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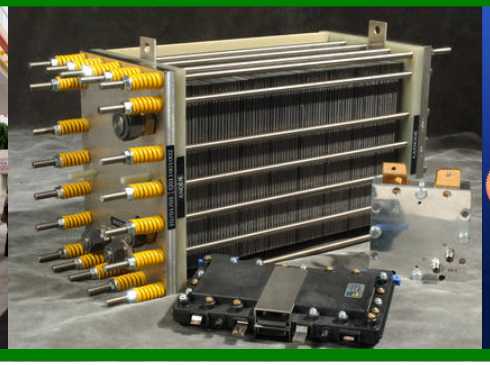
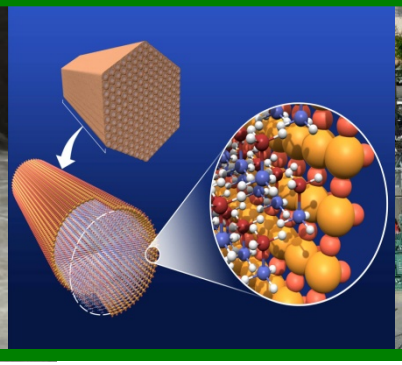

Systems Analysis

Fred Joseck

2012 Annual Merit Review and Peer Evaluation Meeting

May 14, 2012

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

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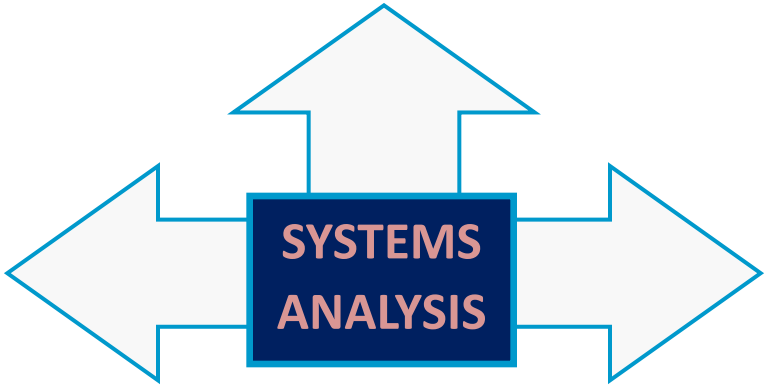
A variety of methodologies are used in combination to provide a sound understanding of hydrogen and fuel cell systems and developing markets—and to quantify the benefits, impacts, and risks of different hydrogen and fuel cell systems.

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

Systems Analysis Budget

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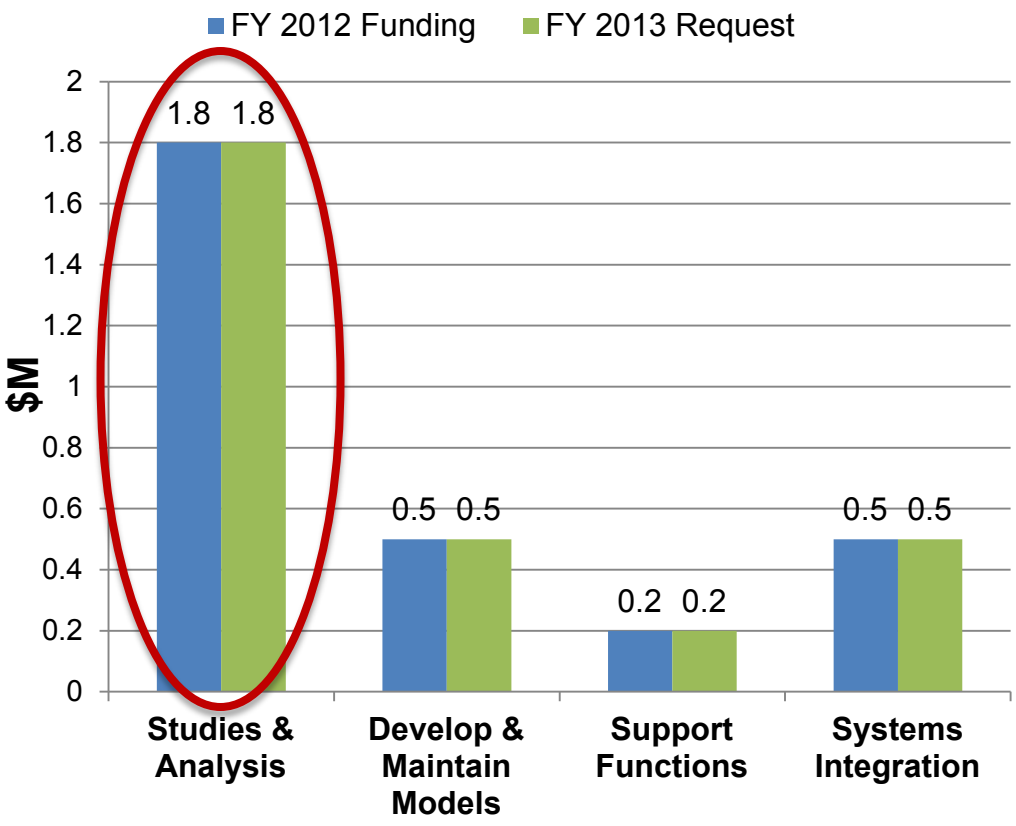
Determine technology gaps, environmental benefits, economic/jobs potential, and quantify technology advancement impacts

FY 2013 Request = $3.0 M

FY 2012 Appropriation = $3.0 M



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 application
- Assess business cases of biogas applications, infrastructure applications and integration in a domestic fueling network, and fuel cell combined heat and power (CHP) applications
- Assess synergies with other fuels and fueling systems
- Validate analysis with input from subject matter experts, industry and peer review process

Early Market Analysis: Integration of Natural Gas and Hydrogen

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Natural Gas workshop with multiple stakeholders provided valuable insight for potential synergies with hydrogen.

Natural Gas Workshop

Argonne NATIONAL LABORATORY

Objectives

- Identify Current status of natural gas and H_2 infrastructure
- Identify key challenges preventing or delaying widespread deployment of natural gas and hydrogen infrastructure
- Identify opportunities for addressing challenges and for government and industry stakeholders

Results *(preliminary)*

- ***NG and H_2 have similar storage and regulatory concerns.***
- ***Build clusters of refueling centers to support a critical mass of both types of vehicles.***
- ***Develop NG and H_2 infrastructure along major commercial corridors.***
- ***Develop consistent , long-term energy policies for NG and hydrogen fuel applications.***
- **Workshop summary report is available at: www.transportation.anl.gov/pdfs/AF/812.PDF**

Next Steps:

- Develop low-cost, conformable lower-pressure (sorbent-based) on-board storage for NG and H_2
- Harmonize codes and regulations for permitting NG and H_2 infrastructure
- Involve business and community leaders in developing NG and H_2 infrastructure
- Involve investment community in financing options

50 participants, including: natural gas and hydrogen producers; vehicle manufacturers; alternative vehicle agencies; fuel cell developers; national laboratories; academia; government agencies

Synergy Analysis: Natural Gas and Hydrogen

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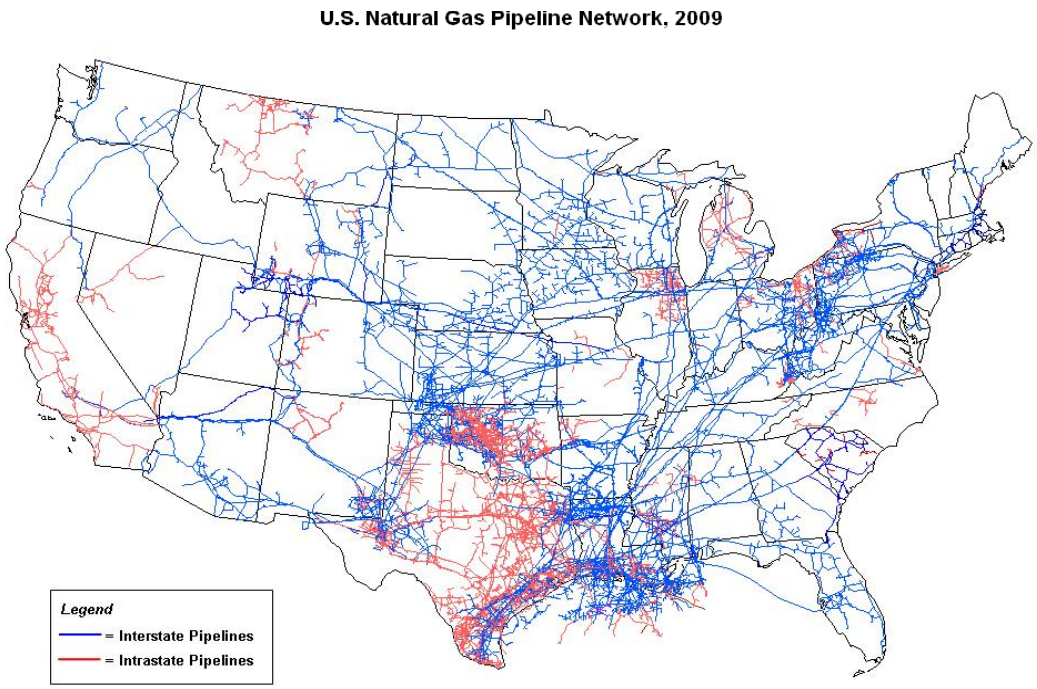
Natural gas infrastructure has the potential to provide storage and transport for injected hydrogen from remote generation sites to urban demand centers.

- **NREL completed analysis of utilizing the natural gas infrastructure to transport injected hydrogen to demand centers. A report will be issued.**
- **NG network comprises >210 pipeline systems and spans >300,000 miles of transmission pipelines.**
- **Study determined hydrogen could be safely injected in concentrations of up to 20%.**
- **Adding renewable H_2 to NG improves air quality by reducing SOx, NOx, and particulate emissions.**
- **Injected H_2 could be extracted from the NG systems at a cost of $0.3-1.3/kg of H_2.**

U.S. Natural Gas Pipeline Network, 2009



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Early Market Analysis: Station Cost Reduction

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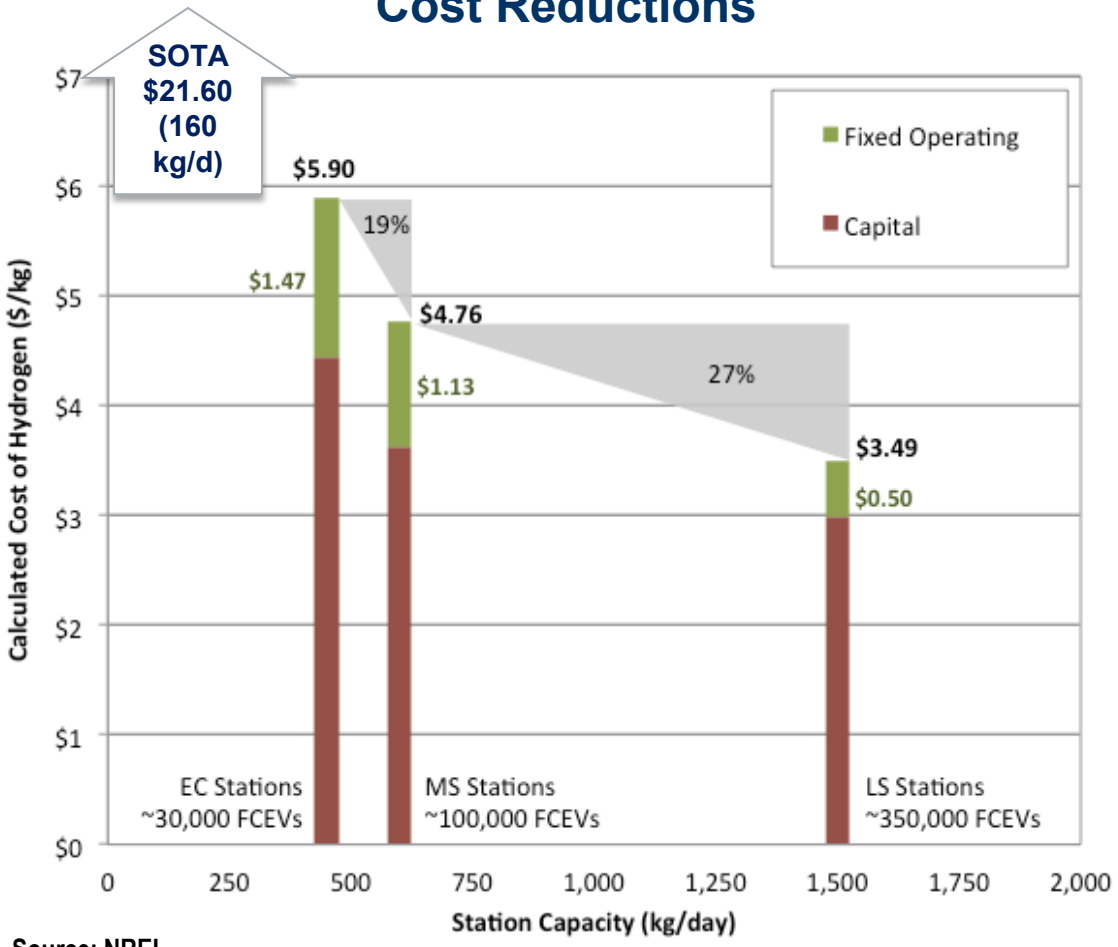
Stakeholders' input identified >80% reduction in hydrogen fueling station cost

Preliminary Analysis: Evolution of Station Cost Reductions



Source: NREL

- **Preliminary results of Infrastructure analysis aggregated from 11 stakeholders' input**
- **Results show high 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
  - Increasing the number of station installers and component suppliers
- **NREL developed station cost calculator tool for analysis.**

Station Description

SOTA: "State of the art" first-of-a-kind station at 100-200 kg/d

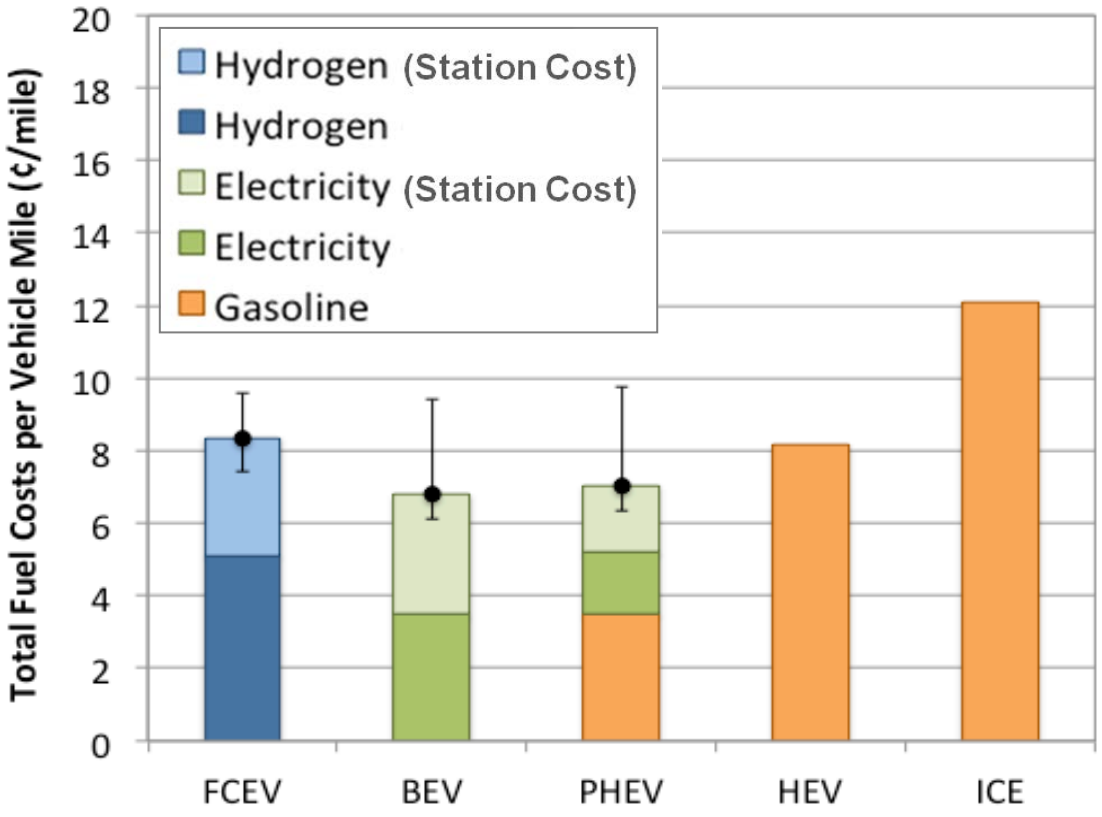
EC: "Early Commercial" station (200-600 kg/d)

MS: "More stations" sized at ~600 kg/d

LS: Larger stations (1,500-2,000 kg/d)

NREL estimated infrastructure cost for various technologies.

Fuel Costs *(preliminary analysis)*



Sensitivities reflect variations in retail infrastructure capital.

Source: NREL

Key Assumptions Used for 2025 Projection

- **Cost of hydrogen delivered to the retail station:** $3.00/kg
- **Cost of electricity:**
  - $0.11/kWh Resid. (Home)
  - $0.095/kWh Comm. (Public)
  - AEO 2012 Early Release
- **Cost of gasoline:** $4.02/gal (AEO)
- **Fuel Economies**
  - FCEV: 59 mpgge
  - BEV: 113 mpgge
  - PHEV: 141/45 mpgge (e/g)
  - HEV: 49 mpg
  - ICE: 33 mpg

Programmatic Analysis: Life-Cycle Analysis Updates

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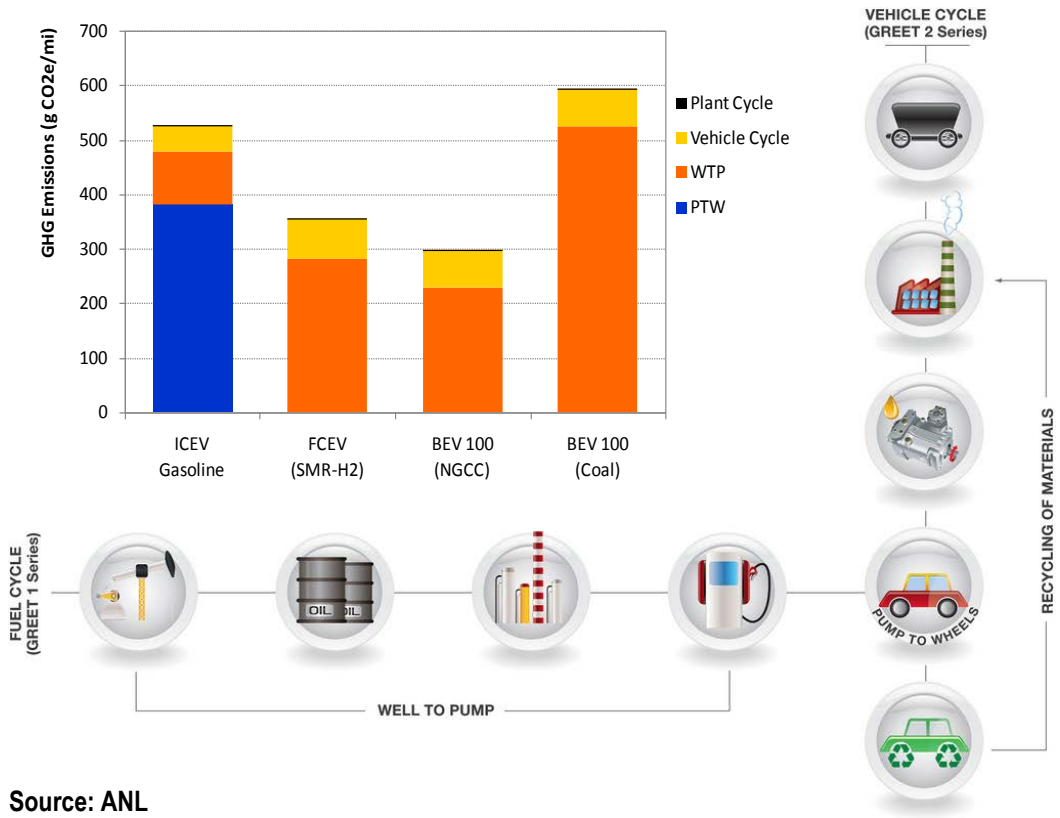
On a life-cycle basis, emissions from plant construction are negligible compared to fuel- and vehicle-cycle emissions.

GREET LCA Analysis = Fuel Cycle + Vehicle Cycle

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



Source: ANL

- **GREET LCA expands analysis of greenhouse gas and criteria emissions and petroleum/energy use to full life-cycle analysis for multiple pathways.**
- **Multi-Program analysis with consistent assumptions and transparent approach**
- **Gaps in LCA analysis care being assessed through the USDRIVE partnership** *(DOE, auto manufacturers, energy companies, and electric utilities)*.

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.

- **Joint analysis project with feedback from the Vehicle Technologies and Biomass Programs**
- **Industry responded to DOE Request for Information (RFI) for input to vehicle life cycle cost analysis on *projected cost reduction rates for technologies that are not yet fully commercial***

Common Assumptions

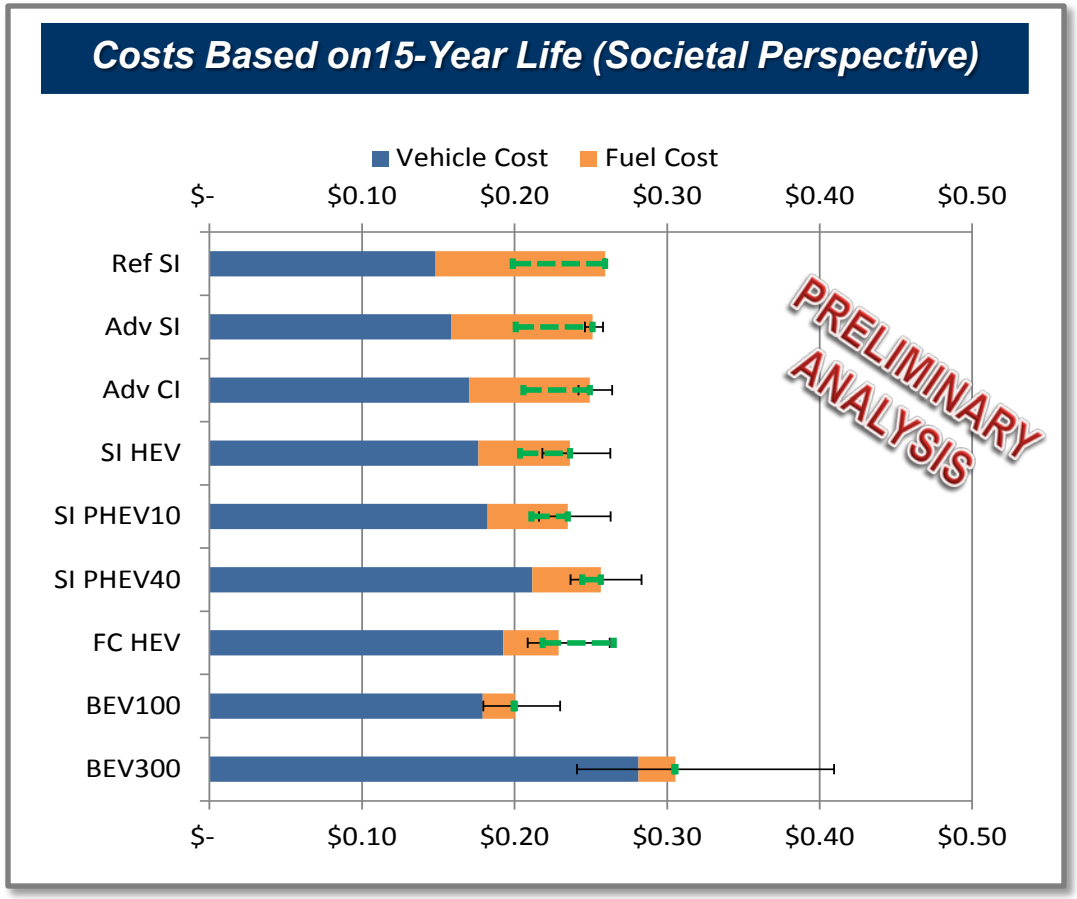
- 15-year ownership
- 10,000 miles per year
- 7% discount for annual fuel costs
- No resale value

Vehicle Types

Ref. SI: Current gasoline car
Adv SI: 2025 gasoline car
Adv CI: 2025 diesel car
SI HEV: 2025 hybrid electric car
SI PHEV10: 2025 gasol PHEV10
SI PHEV40: 2025 gasol PHEV40
FC HEV: 2025 fuel cell car
BEV: battery electric car

Error Bars

Green: range of assumptions for fuel prices (EIA projections for fuels other than hydrogen; hydrogen range: $2.50 - $4.50 per kg)
Black: range of assumptions for technology success.



	FC HEV	BEVs
Battery Cost, $/kWh		$125, $175, $250
Battery Cost, $/kW	$22, $27, $40	
Fuel Cell Cost, $/kW	$27, $31, $43	
Fuel Cost in $/gge (¢/kWh)	$2.50, $3.50, $7.00	$3.51 (10.5¢), $3.68 (11¢)

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.

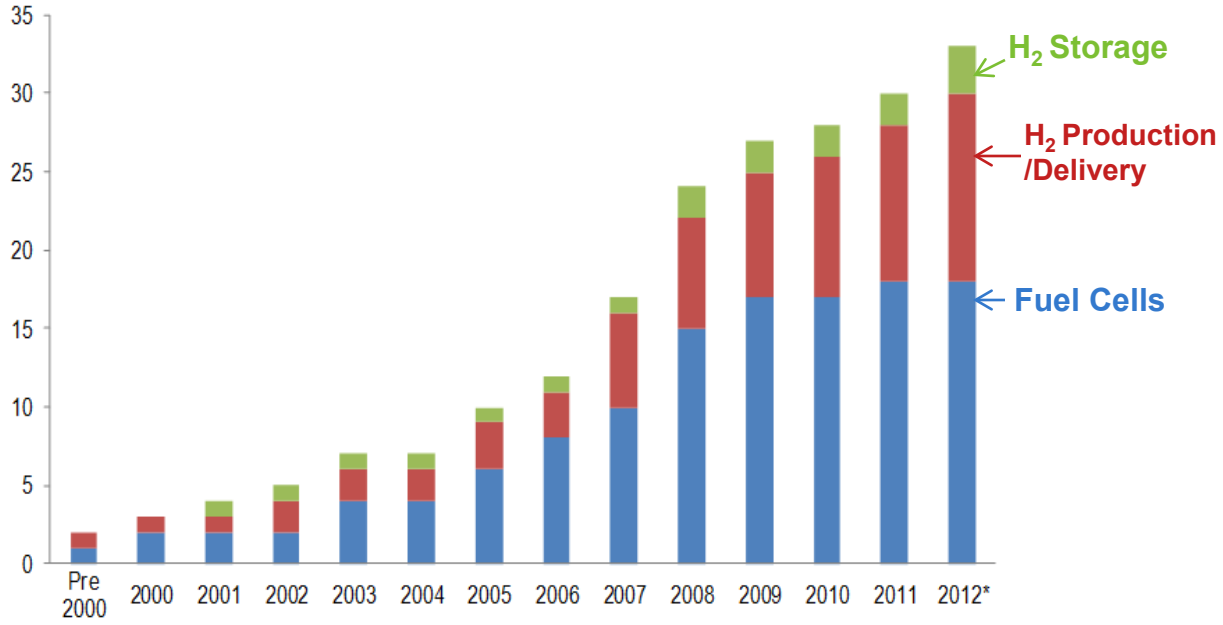
Accelerating Technology Innovation and Application

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

Patents

EERE-funded Fuel Cell Technologies resulted in >310 patents.

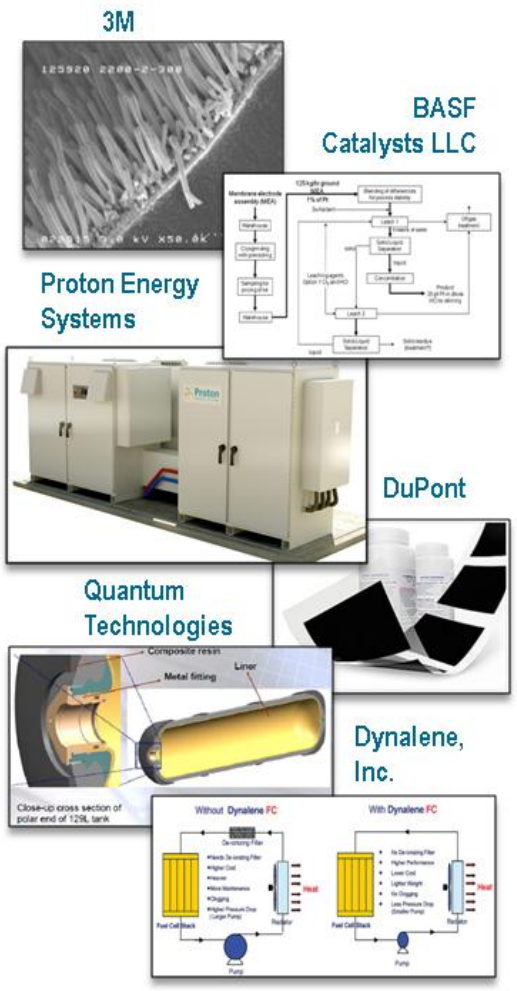
Cumulative Number of Commercial Technologies Developed with FCT-Program Funding



* Partial data for 2012

Source: PNNL *Commercial Pathways* report to be published September 2012

- Examples -



Programmatic Analysis: Socio-Economic Benefits of Fuel Cell Industry Impact on Employment

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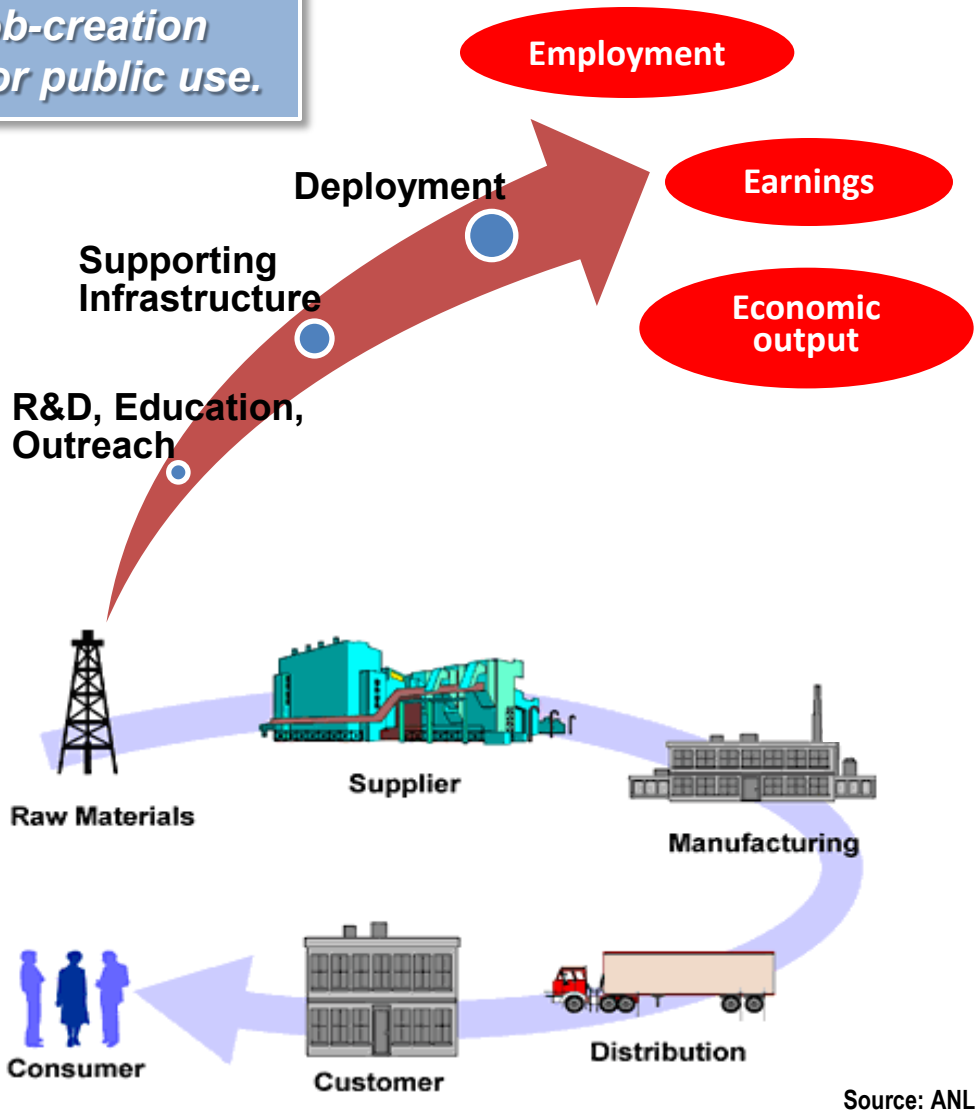
Peer-reviewed employment model for job-creation potential for states and regions released for public use.

- ANL-RCF developed an 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
- Model was peer reviewed and beta tested prior to launch.
- State-, regional-, and national-level analyses including supply chain impacts
- Applications included forklifts, back-up power, specialty vehicles, etc.
- Jobs model will enable analysis of gross and net jobs, and revenues generated from fuel cell installation and investment.



Source: ANL

Model *now* available from ANL website: JOBSFC.es.anl.gov

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

FY 2012	FY 2013	FY 2014	FY 2015	FY 2016-2020
Update well-to-wheels analysis and quantify reductions in petroleum use, greenhouse gas emissions, and criteria pollutant emissions	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 jobs model development	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 environmental analysis of impacts for H_2 scenarios

Systems Analysis Collaborations

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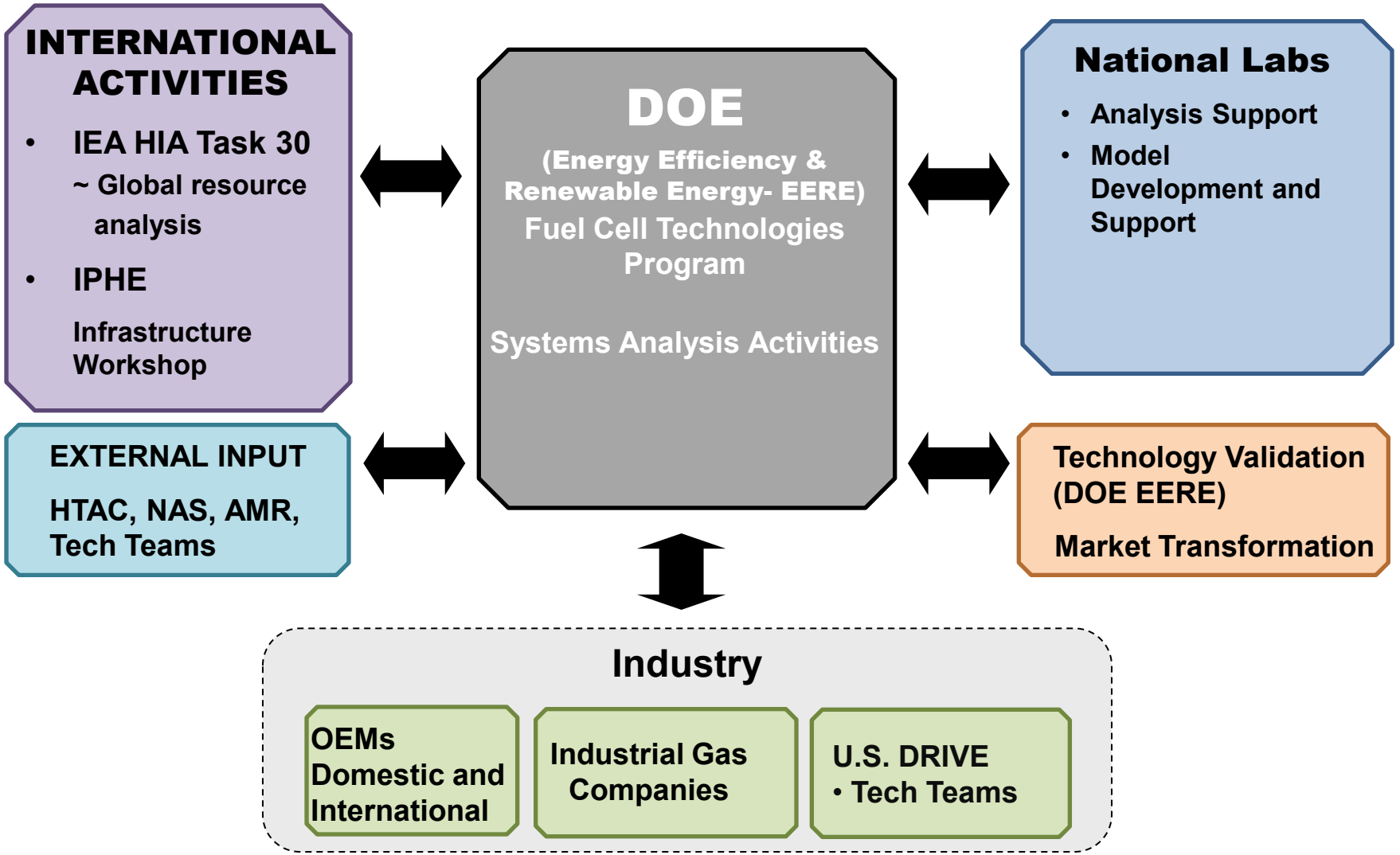
Analysis and peer review input coordinated among national and international organizations



International Analysis and Collaboration: IEA HIA Task 30 Resource Analysis

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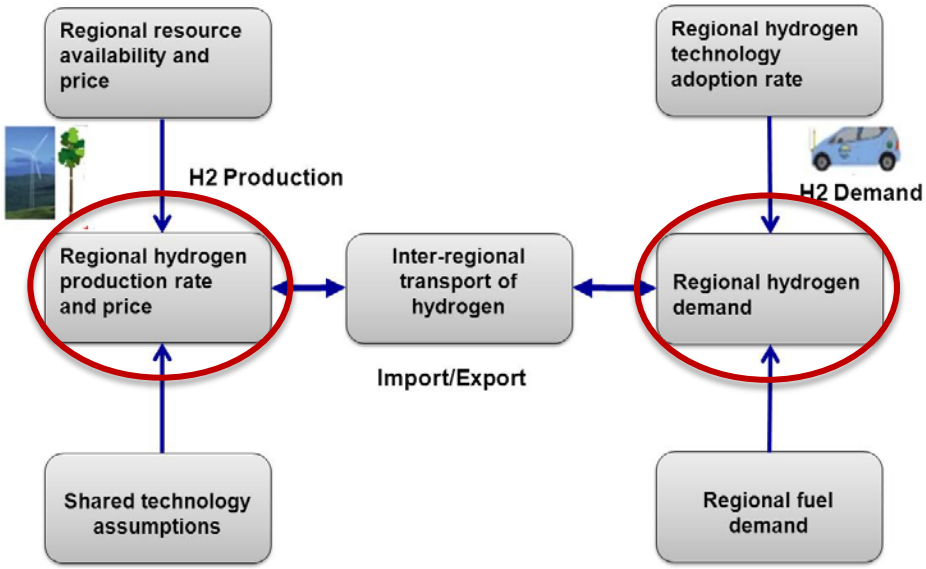

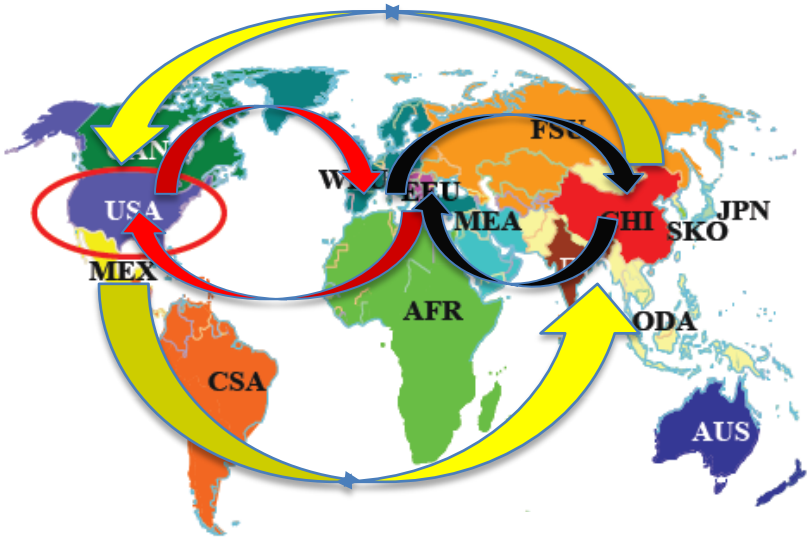

International Resource Flow

Objectives:

- Through collaboration with IEA analysts and IPHE, perform comprehensive technical and market analysis of
  - Hydrogen technologies and resources
  - Resource supply and demand related to projected hydrogen use
  - Global hydrogen infrastructure
  - GHG emissions and petroleum reduction
- Identify international flows of:
  - Energy
  - Hydrogen
  - Natural gas, LNG, coal
  - Platinum and other materials
- Enable informed decisions that lead to sustainable clean energy systems

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
- Show the socio-economic benefits of various fuel cell applications

For More Information

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