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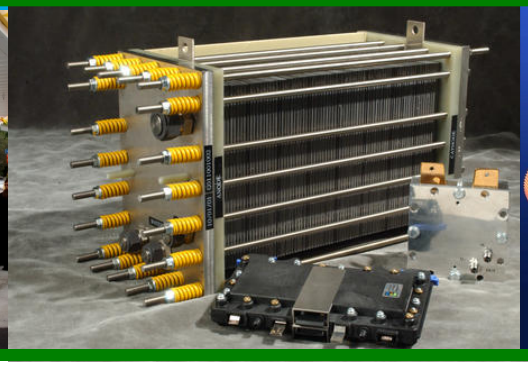
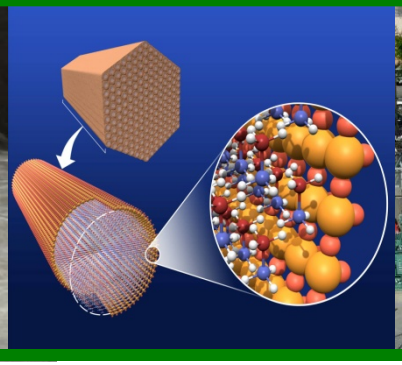

Systems Analysis

Fred Joseck

2013 Annual Merit Review and Peer Evaluation Meeting

May 13, 2013

Goal & Objective

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***GOAL:** Support infrastructure development and technology readiness through system-level analysis—including 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 benefits of hydrogen and fuel cells (on a life-cycle basis) 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
- Assess the socio-economic benefits of the Program (e.g., job creation)

Challenges

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Challenges include market complexities and the limited availability, accuracy, and consistency of data

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

Data availability, accuracy, and consistency

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

Coordination of Analytical Capability

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

Systems Analysis Overview: Technical Approach

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Partnerships with labs, industry, academia

System Analysis Framework

- Provide consistent and transparent data for analytical efforts
- Determine and prioritize analysis tasks
- Organize data and results for decision making
- Conduct analytical workshops to gather key input assumptions for analysis

Models and Tools

- Validate models with data
- Assess the Life Cycle Analysis benefits of hydrogen and fuel cells for diverse applications
- Maintain portfolio of models to perform program analysis

Studies and Analysis

- Perform planned studies and analysis
- Understand the initial phases of fuel cell and hydrogen technologies early market penetration
- Understand long-term potential and issues
- Environmental analysis
- Energy storage analysis
- Resource supply for hydrogen production

Deliverables/ Results

- Support Program decision-making processes and milestones
- Provide direction, planning and resources
- Provide independent analysis to validate decisions
- Provide risk analysis of sub-program targets

Internal and External Peer Review

Analysis Portfolio

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A variety of methodologies are used in combination to provide a sound understanding of hydrogen and fuel cell systems and developing markets—and to quantify the benefits, impacts, and risks of different hydrogen and fuel cell systems

MARKETS/BENEFITS & POLICY ANALYSIS

- Energy Market Analysis

TECHNOLOGY ANALYSIS

- Technical Feasibility & Cost Analysis
- Environmental Analysis

IMPLEMENTATION & IMPACT ANALYSIS

- Resource Analysis
- Delivery Analysis
- Infrastructure Development & Financial Analysis

Systems Analysis on the Web: www.hydrogen.energy.gov/systems_analysis.html

Model Hierarchy

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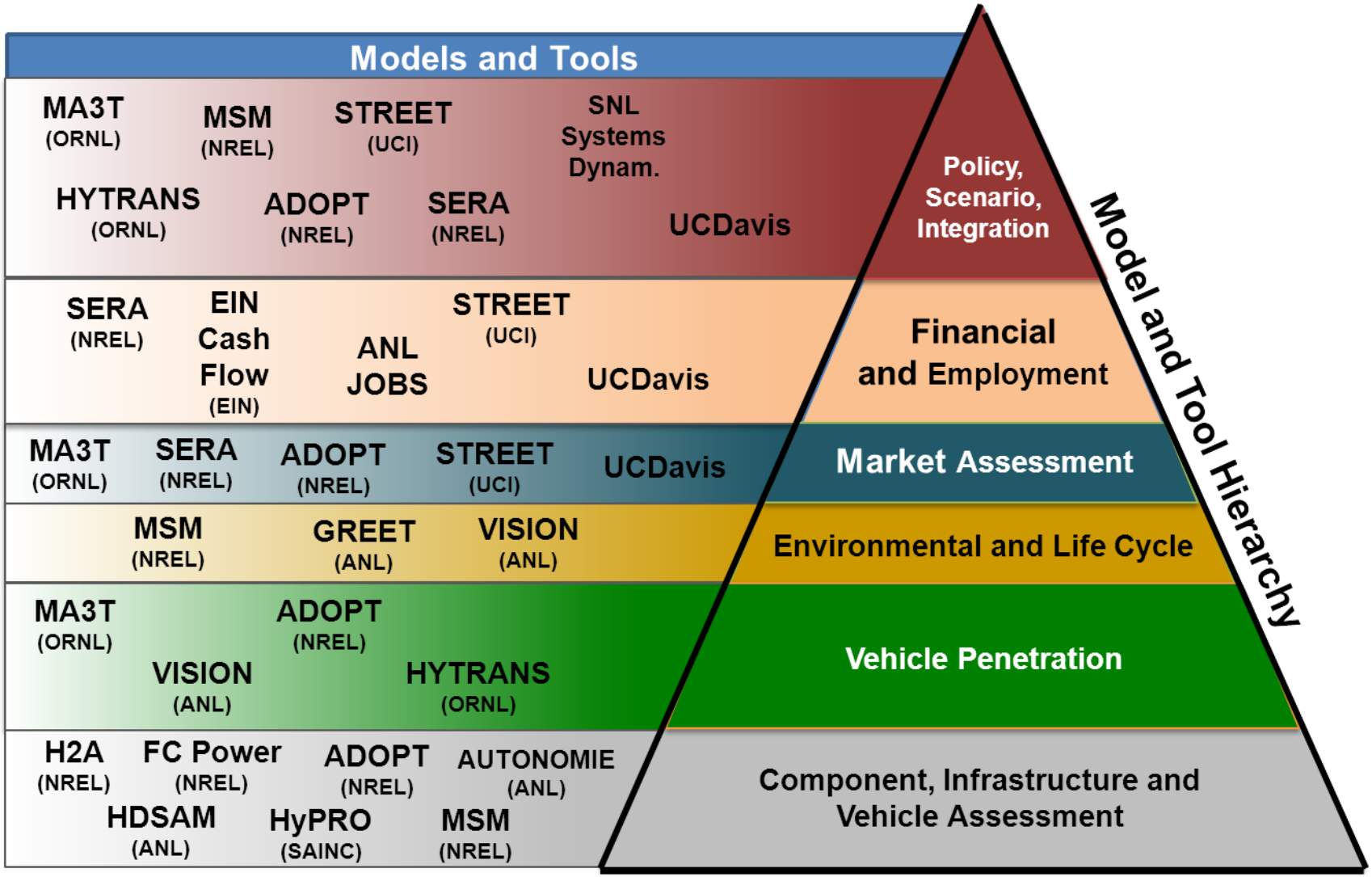
DOE's Fuel Cell Technologies Office model and tool portfolio is comprehensive and multi-functional



Systems Analysis Budget

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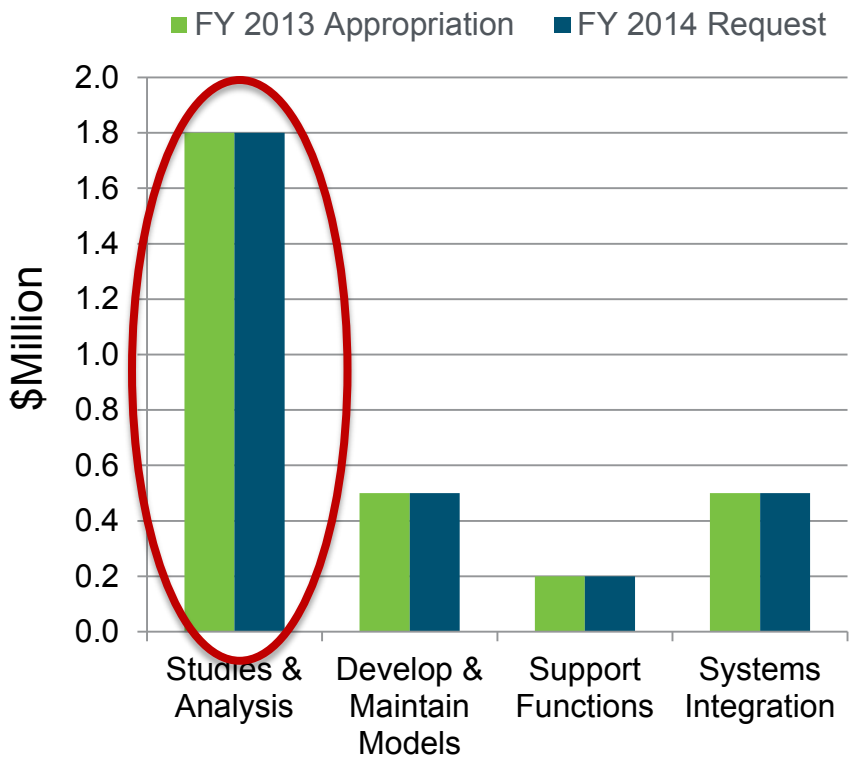
Focus: Determine technology gaps, economic/jobs potential, and benefits of key technology advances; and quantify 2013 technology advancement

FY 2013 Appropriation = $3.0 M

FY 2014 Request = $3.0 M



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Update and refine models for program analysis using cost, performance and environmental (emissions, etc.) information.
- Continue life-cycle analyses of cost, greenhouse gas emissions, petroleum use and criteria emissions, and impacts on water use.
- Assess gaps and drivers for early market infrastructure cost for transportation and power generation applications
- Assess programmatic impacts on market penetration, job creation, return on investment, and opportunities for fuel cell applications in the near term.

Infrastructure Analysis: Single Station Cash Flow Analysis

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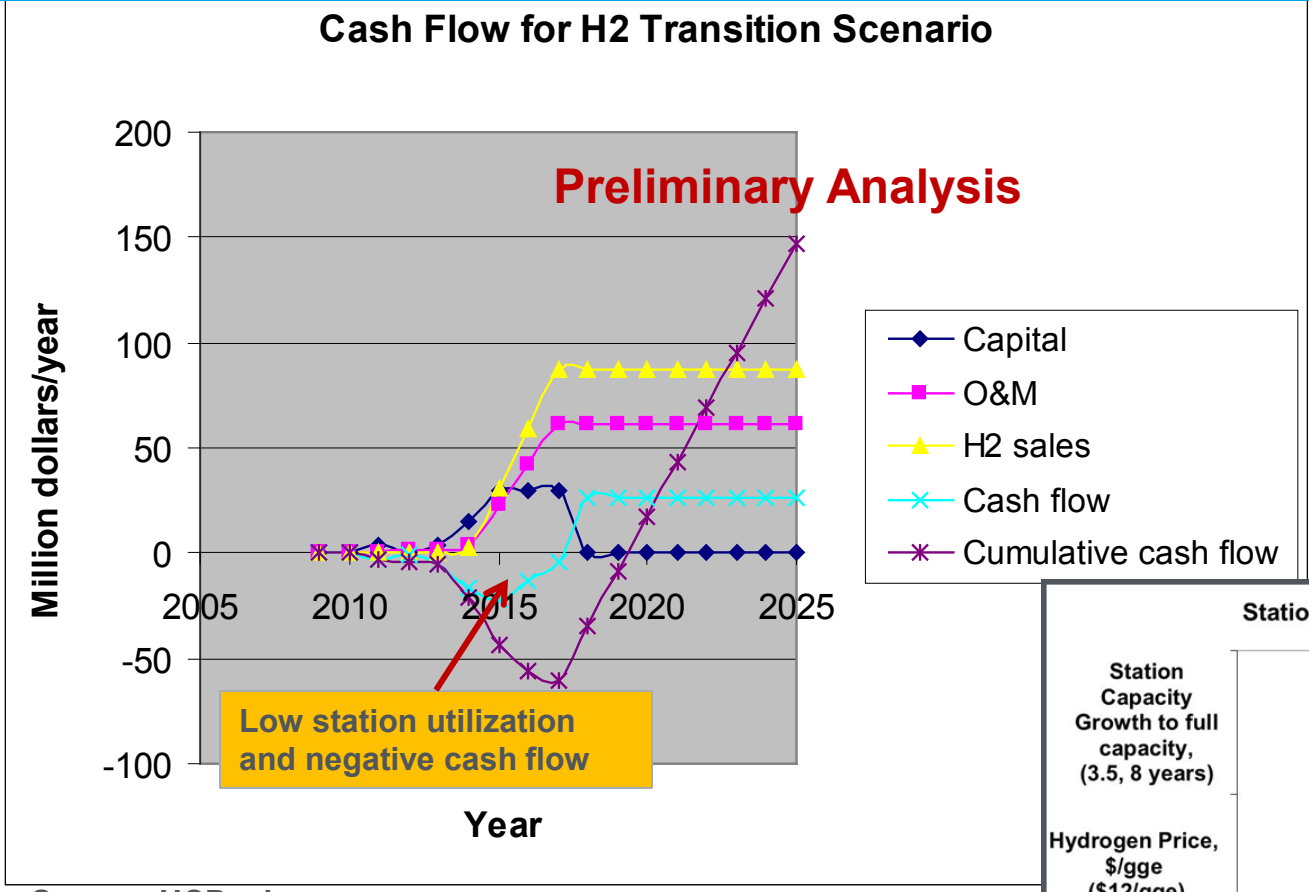
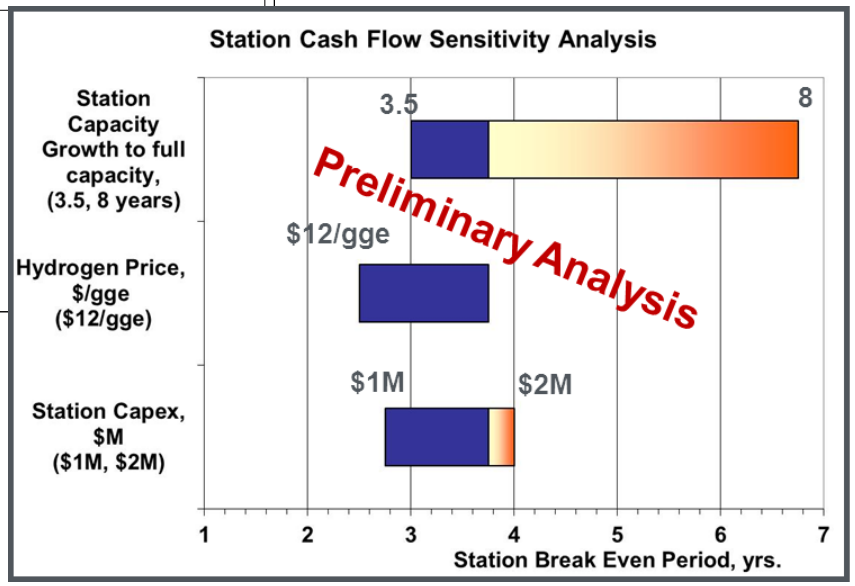
Hydrogen Fueling Station positive cash flow is sensitive to station utilization



Source: UCDavis

Single 500 kg/d Hydrogen Station with Compressed Hydrogen delivery from Central production facility



Assumptions:

- Delivered H_2 @ $6/gge
- H_2 selling price $10/gge
- H_2 station cost $1.5 million
- Full station utilization in 4 yrs.
- Loan 5.5% for 10 yrs.
- 700 bar dispensing
- O&M: $100,000

Programmatic Analysis: Water Life-Cycle Analysis

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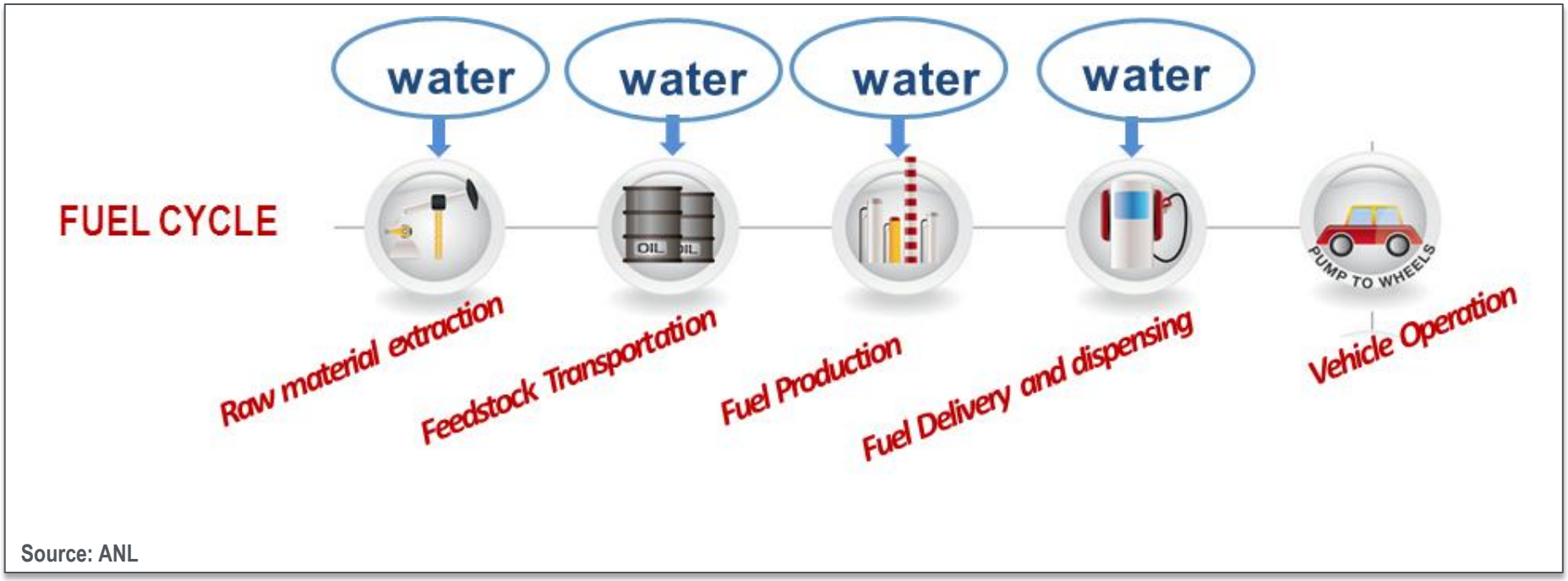
On a life-cycle basis, analysis capabilities will be added to GREET to assess water consumption for hydrogen production pathways

GREET = the Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model



Source: ANL

- **GREET LCA analysis capabilities are being expanded to include fuel cycle water consumption for hydrogen and other fuels.**
- **Model will be able to assess water consumed on a "per gge" and "per mile" basis.**

Technology Analysis: Total Cost of Ownership for Future Light-Duty Vehicles

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Multiple alternative-fuel vehicles are cost competitive on a life-cycle basis—supporting a portfolio approach for advanced vehicle evolution

- **Analysis project in collaboration with the Vehicle Technologies Office**
- **Vehicle life cycle costs updated based on stakeholder input received from 2011 RFI**

Common Assumptions

- 15-year ownership
- 10,000 miles per year
- 7% discount for annual fuel costs
- 0 resale value at the end of 15 years

Vehicle Types

2012 Spark ignition (SI): Current gasoline car
Adv SI ICEV: 2035 gasoline car
Adv Compression ignition (CI): 2035 diesel car
Adv NG SI ICEV: 2035 natural gas car
Gasol HEV: 2035 hybrid electric car
SI PHEV10: 2035 gasol PHEV10
SI EREV40: 2035 gasol EREV40
FCEV: 2035 fuel cell hybrid electric car
BEV100, BEV300: 2035 battery electric cars

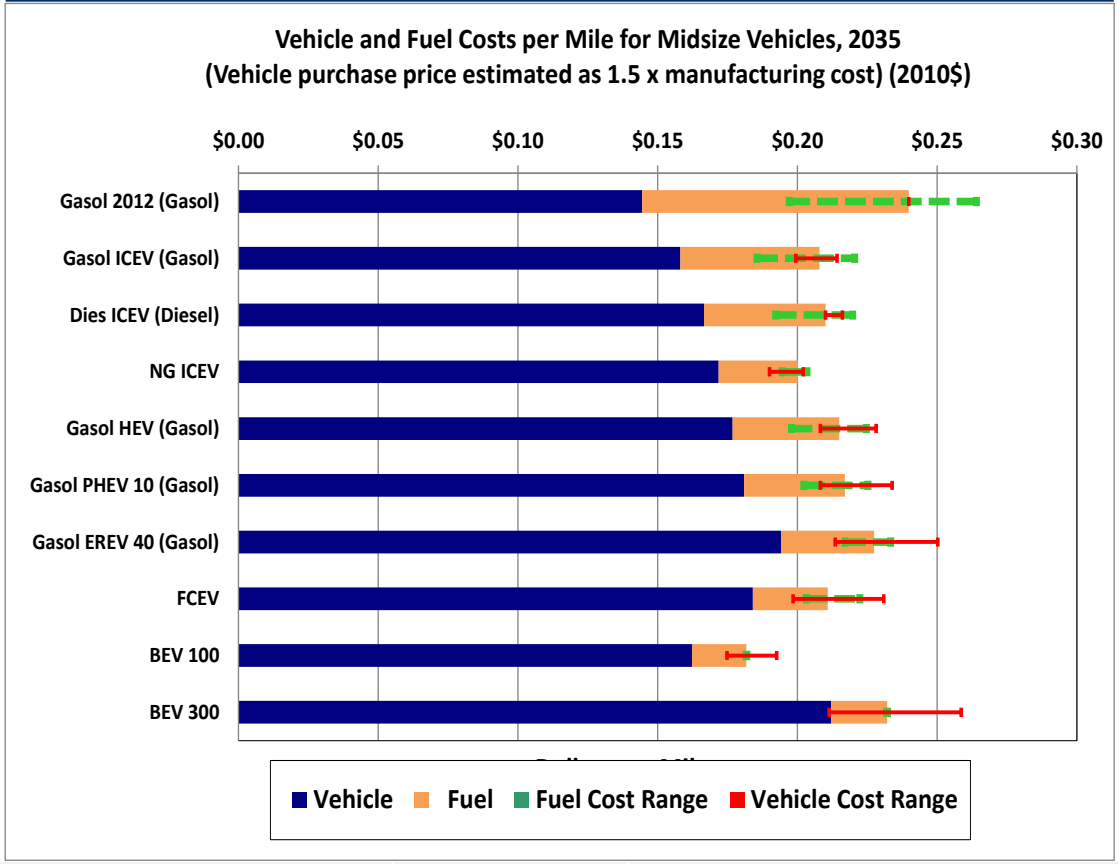
Error Bars

Green: range of assumptions for fuel prices (EIA projections for fuels other than hydrogen; hydrogen range: $2.50 - $5.00 per kg)

Red: range of assumptions for technology success.

See record:
http://hydrogen.energy.gov/pdfs/13006_ldv_life_cycle_costs.pdf

Costs Based on 15-Year Life (Societal Perspective)



	FCEV	BEVs
Battery Cost, $/kWh		$75, $81, $84
Battery Cost, $/kW	$20, $25, $28	
Fuel Cell Cost, $/kW	$32, $35, $38	
Fuel Cost in $/gge (¢/kWh)	$2.50, $3.50, $5.00	$3.94 (11.7¢), $3.98 (11.8¢), $4.01 (11.9¢)

Technology Analysis: Well-to-Wheel GHG Emissions

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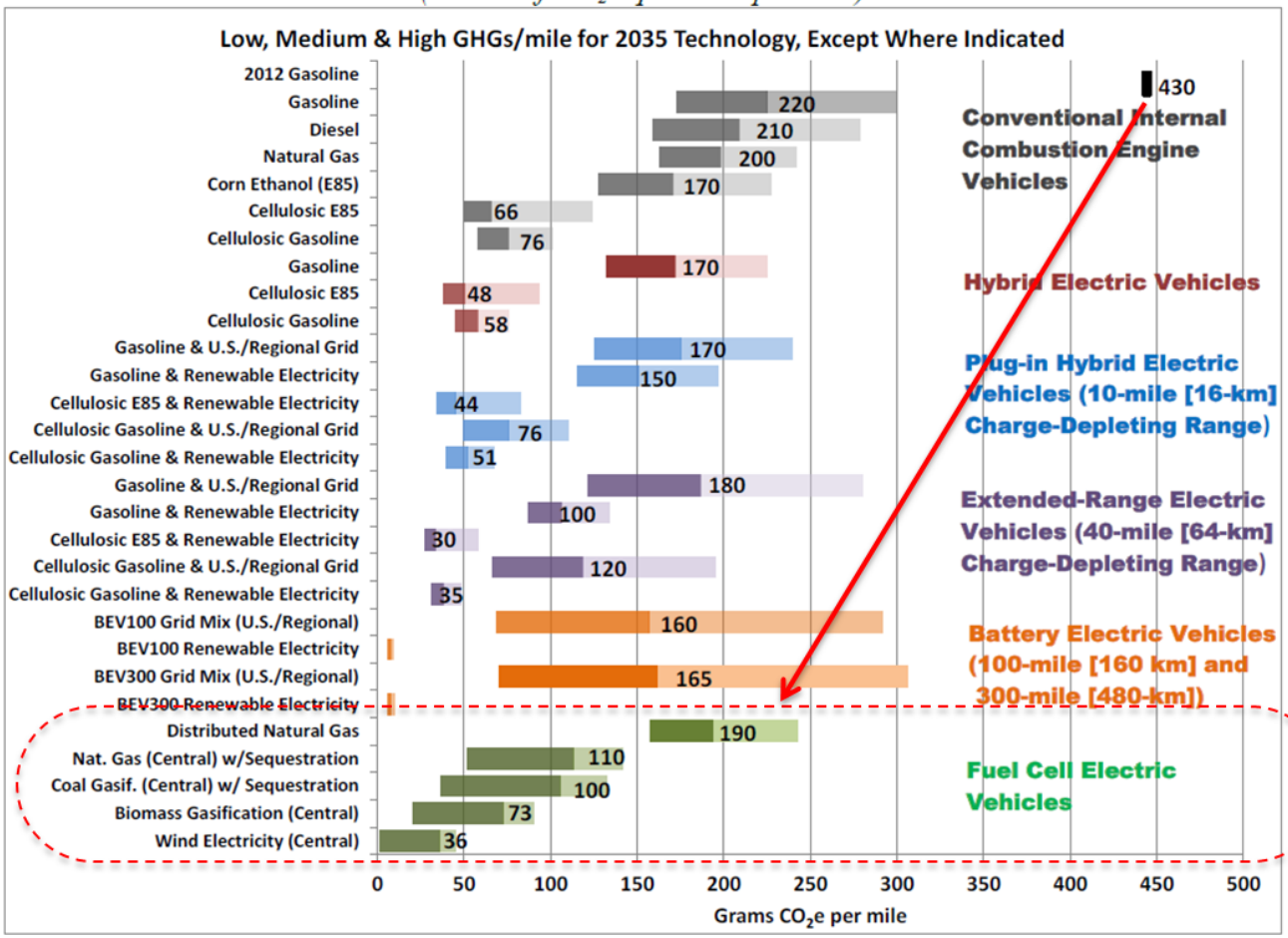
Analysis by Argonne National Lab, National Renew. Energy Lab, DOE Vehicle Technologies Office, DOE Bioenergy Technologies Office and DOE Fuel Cell Technologies Office shows benefits from a portfolio of options

- **Analysis project in collaboration with the Vehicle Technologies Office and Bioenergy Technologies Office**
- ***Updated analysis is posted as an Office analytic record.***

[See record: http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf](http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf)

Figure 1. Well-to-Wheels Greenhouse Gases Emissions for 2035 Mid-Size Car

(Grams of CO_2-equivalent per mile)



Low/medium/high: sensitivity to uncertainties associated with projected fuel economy of vehicles and selected attributes of fuels pathways, e.g., electricity credit for biofuels, electric generation mix, etc.

Technology Analysis: Well-to-Wheel Petroleum Life Cycle Analysis for Light Duty Vehicles

U.S. DEPARTMENT OF ENERGY

Analysis by Argonne National Lab, National Renew. Energy Lab, DOE Vehicle Technologies Office, DOE Bioenergy Technologies Office and DOE Fuel Cell Technologies Office shows benefits from a portfolio of options

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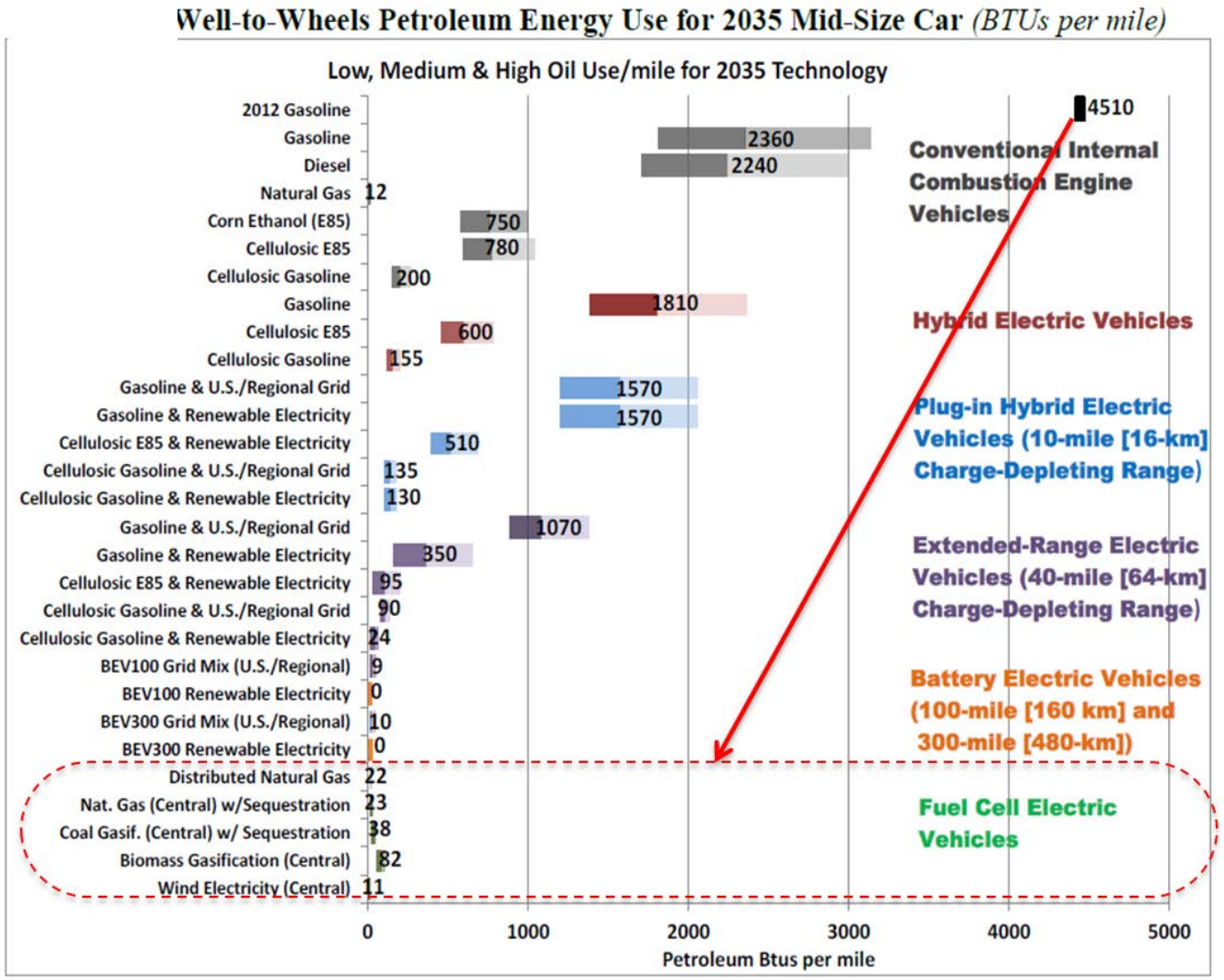

Technology Analysis: Life Cycle Analysis of On-Board Storage Options

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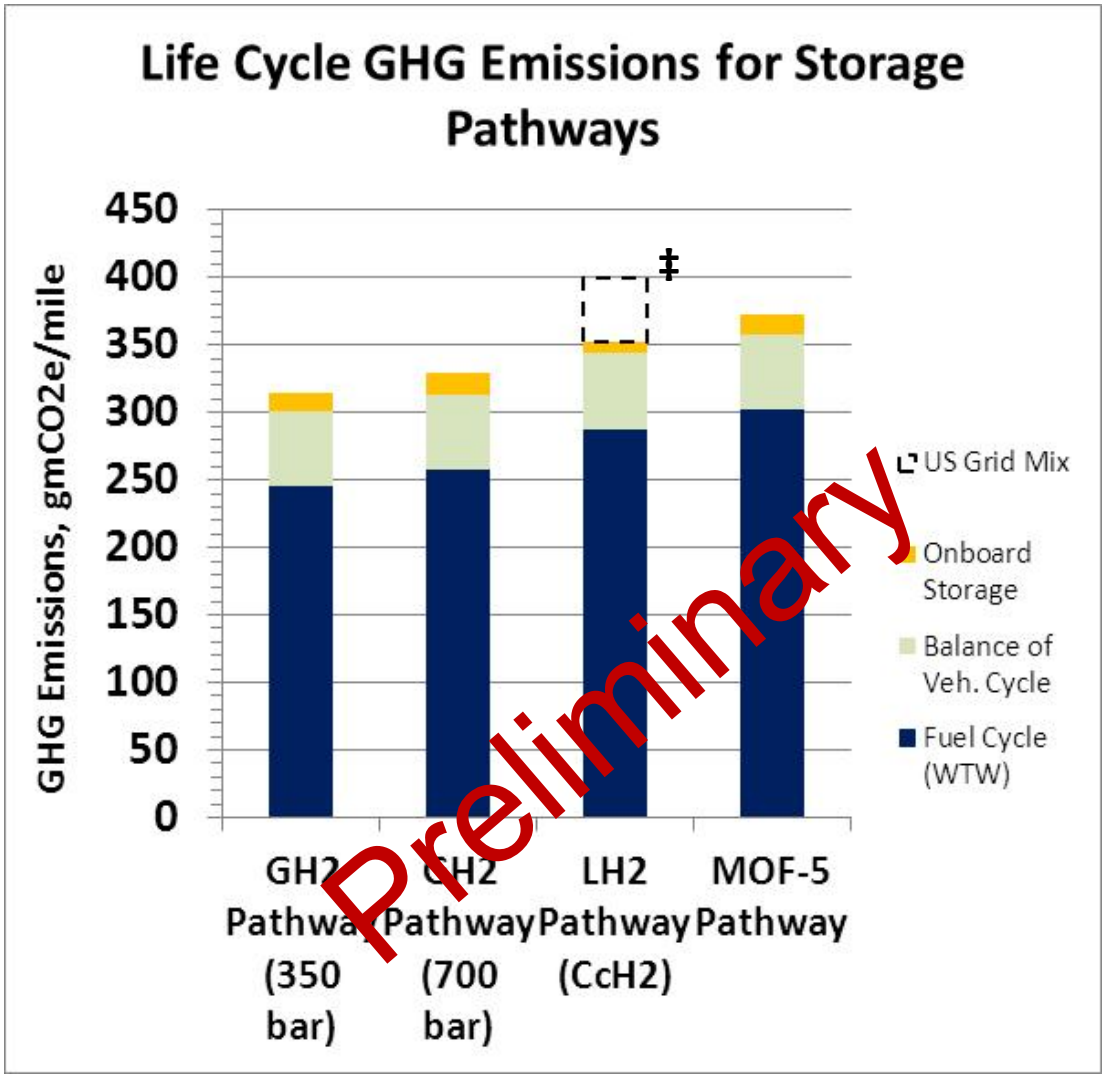
Onboard storage represents 3-5% of total LCA GHG emissions of compressed GH2, LH2 and MOF-5 pathways



* Assumed 60 mi/kg H_2 fuel economy for FCEVs, and 160,000 lifetime VMT

‡ Assumed electricity from US grid mix for H_2 liquefaction

Hydrogen for the pathways assumed to be produced from central steam methane reforming of natural gas.

Source: ANL

Programmatic Analysis: Commercialization

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Continued annual growth of ~10% in the number of commercial products resulting from DOE Fuel Cell Technologies Program funding

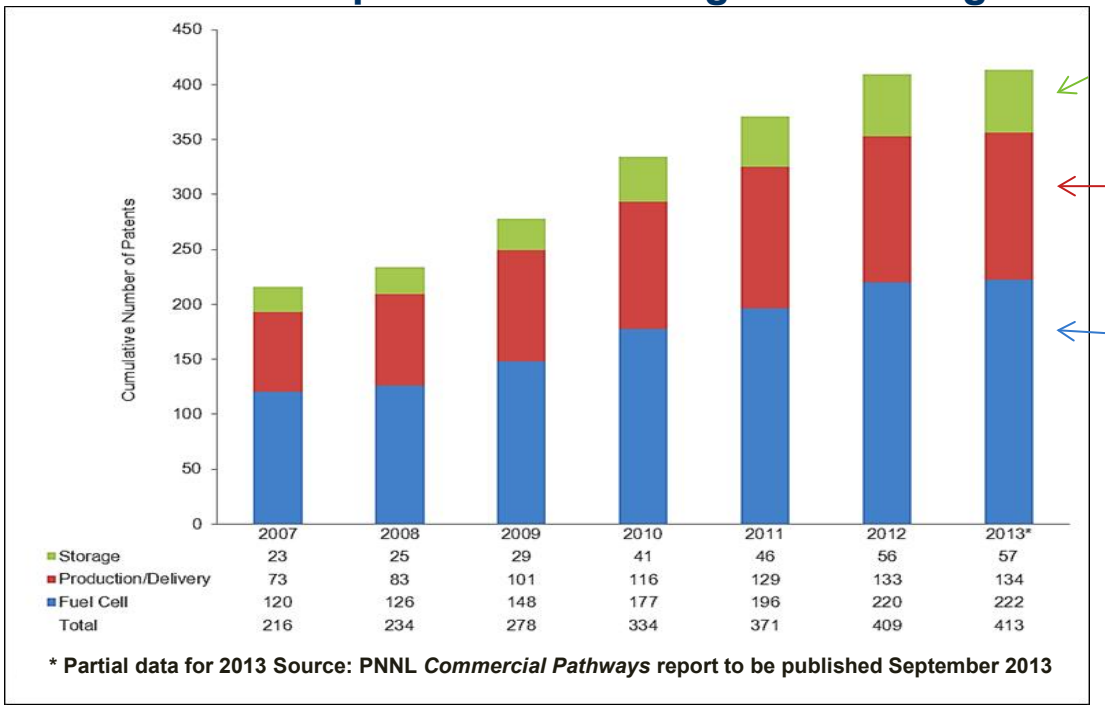
Accelerating Technology Innovation and Application

39 commercial products have resulted from EERE-funded Fuel Cell Technologies R&D

Patents

EERE-funded Fuel Cell Technologies resulted in >410 patents.

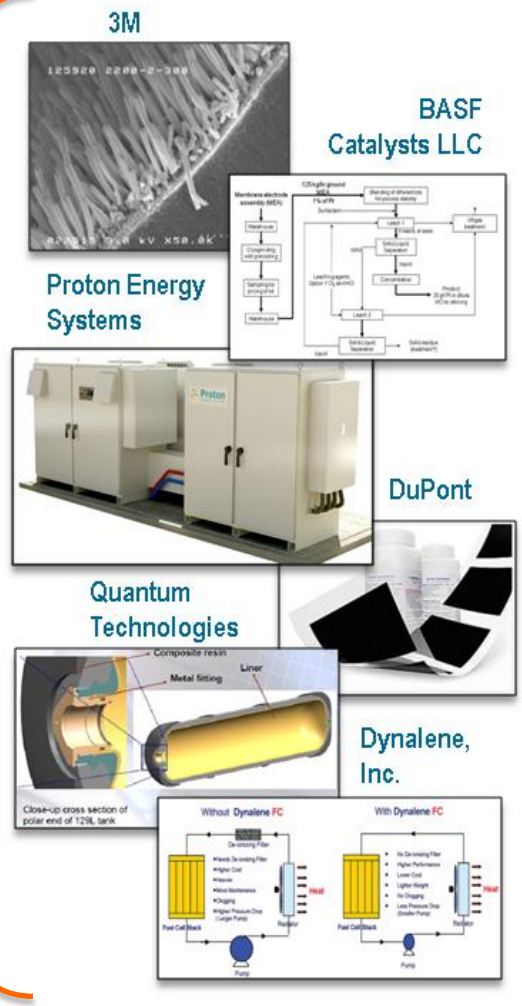
Cumulative Number of Commercial Technologies Developed with FCT-Program Funding



	2007	2008	2009	2010	2011	2012	2013*
Storage	23	25	29	41	46	56	57
Production/Delivery	73	83	101	116	129	133	134
Fuel Cell	120	126	148	177	196	220	222
Total	216	234	278	334	371	409	413

*** Partial data for 2013 Source: PNNL *Commercial Pathways* report to be published September 2013**

- Examples -



Resource Analysis

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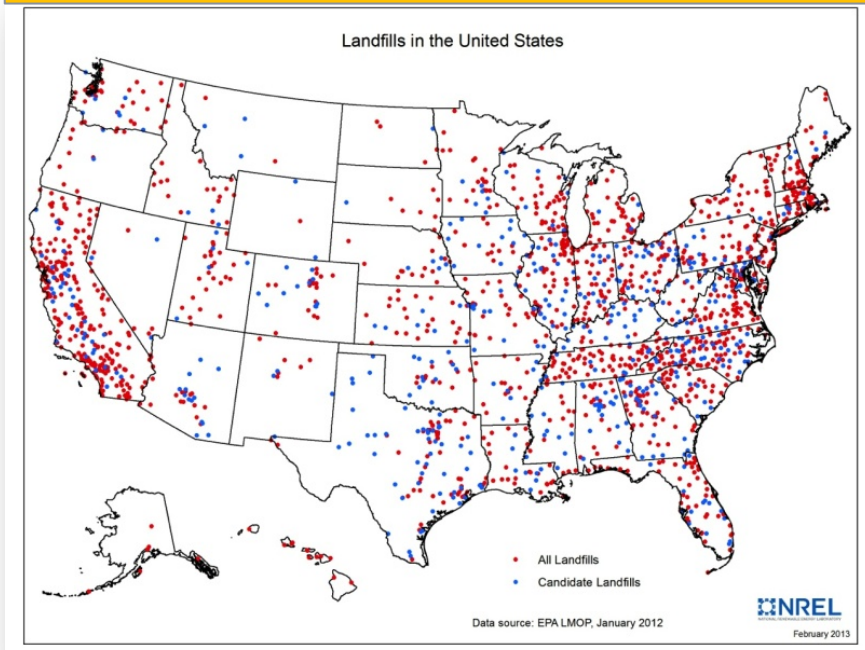
The U.S. has an abundance of regionally distributed domestic resources to produce renewable hydrogen

- **Renewable hydrogen can be produced from a variety of domestic resources including solar, wind, biomass and biogas.**
- **Abundance of resources for hydrogen production quantified below:**

Solar > Wind > Biomass and Biogas (Source: NREL)

- **Renewable resources are regionally concentrated which limit the distribution of the resultant hydrogen production to urban demand centers.**
- **Each resource faced with barriers such ecological, physical and environmental restrictions.**

Landfill Gas Resource



Net CH_4 Potential	1,600 thousand tonnes
Net H_2 Potential	493 thousand tonnes
FCEV Supported	2.8 million vehicles

Data Source: EPA's Landfill Methane Outreach Program [2]

Gross Availability: 10,500 thousand tonnes, ~2,000 records with waste data

Net Availability: 445 candidate* sites identified by EPA

Methane range: 40%-60% methane by volume of biogas

* Candidate sites must meet certain waste requirements and have no operational or under construction energy project

Programmatic Analysis: Socio-Economic Benefits of FCTO ARRA Projects Impact on Employment

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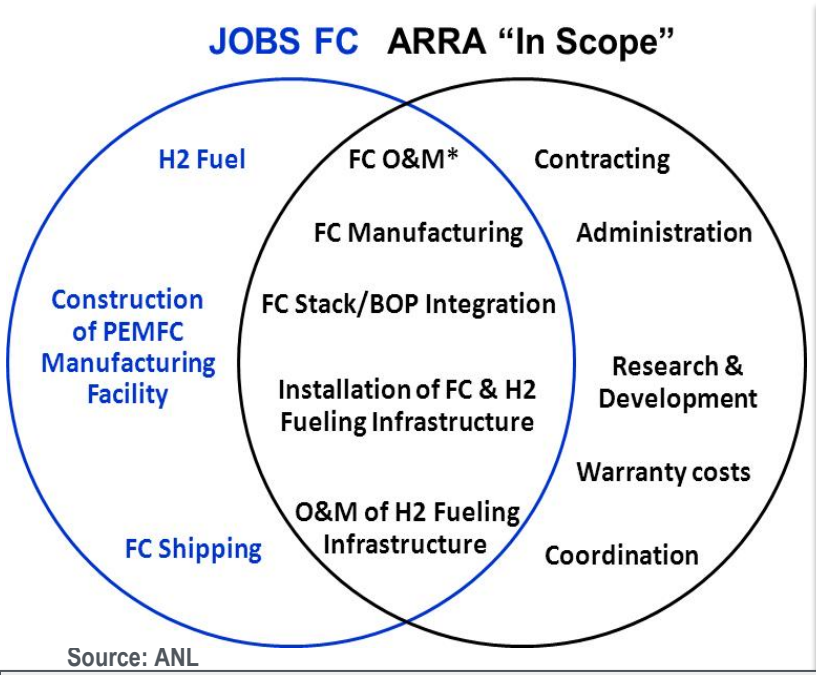
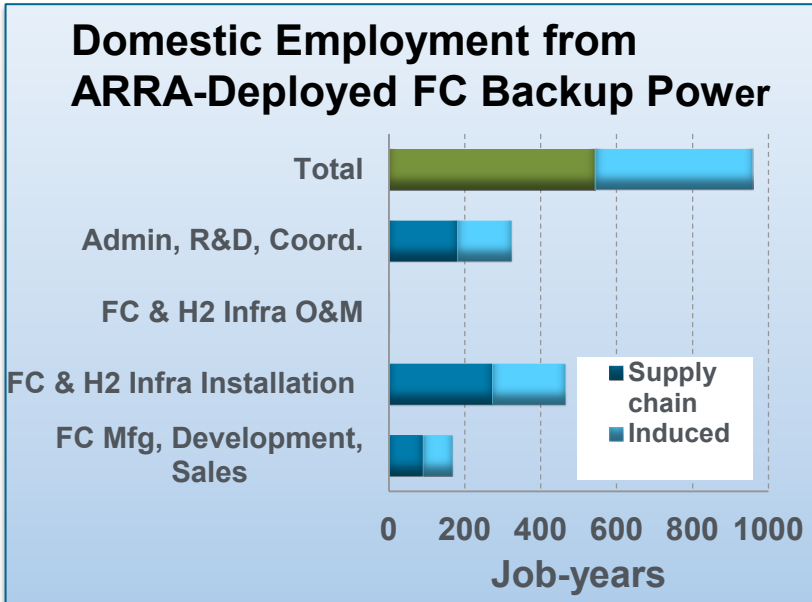
~1300 Domestic Job-years Created/Retained as a result of FCTO Funding for ARRA Projects for Fuel Cell Forklifts and Backup Power



Source: ANL



- ~950 total job-yrs created/ retained
- ~45% from FC & H2 infrastructure installation
- Induced employment = 44% of BUP employment
- BUP = 73% total ARRA-related FC employment

…another ~350 job-yrs. created by fuel cell forklifts

NEXT STEPS

- ANL-RCF is expanding the JOBS FC model to include module for analysis of infrastructure development employment impacts.
- Beta test of infrastructure planned for end of 2013.
- Jobs model module will enable analysis of gross and net jobs, and revenues generated from hydrogen infrastructure installation and investment. See ANL JOBS FC website: http://JOBSFC.es.anl.gov

Summary

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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 societal benefits.
- Plans continue to enhance existing models and expand analyses.

FY 2013	FY 2014	FY 2015	FY 2016-2020
Complete analysis of job growth for MHE	Complete analysis of resources/ feedstock, production/ delivery and existing infrastructure for technology readiness	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 biogas resources for H_2 production and stationary power generation	Complete analysis of job growth for distributed power generation		Complete analysis of H_2 quality impact on H_2 production cost and FC cost for long-range technologies and technology readiness
Complete analysis for fuel cell CHP application with bio-fuels	Complete infrastructure analysis for H2USA		Complete environmental analysis of impacts for H_2 scenarios
Complete coordinated well-to-wheel and Total-Cost-of-Ownership (TCO) with Vehicles and Biomass Technologies Offices			

Systems Analysis Collaborations

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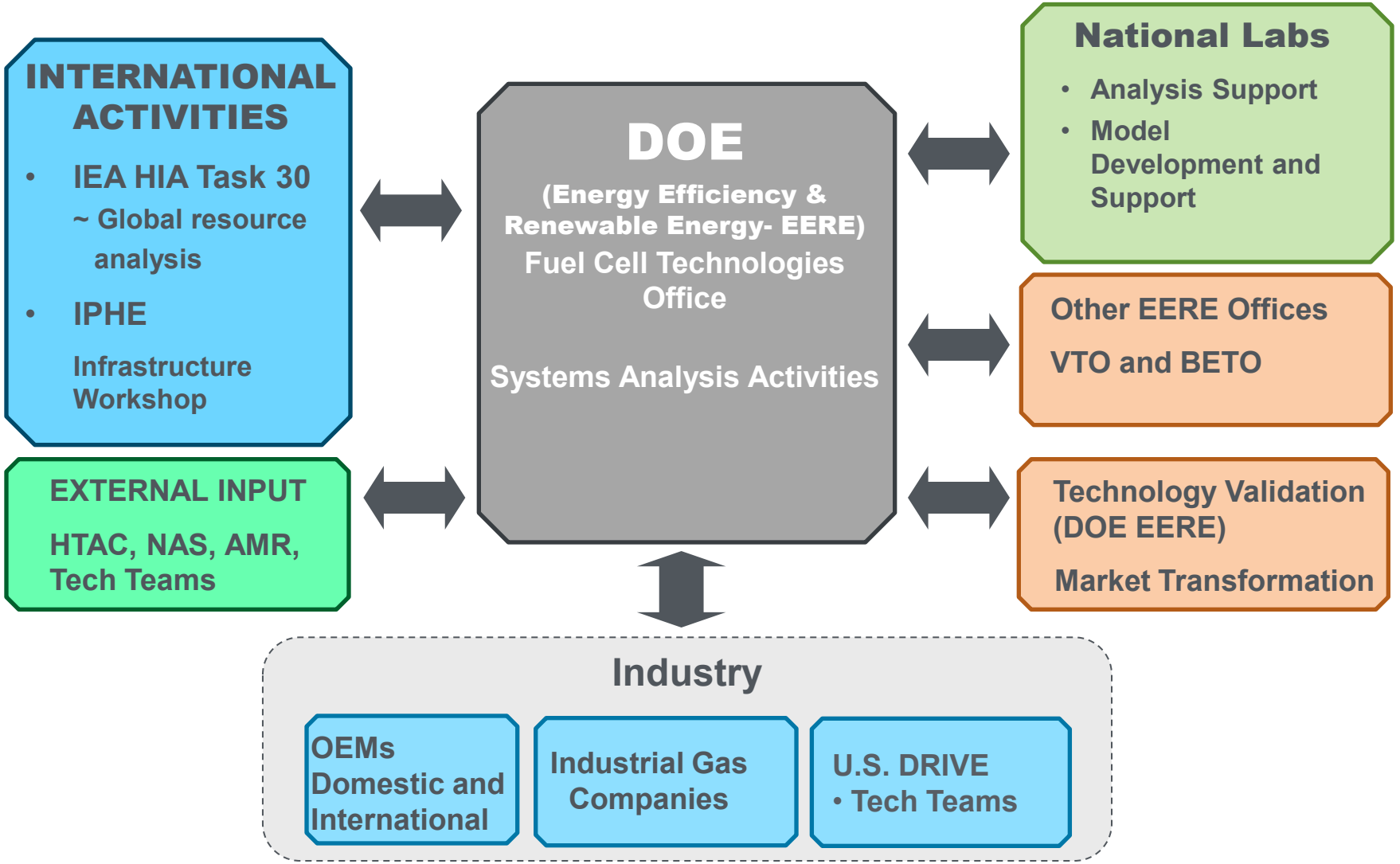
Analysis and peer review input coordinated among national and international organizations



Summary

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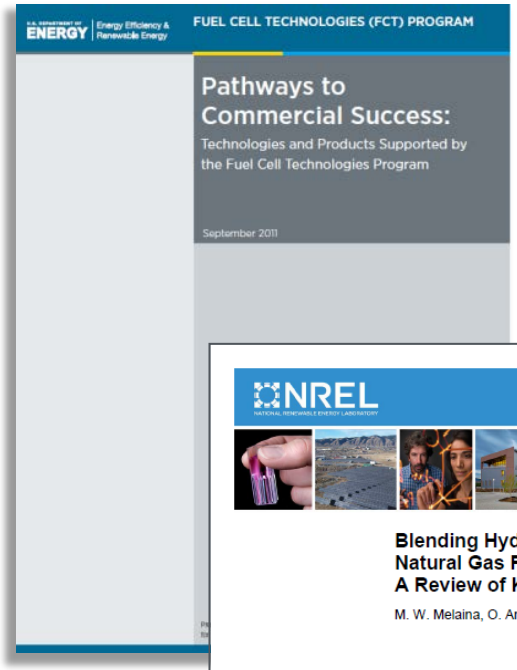
Systems Analysis is an integral component of EERE and the Fuel Cell Technologies Program.

The Systems Analysis sub-program will

- Identify the synergies of hydrogen and fuel cells with other fuels and technologies to minimize barriers to market entry
- Confirm the technology advances needed to reduce infrastructure cost and show the similarity among costs for hydrogen fueling infrastructure and conventional or other alternative fueling infrastructure
- Assess impact of domestic and international growth in hydrogen demand on renewable resource availability and cost
- Assess water consumption of hydrogen production from natural gas and renewable resources
- Show the socio-economic benefits of various fuel cell applications

Key Model, Report and Record Releases



Publications

Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program
By PNNL, http://www.pnl.gov/
See report:
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2012.pdf

Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues
By NREL, http://www.NREL.gov
See report: http://www.nrel.gov/docs/fy13osti/51995.pdf

Cost Comparison of Wind Energy Delivered as Electricity or Hydrogen for Vehicles
By NREL (At SAE conference)

Records

(http://hydrogen.energy.gov/program_records.html)

13005-Well-to-Wheels Greenhouse Gas Emissions and Petroleum Use for Mid-Size Light-Duty Vehicles

13006-Life-cycle Costs of Mid-Size Light-Duty Vehicles

12024-Hydrogen Production Cost Using Low-Cost Natural Gas

Models

JOBS FC

By ANL and RCF

http://JOBSFC.es.anl.gov

For More Information

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