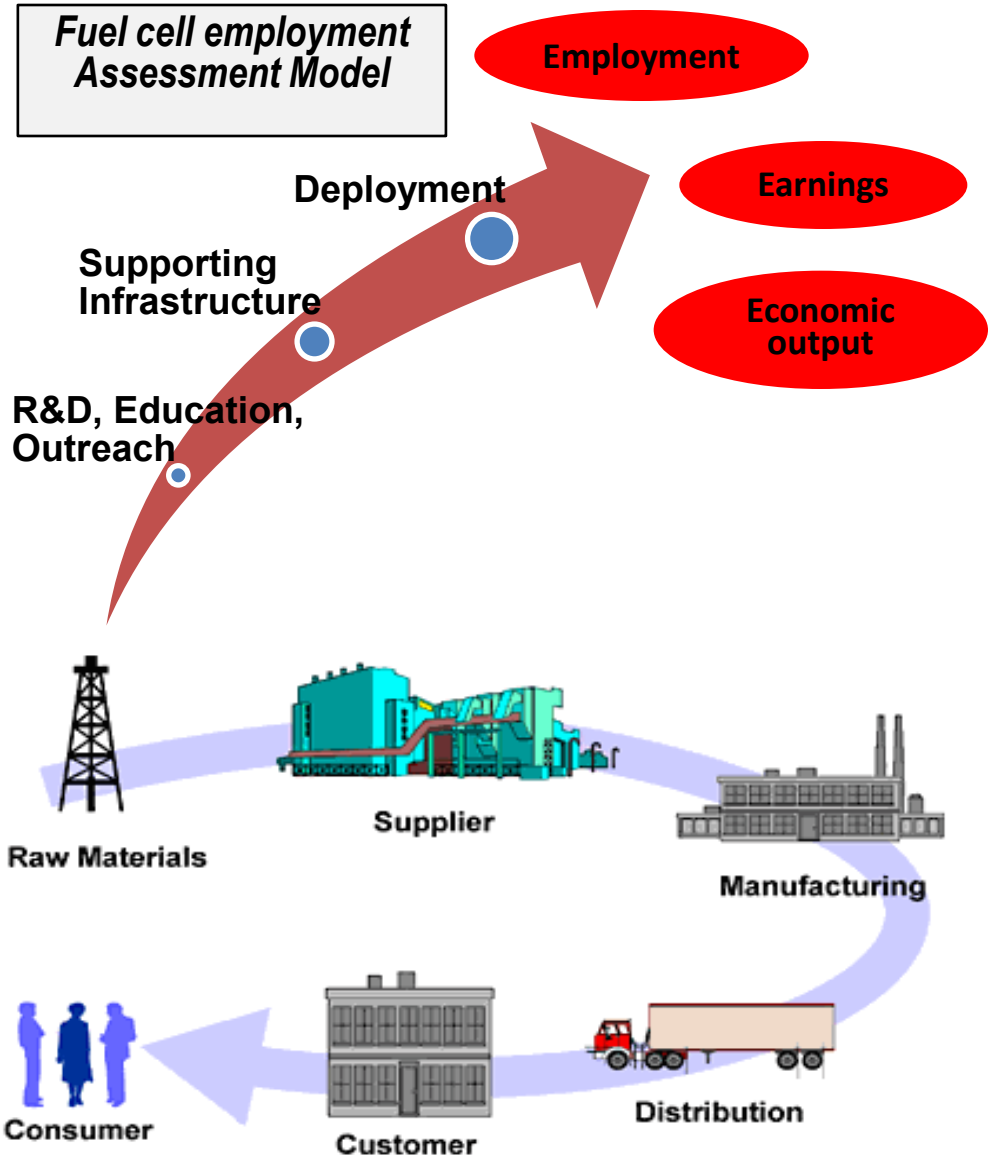
Fuel Cell Technologies Create Jobs and ***Grow Our Clean Energy Economy***

Fuel cell employment Assessment Model

Plans:

- Publish the employment model for public use
- Assess impacts of various market penetration scenarios on the socio-economics of fuel cells and related technologies at the state, regional and national levels
- Coordinate analysis and model implementation with the Education Sub-program



Key Systems Analysis Milestones & Future Plans

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- 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.

FY 2011	FY 2012	FY 2013-14	FY 2015	FY 2016-2020
Complete analysis of H_2 infrastructure and technical target progress for H_2 fuel and vehicles.	Update well-to-wheels analysis and quantify reductions in petroleum use, greenhouse gas emissions and criteria pollutant emissions.		Provide analysis of Program milestones and technology readiness goals-including risk analysis, independent reviews, financial evaluations, and environmental analysis-to identify technology and risk mitigation strategies.	Complete analysis of program technology performance and cost status and potential to enable use of fuel cells for a portfolio of commercial applications.
				Complete analysis of H_2 quality impact on H_2 production cost and FC cost for long range techs and tech readiness.
	Complete scenario analysis of early market integration and infrastructure for multiple fuel cell applications.			Complete environmental analysis of tech env impacts for H_2 scenarios and tech readiness.

Systems Analysis Collaborations

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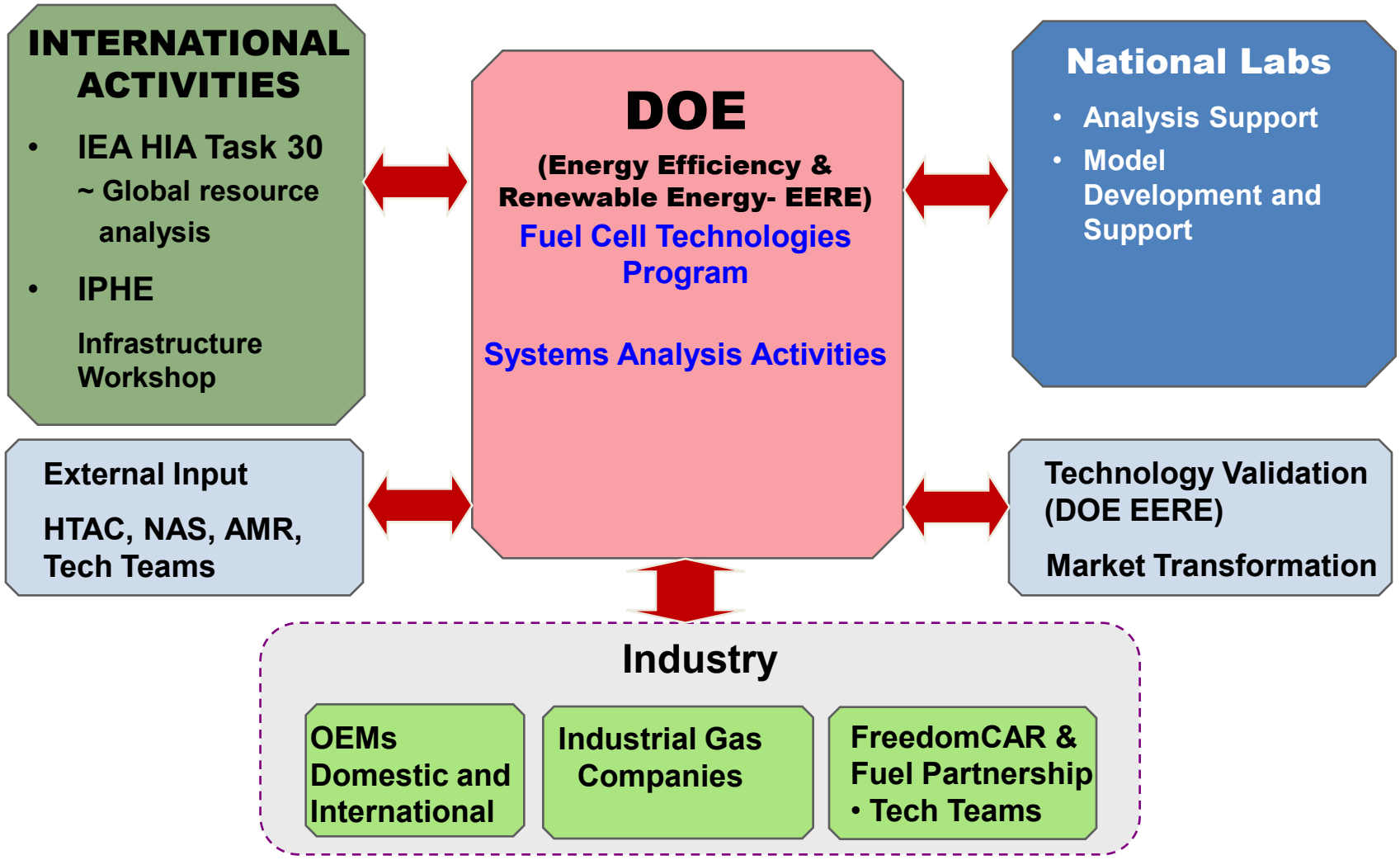
Analysis and peer review input coordinated among national and international organizations.



Summary

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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

Session Instructions

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- This is a review, not a conference.
- Presentations will begin precisely at the scheduled times.
- Talks will be 20 minutes and Q&A 10 minutes.
- Reviewers have priority for questions over the general audience.
- Reviewers should be seated in front of the room for convenient access by the microphone attendants during the Q&A.
- Please mute all cell phones, BlackBerries, etc.
- Photography and audio and video recording are not permitted.

Reviewer Reminders

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- Deadline for final review form submittal is **May 20th at 5:00 PM EDT.**
- ORISE personnel are available on-site for assistance. A reviewer-ready room is set up in *The Rosslyn Room* (on the lobby level) and will be open Tuesday –Thursday from 7:30 am to 6:00 pm and Friday 7:30 am to 2:00 pm.
- Reviewers are invited to a brief feedback session – at 4:45 PM on Tuesday, in this room.

For More Information

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Systems Analysis Team

Fred Joseck, Team Leader
202-586-7932
fred.joseck@ee.doe.gov

Tien Nguyen
202-586-7387
tien.nguyen@ee.doe.gov

Joe Stanford
202-586-6757
joseph.stanford@ee.doe.gov

Support:
Elvin Yuzugullu (SRA)

Kathleen O'Malley (SRA)

EERE Fellowship Program

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- Fuel Cell Technologies Program Opportunities Available
  - Conduct applied research at universities, national laboratories, and other research facilities
  - Up to five positions are available in the areas of hydrogen production, hydrogen delivery, hydrogen storage, and fuel cells
    - ❑ Applications are due June 30, 2011
    - ❑ Winners will be announced mid-August
    - ❑ Fellowships will begin in mid-November 2011

www.eere.energy.gov/education/postdoctoral_fellowships/

Postdoctoral fellowships in hydrogen and fuel cell research ▸

Backup Slides

Programmatic Analysis: Hydrogen Threshold Cost

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High volume projected costs for hydrogen production technologies continue to decrease. Low volume/early market costs are still high. Hydrogen cost range reassessed – includes gasoline cost volatility and range of vehicle assumptions.

Assess Status of Projected High-Volume Cost of Hydrogen (Dispensed)

NEAR TERM:

Distributed Production

- Natural Gas Reforming
- Ethanol Reforming
- Electrolysis

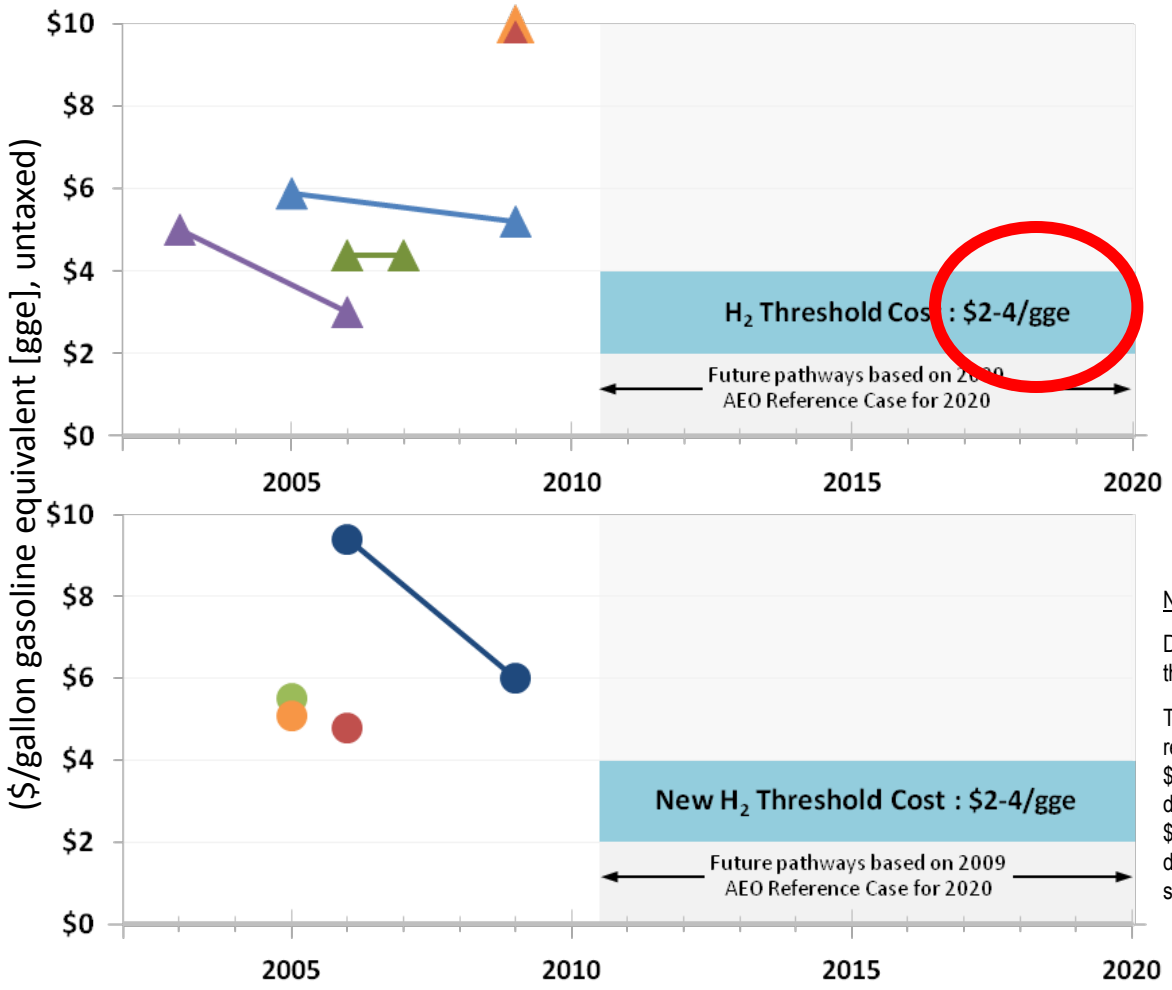
Low-volume (200 kg/day)

- Steam Methane Reforming
- H_2 from Combined Heat, Hydrogen, and Power Fuel Cell

LONGER TERM:

Centralized Production

- Biomass Gasification
- Central Wind Electrolysis
- Coal Gasification with Sequestration
- Nuclear



Notes:

Data points are being updated to the 2009 AEO reference case.

The 2010 Technology Validation results show a cost range of $8-$10/gge for a 1,500 kg/day distributed natural gas and $10-$13/gge for a 1,500 kg/day distributed electrolysis hydrogen station.

Source: US DOE 09/2010

Note: Hydrogen cost being updated from $2-$3/gge.

Early Markets: Infrastructure Analysis

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Infrastructure Modeling

Application Tool

- NREL SERA Model

Results

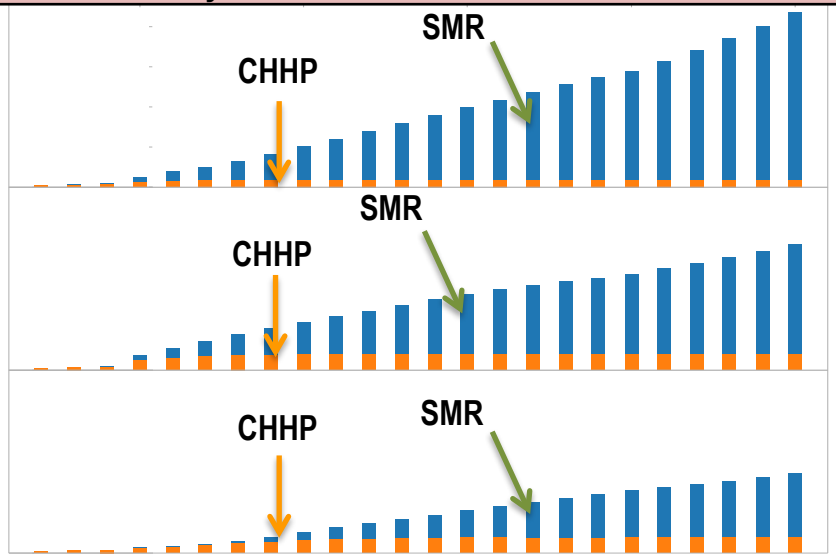
- In early market and transition phase for small to moderate supply requirements, several pathways dominate in terms of cost
  - Integrated hydrogen production from Combined Heat, Hydrogen and Power (CHHP) stationary fuel cells
  - Distributed natural gas steam methane (SMR) reforming
  - LH2 truck for moderate distance and moderate quantity
  - Gaseous H2 (GH2) pipeline for moderate distance and large quantity
  - GH2 truck for short distance or small quantity
- For larger stations in later years, SMR tends to have cost advantages over CHHP.
- In longer term, central production with pipeline delivery dominates the hydrogen supply

Plans:

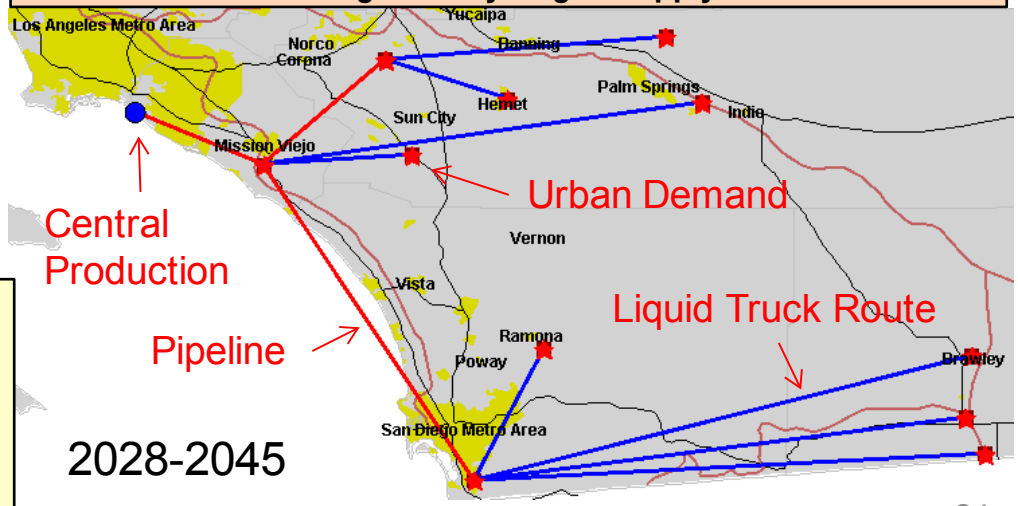
Develop a detailed "Scenarios Analysis" to examine the integration of early market and installed stations with evolving hydrogen demand.

Develop infrastructure requirements based on information obtained from workshops and utilize models to develop infrastructure requirements.

Early Market and Transitional Period 2015 -2035



Long Term Hydrogen Supply



Programmatic Analysis: Well-to-Wheels Analysis Updates

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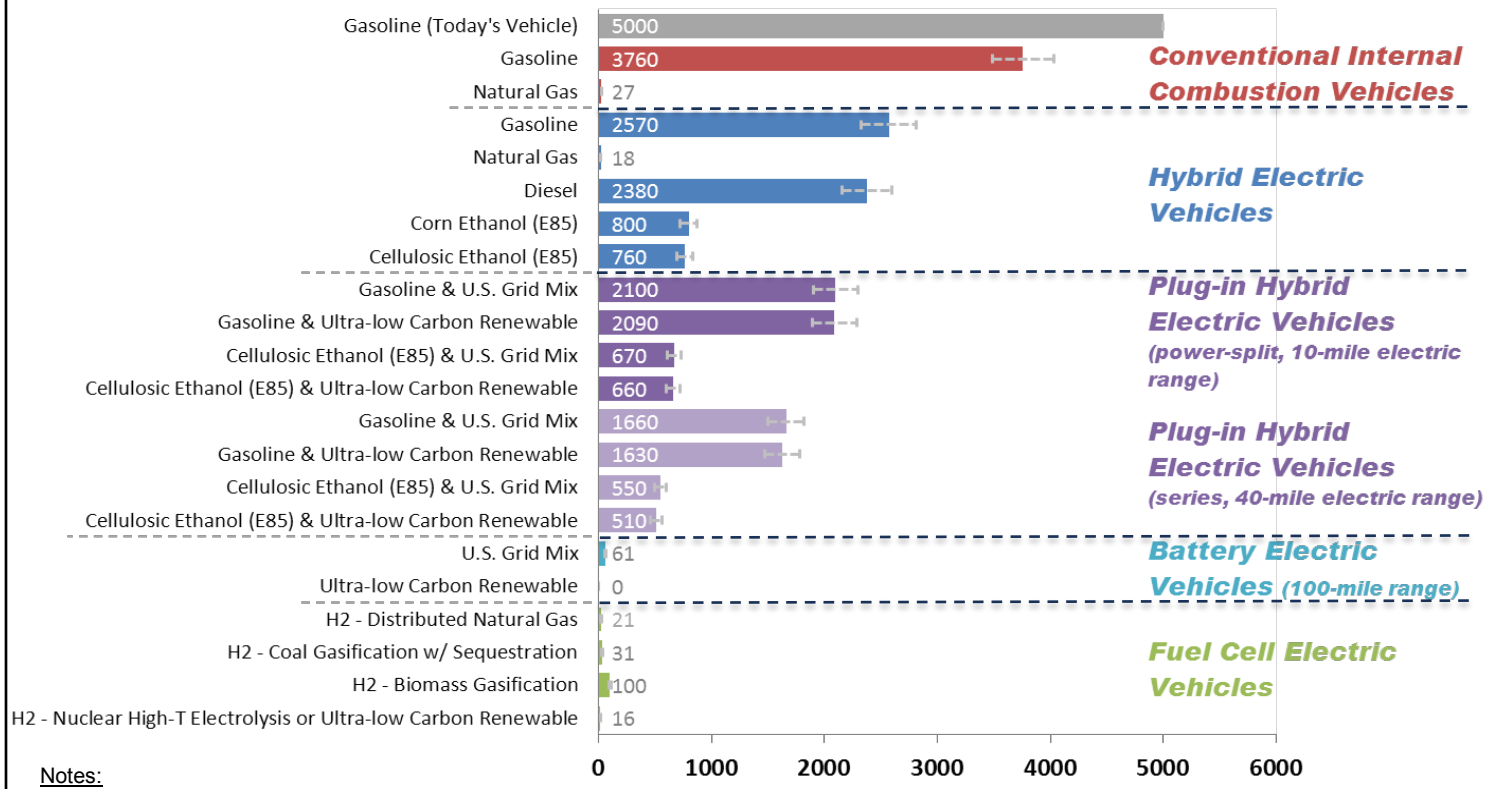
DOE is pursuing a portfolio of technologies with the potential to significantly reduce the consumption of petroleum by light-duty vehicles.

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



Notes:
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**
- **Illustrates need for portfolio approach to reduce petroleum use from conventional vehicle fleet**

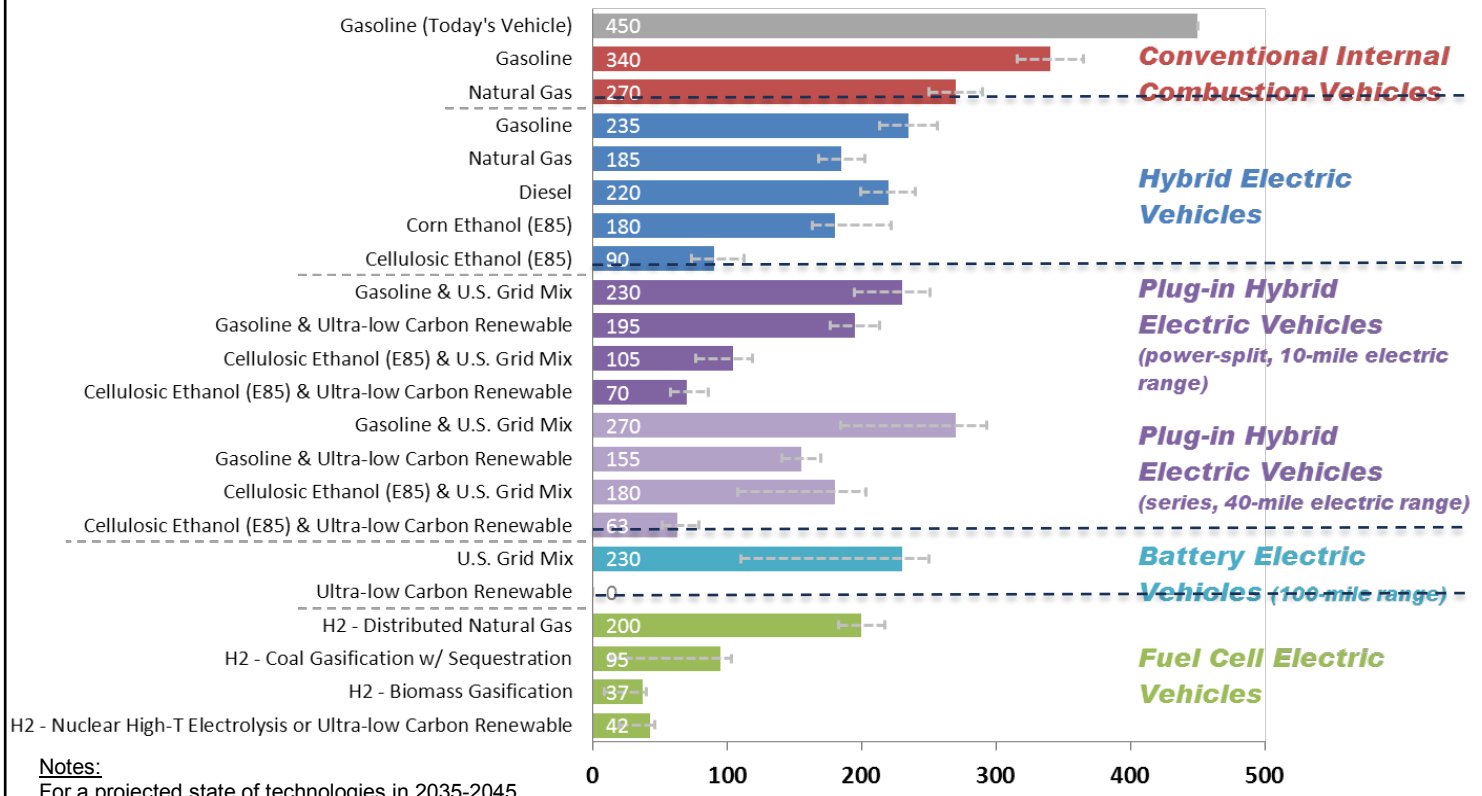
Analysis & Assumptions at: ***http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf***

Programmatic Analysis: Well-to-Wheels Analysis Updates

U.S. DEPARTMENT OF ENERGY

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 CO_2-equivalent per mile*)



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- **Illustrates need for portfolio approach to reduce greenhouse gas emissions from conventional vehicle fleet**

Analysis & Assumptions at: ***http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf***

Key Stakeholders

U.S. DEPARTMENT OF ENERGY

- **Systems Analysis**
  - ANL
  - LANL
  - LLNL
  - NREL
  - ORNL
  - PNNL
  - RCF Economic & Financial Consulting, Inc.
  - SNL
  - UC - Davis