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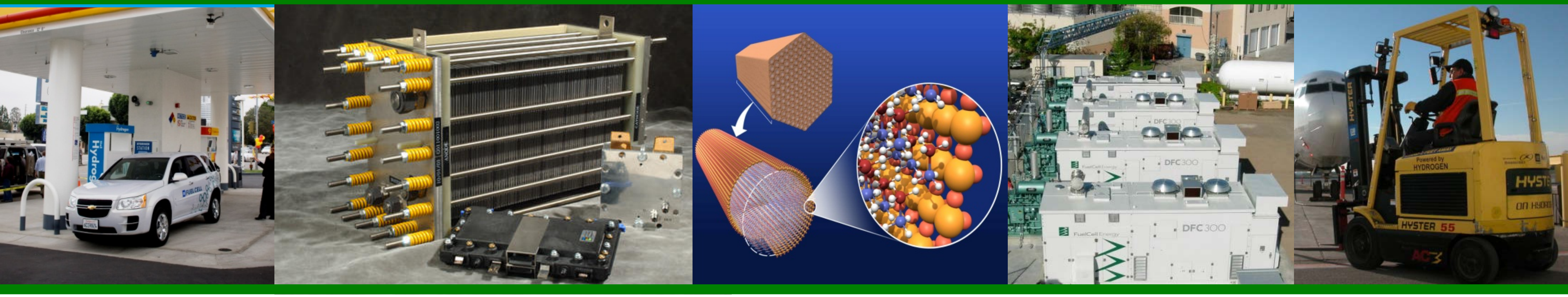

Systems Analysis Program Area
- Plenary Presentation -

Fred Joseck
Fuel Cell Technologies Office

2015 Annual Merit Review and Peer Evaluation Meeting
June 8-12, 2015

Goals and Objectives

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GOAL: Support infrastructure development and technology readiness through system-level analysis—evaluating technologies and pathways, guiding selection of RD&D technology approaches/options, and estimating potential value of RD&D efforts.

Objectives:

- Assess benefits of hydrogen and fuel cells (on a life-cycle basis) for diverse applications.
    - ghg reduction
    - Petroleum use reduction
    - Water use
- Quantify benefits of integrating hydrogen fuel production with stationary fuel cell power generation.
- Evaluate targets and impact and progress to targets for the near and long term.
- Evaluate fueling station costs for early vehicle penetration.
- Evaluate use of hydrogen for energy storage and as an energy carrier.
- Assess the socio-economic benefits (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 near term penetration and 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.

Strategy

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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 analyses

Studies and Analysis

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

Deliverables /Results

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

Internal and External Peer Review

Systems Analysis Portfolio

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Variety of methodologies are used in combination to provide 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

SYSTEMS ANALYSIS

IMPLEMENTATION & IMPACT ANALYSIS

- ❑ Resource Analysis
- ❑ Delivery Analysis
- ❑ Infrastructure Development & Financial Analysis
- ❑ Employment
- ❑ Energy Storage

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

Systems Analysis Model Hierarchy

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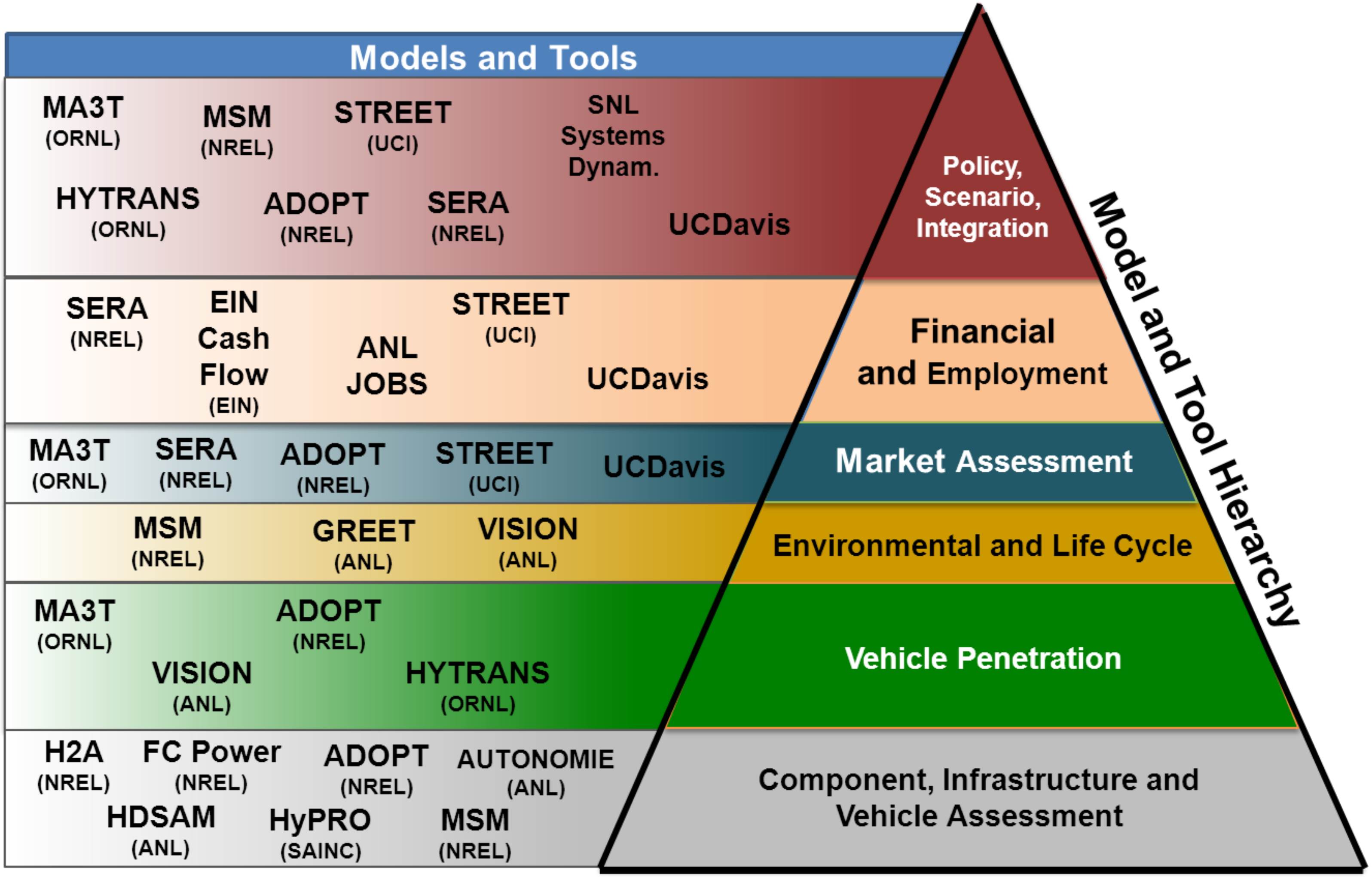
DOE's Fuel Cell Technologies Office model and tool portfolio is versatile, comprehensive and multi-functional.



Model Fact Sheets: http://www.energy.gov/eere/fuelcells/systems-analysis

Interim H_2 Cost Target

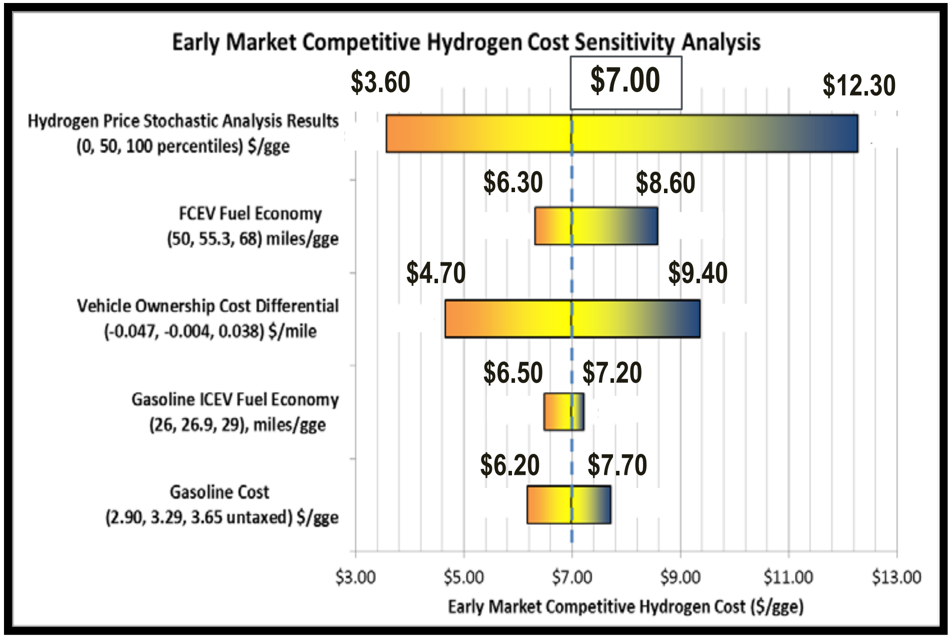
H_2 Cost Target of $7/gge could be competitive with gasoline in the early markets.

Objective:

Establish an interim hydrogen cost target to evaluate and measure cost of hydrogen for early market applications for transportation fuel.

Methodology:

- "Top-down" analysis of the hydrogen cost in the early market (2015-2017).
- Hydrogen is compared with gasoline in the light-duty vehicle (LDV) markets of California and Northeast.
  - Early adoption regions for fuel cell electric vehicles (FCEVs).
- FCEV is referenced to the gasoline ICE in the early market since it will be the predominate vehicle platform in the early market phases of the FCEV rollout.
  - Included maintenance savings and Federal and state incentives for early alternative vehicle adoption



DOE record for Interim H_2 Cost Target: http://hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf

Assumptions:

Gaso. Prices, untaxed [1]	Low	Medium	High
California	$2.99/gge	$3.29/gge	$3.65/gge
Northeast	$3.10/gge	$3.29/gge	$3.47/gge
Fuel Economies [2]	Low	Medium	High
Gasoline ICE	26 mi./gge	26 mi./gge	29 mi/gge
FCEV	50 mi/gge	50 mi/gge	68 mi/gge

[1] http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm

[2] http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

Current Targets and Status

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Pathways#	Current Status	Goal
Interim Hydrogen Cost Target (Near Term)*		• **Reduce the cost of dispensed hydrogen to <$7/gge[3]**
Distributed Natural Gas Reforming	~$3.70-$4.20/gge[1] (2012) at *high volume* and 1,500 kg/d.	• Reduce the cost of dispensed hydrogen to <$7/gge
Distributed Electrolysis	~$4.80-$5.50/gge[2] (2014) at *high volume* and 1,500 kg/d. ~$5.80/gge[2] (2014) at high volume and 500 kg/d.	• Reduce the cost of dispensed hydrogen to <$7/gge
Current H_2 selling price in California	The selling price at the pump is $13.60-$15.00/kg at *low volume*.	• Reduce the cost of dispensed hydrogen to <$7/gge
Ultimate Hydrogen Cost Target (Long Term)*		• **Reduce the cost of dispensed hydrogen to <$4/gge[4]**
Distributed Natural Gas Reforming	~$3.70-$4.20/gge[1] (2012) at *high volume* and 1,500 kg/d.	• Reduce the cost of dispensed hydrogen to <$4/gge
Distributed Electrolysis	~$4.10-4.40/gge[2] (2014) at *high volume* and 1,500 kg/d. ~$5.80/gge[2] (2014) at *high volume* and 500 kg/d .	• Reduce the cost of dispensed hydrogen to <$4/gge

* Hydrogen cost targets are pathway independent.

Pathways include production, compression, storage and delivery

[1] DOE record 12024: http://hydrogen.energy.gov/pdfs/12024_h2_production_cost_natural_gas.pdf

[2] DOE record 14004: http://hydrogen.energy.gov/pdfs/14004_h2_production_cost_pem_electrolysis.pdf

[3] DOE record 14013: http://hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf

[4] DOE record 11007: http://hydrogen.energy.gov/pdfs/11007_h2_threshold_costs.pdf

Budget

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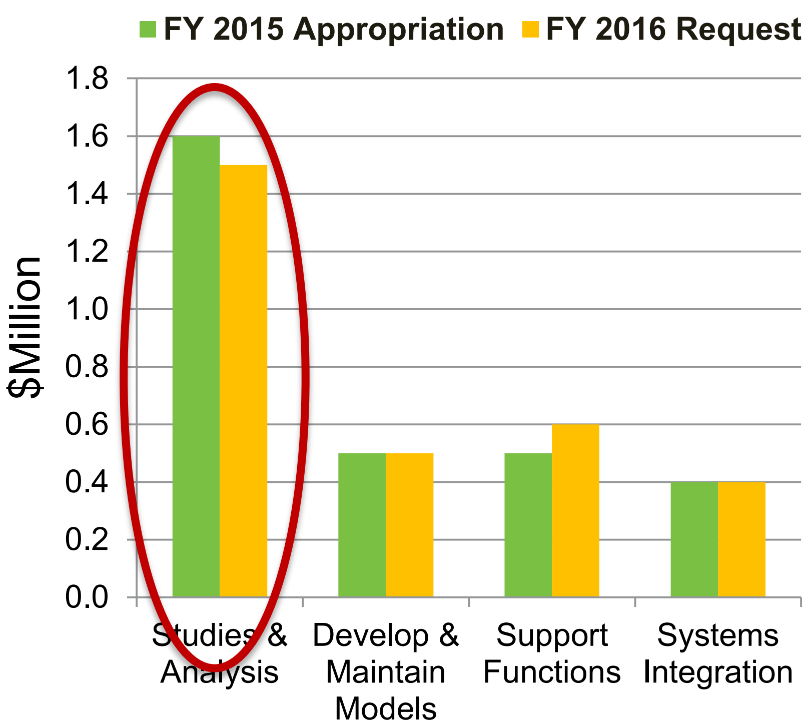
Focus: Determine technology gaps, economic/jobs potential, and benefits of key technology advances; and quantify 2015 technology advancement.

FY 2015 Appropriation = $3.0 M

FY 2016 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
- 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 business case assessment of infrastructure.
- Assess programmatic impacts on market penetration, job creation, return on investment, and opportunities for fuel cell applications in the near term.
- Evaluate the use of hydrogen for energy storage and as an energy carrier.

Accomplishments: (Component and Infrastructure Assessment)
Station Cost Analysis for Capacity and Fueling Pressure

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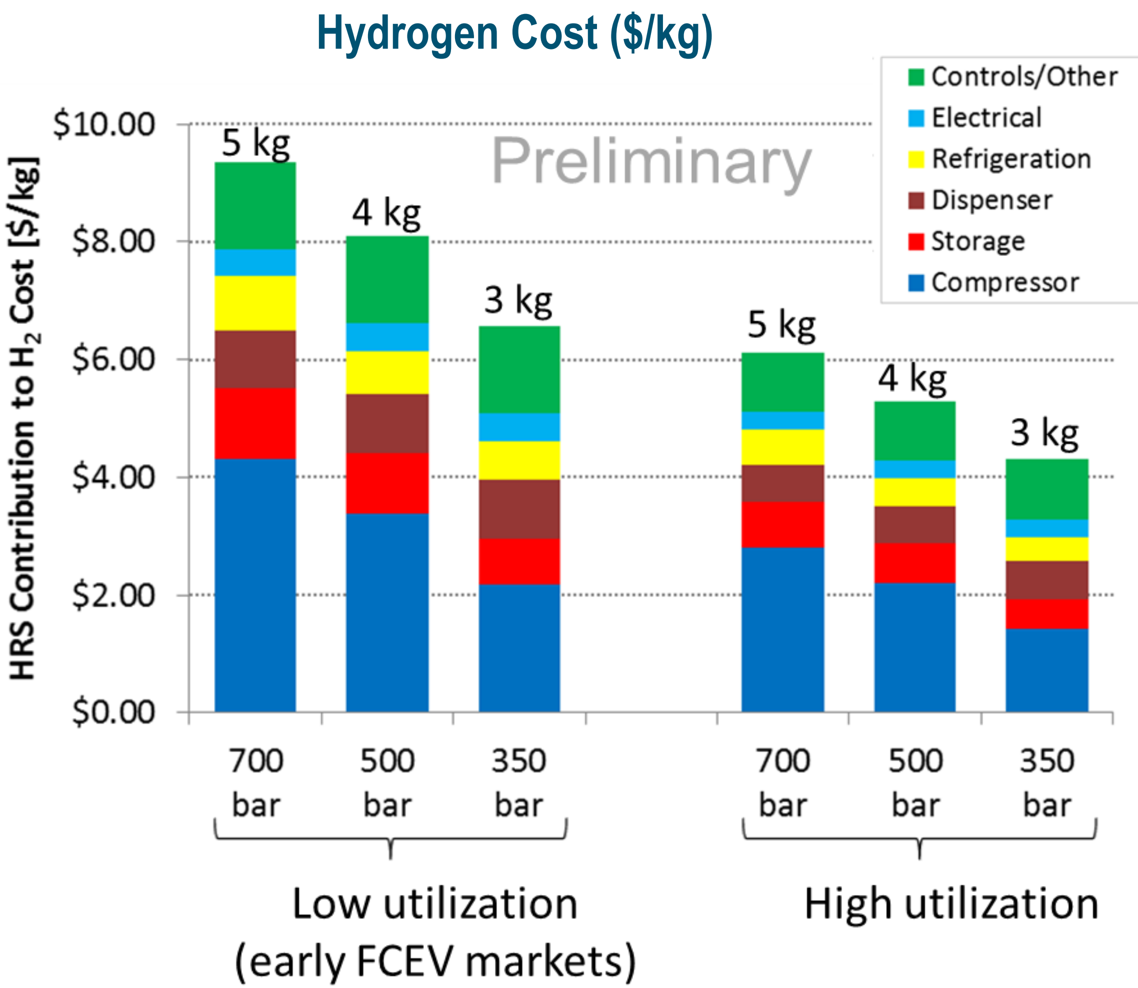
Focus on 700 bar fueling pressure for FCEV rollout. Critical to achieve high utilization of fueling station to reduce cost of dispensed hydrogen.



Source: ANL

Station Cost Analysis

- Hydrogen Delivery Systems Analysis Model (HDSAM) used to model station costs.
- Lower fueling pressure at higher temperature can achieve a fill time target of <3 min and will reduce the capital equipment required for compression, storage and cooling.
- Assumes a Type IV tank and constant volume.

Analysis Accomplishment

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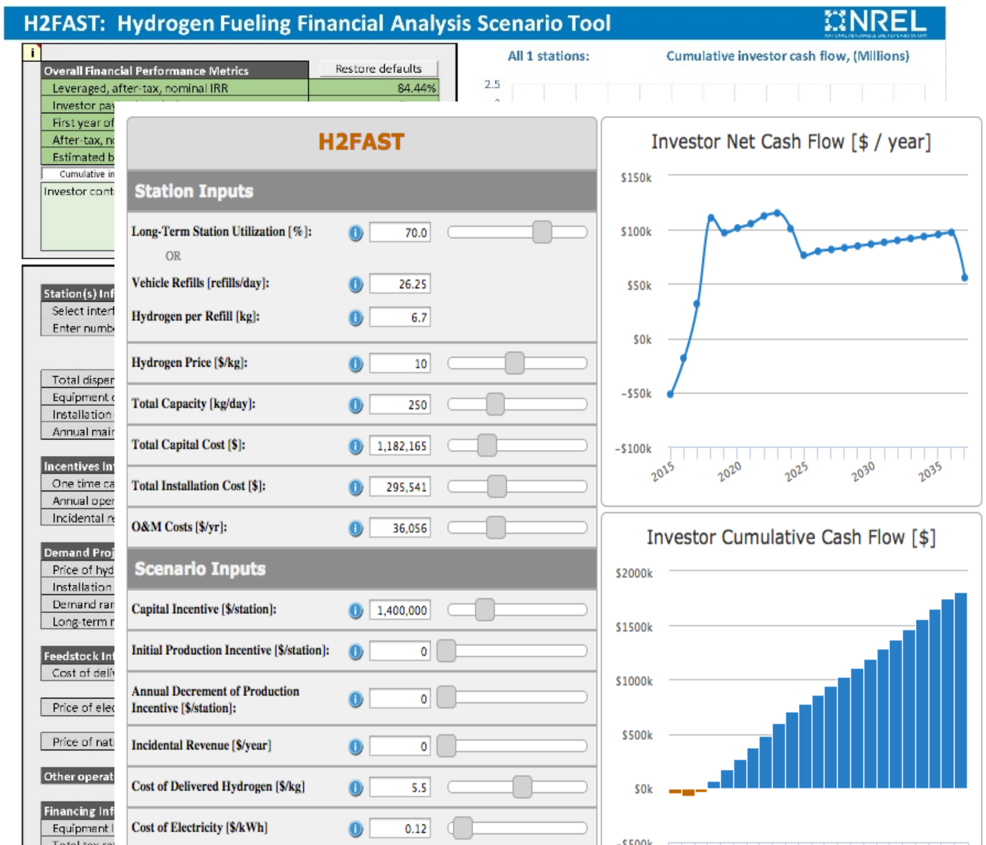
Hydrogen Financial Analysis Scenario Tool (H2FAST) -

*Provides **cash flow and ROI** for hydrogen fueling stations based on key financial inputs such as station capital cost, operating cost, and financing mechanisms.*



Web-based online calculator and Excel spreadsheet versions available

Input Functionality

- Enter information for up to 10 stations and assess finances for individually or as a cluster.
- Two modes to provide inputs:
  - Basic mode: 20 parameters
  - Advanced mode: 51 parameters
- Inputs and outputs have hover-over descriptions to orient users.

Outputs

- Side-by-side station comparison
- Detailed report tables by year
  - Scenario parameters (e.g. volumes of sales)
  - Income statement
  - Cash flow statement
  - Balance sheet
  - Select ratio analyses

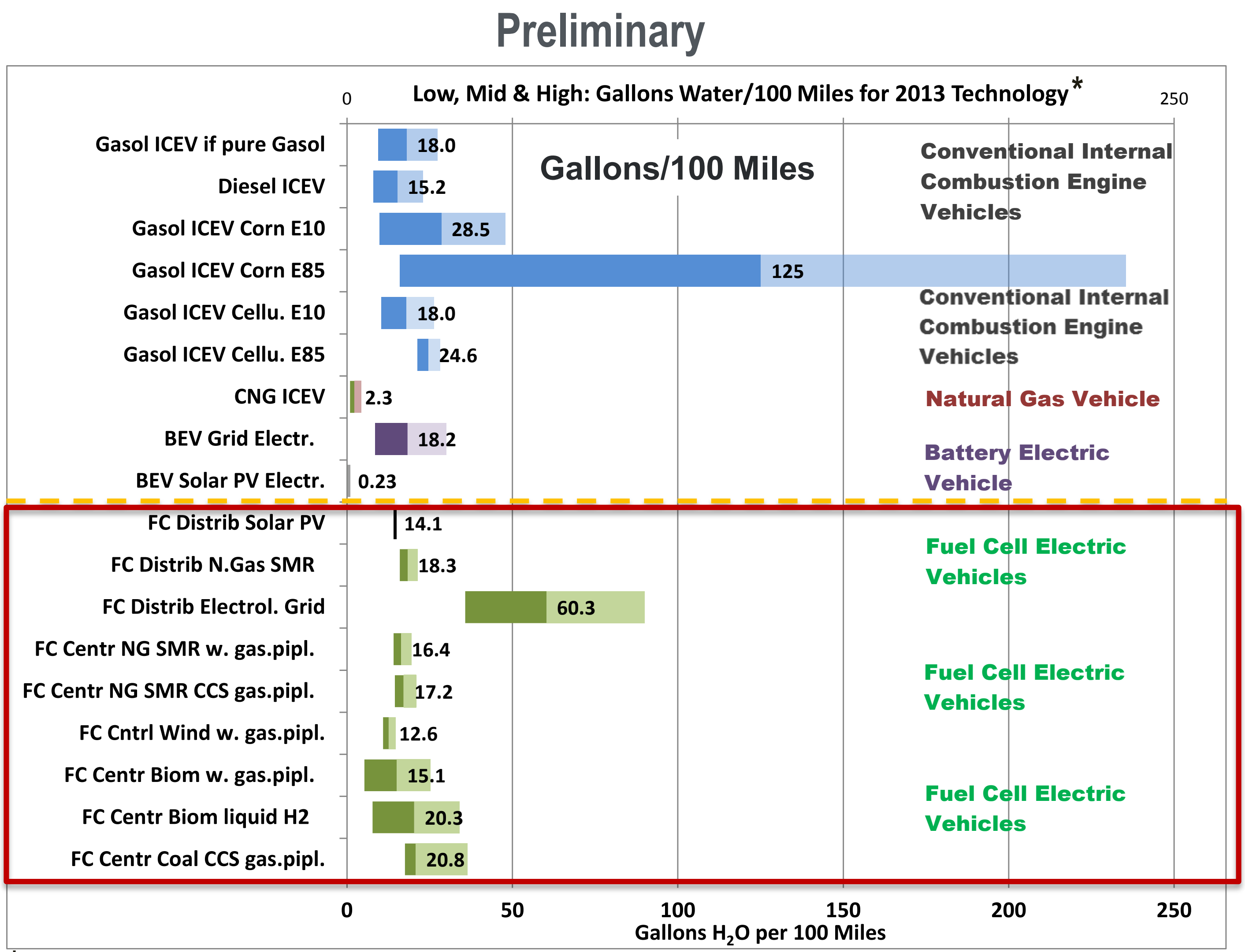
Public webinar held to discuss tool and model details.

url: http://www.nrel.gov/hydrogen/h2fast

Source: NREL

Accomplishments: (Technology Analysis) Life Cycle Analysis of Water Use for Light Duty Vehicle Pathways

Water Consumption of H_2 pathways comparable to Conventional Fuels



* Record in process.

- Multiple DOE Offices collaborated on the analysis.
- CNG ICEV, BEV, FCEV Natural Gas, FCEV Wind or Solar PV, and FCEV Central Woody Biomass (unirrigated) are less water-intense than current gasoline-corn ethanol blends.
- Greatest water consumption is associated with pathways that rely primarily on the U.S. grid, whether for BEV or FCEV.
- Biofuel pathway water use is high for pathways using irrigation.
- ANL GREET model expanded to include water life cycle analysis for hydrogen and other fuels.

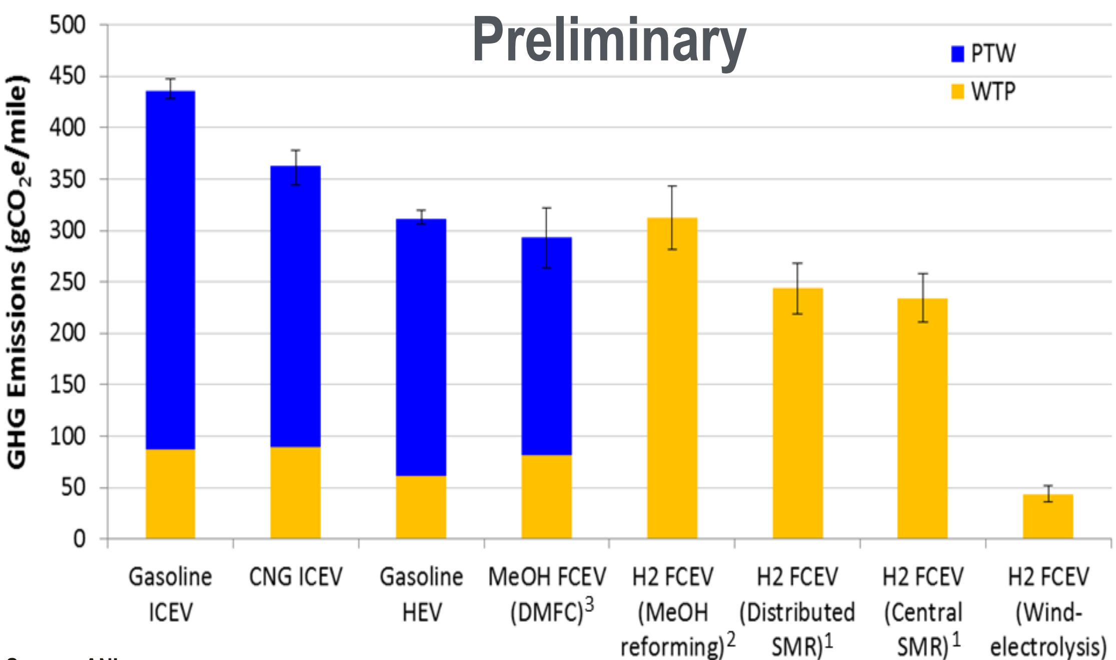
Assumptions

2013 Technology	Miles/gge
Gasol ICEV	27
Diesel ICEV	32
CNG ICEV	26
FCEV	53
BEV	86

Accomplishment: Hydrogen from Methanol Reforming

The Methanol (MeOH) to Hydrogen FCEV pathway can reduce GHG emissions by 30-35% compared to gasoline internal combustion engine vehicles.

Well-to-Wheel GHG emissions of H_2 FCEV pathways compared to Gasoline and CNG ICEV pathways



Source: ANL

Notes:

1. Steam methane reforming of natural gas at central location to produce hydrogen with distribution to refueling site.
2. Synthesis of natural gas to methanol (MeOH) at central location with distribution to refueling site and reformed to produce hydrogen for dispensing to FCEV.
3. Synthesis of natural gas to MeOH at central facility with methanol transported to refueling site and dispensed into a direct methanol fuel cell vehicle (DMFC).

Assumptions:

1. Conversion efficiency of natural gas to MeOH: 72%
2. H_2 production efficiency from natural gas at central SMR: 72%
3. Baseline gasoline ICEV fuel economy: 23, 25, 27 mpg
4. Gasoline HEV fuel economy: 35 mpg
5. CNG ICEV fuel economy: 25 mpgge
6. H_2 FCEV fuel economy: 52, 57, 68 mpgge
7. MeOH fuel economy: 35, 38, 45 mpgge

Note:

References for the assumptions are detailed in DOE record in process.

"Tech to Market" Assessing the Impact of DOE Funding

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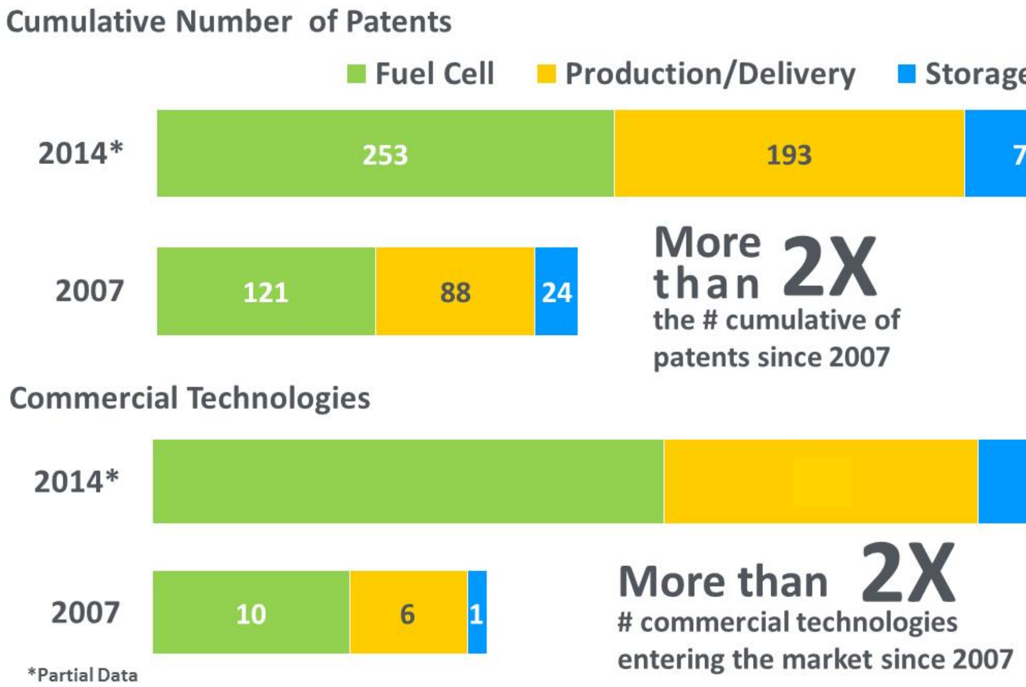
- **DOE funding has led to more than 40 commercial hydrogen and fuel cell technologies and 65 emerging technologies.**
- **More than 516 PATENTS resulting from EERE-funded R&D:**
  - ***Includes technologies for hydrogen production and delivery, hydrogen storage, and fuel cells***

Accelerating Commercialization



516 patents and more than 40 commercial technologies

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2014.pdf

Source: Pacific Northwest National Laboratory,

Early Market Cost Reduction Analysis

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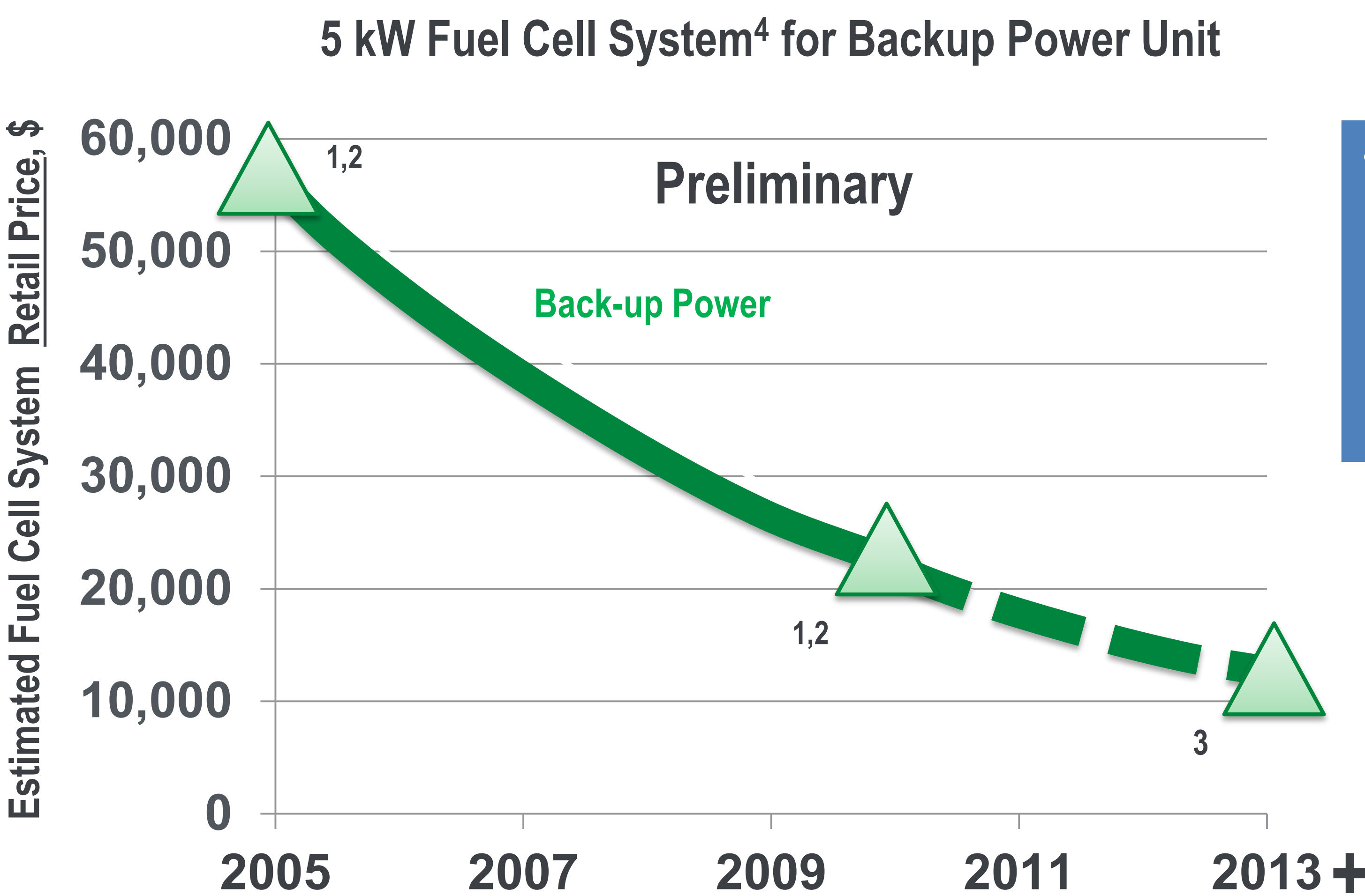
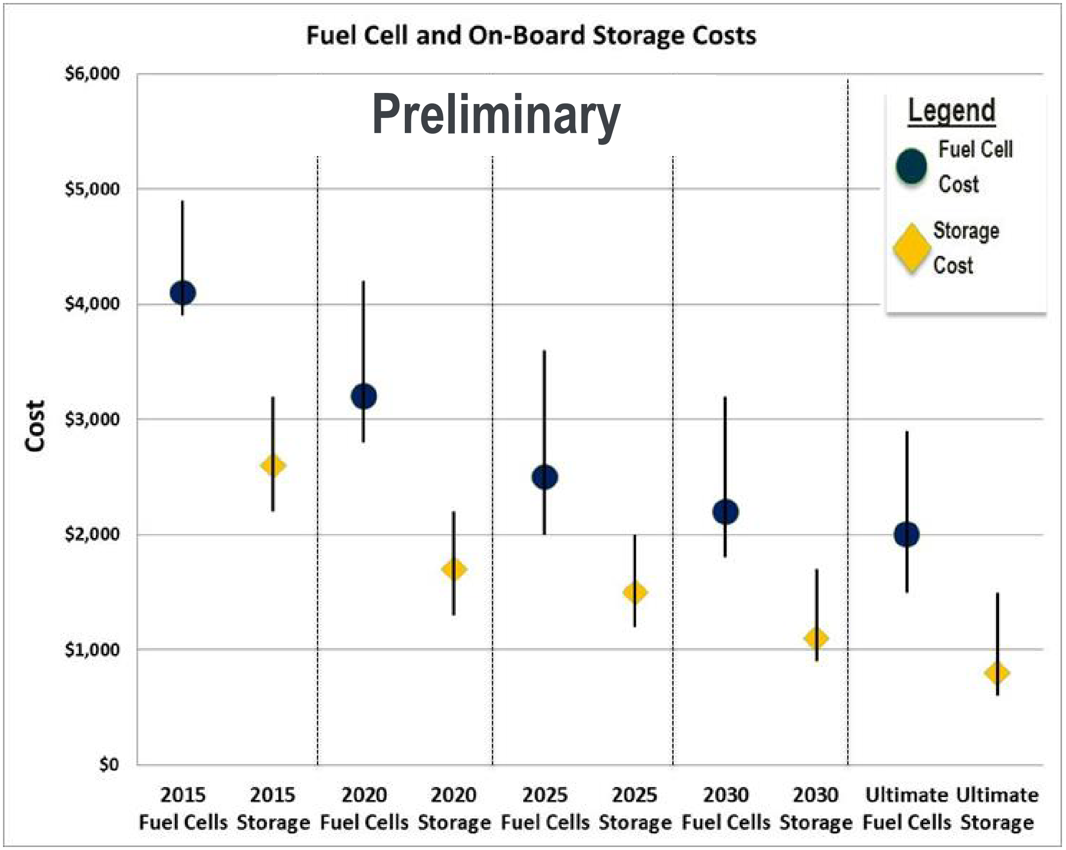


- Over 60% reduction in the fuel cell system price for back-up power units since 2005 and ~50% reduction since 2010.

1. 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.
2. ORNL "Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities"
3. Results of input from OEMs on Backup Power and Material Handling fuel cell systems. Results to be published in 2015.
4. Includes fuel cell stack and balance of plant

Accomplishments: (Component and Vehicle Assessment) Impact of Fuel Cell System Peak Efficiency, Fuel Consumption, and Cost

Fuel cell R&D focused to increase the fuel cell efficiency to ~70% could lead to fuel cell and on-board storage cost reduction of ~50% and 60%, respectively*



Source: ANL

- Fuel cell efficiency of 60% has been achieved and demonstrated. http://www.nrel.gov/hydrogen/cdp_topic.html
- ANL Autonomie model used to evaluate fuel cell and on-board FCEV vehicle costs and performance.
- Fuel economy improvement results from improved fuel cell peak efficiency from 60% to ~70%.
- Achieving increased fuel cell efficiency and resultant fuel economy yields reduced fuel requirements for constant driving range, reduced on-board storage tank size and weight.

Parameter	Units	2010	2015			2020			2025			2030			2045		
			low	Med	high	low	Med	high	low	Med	high	low	Med	high	low	Med	high
Peak Fuel Cell System Efficiency	%	59	59	59	60	63	65	66	64	66	67	65	67	68	68	69	70
Platinum Price	$/Troy OZ	$1,100	$1,500			$1,500			$1,500			$1,500			$1,500		

*Fuel cell efficiency is on LHV basis.

Accomplishment: Vehicle Penetration Analysis

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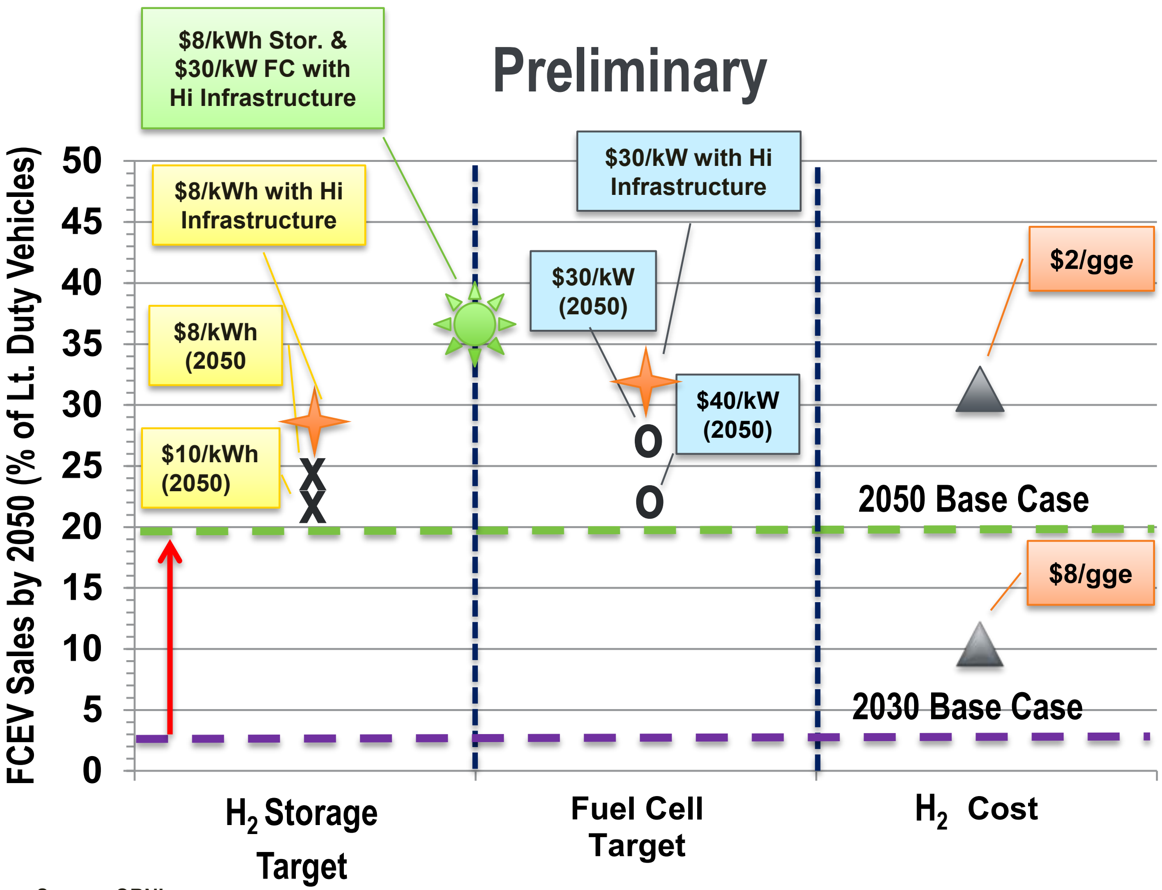
Achieving FCTO targets and establishing infrastructure are important for increasing FCEV sales penetration in 2050



Source: ORNL

- Analysis based on ANL Autonomie results of FCEV analysis.
- ORNL used the MA3T model to analyze the impact of individual FCTO target progress and infrastructure development for the near and long term.

Base Case	
Targets	
Fuel Cell Cost, \$/kW	\$55/kW
On-Board Storage, \$/kWhr	\$18/kWhr
H_2 Cost, \$/gge	\$4/gge
H_2 Infrastructure Buildout	Low H_2 infrastructure buildout rate. Deployment of H_2 infrastructure reaches ~2.5% by 2030 and ~20% by 2050.

Workshops

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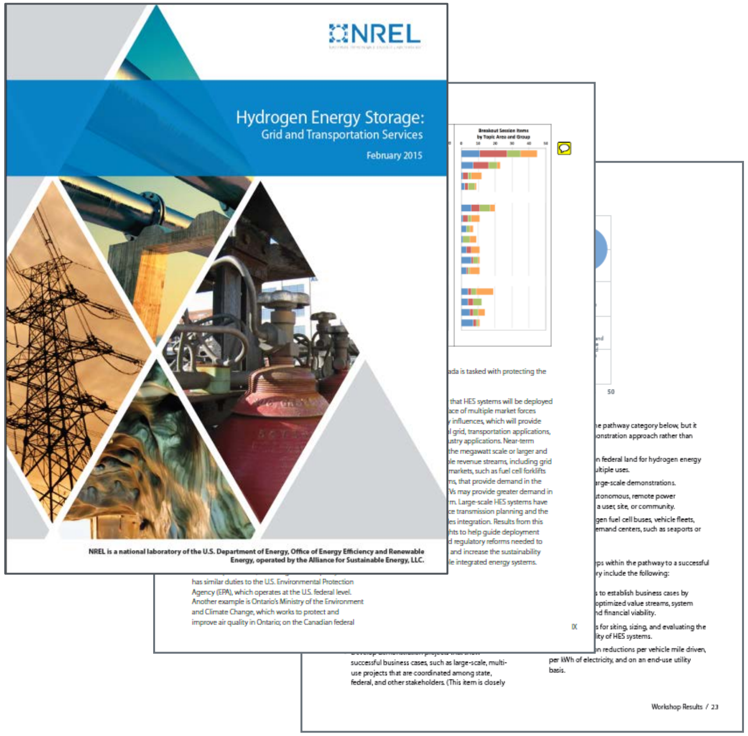
Workshop	Date	Objectives/Deliverables
COMPLETED		
Energy Storage Workshop	**August 2014**	**Objectives:** Identify 1) best applications, 2) barriers, and 3) potential collaboration areas for U.S. and Canada to use hydrogen for energy storage. **Outcomes/Deliverables:** Workshop proceedings and identification of next steps, including analysis, R&D topics for FCTO program areas, and opportunities for international collaboration. **Proceedings location**: http://www.nrel.gov/docs/fy15osti/62518.pdf
Hydrogen and CNG Workshop	**September 2014**	**Objectives:** Explore intersection of hydrogen FCEVs and compressed natural gas (CNG) vehicles. Identify synergistic opportunities for FCEVs and CNG vehicles, regional issues, and consumer preferences. **Outcomes/Deliverables:** Workshop proceedings and identification of next steps, including analysis, R&D topics for FCTO program areas, and opportunities for collaboration. **Proceedings location:** http://energy.gov/eere/fuelcells/downloads/transitioning-transportation-sector-exploring-intersection-hydrogen-fuel
PLANNED		
Advanced H_2 Infrastructure Finance and Investor Workshop	**September 2015**	**Objectives:** Build on learnings from first investment workshop and explore gaps and potential resolutions. **Outcomes/Deliverables:** Workshop proceedings and identification of next steps, including investment scenarios to overcome barriers to market entry for fuel marketers/retailers to adopt H_2 fuel.

Hydrogen Energy Storage Workshop

- **Hydrogen Energy Storage (HES) Workshop**
  - Held May 2014 in Sacramento, CA and included a diversity of stakeholder types
  - Explored barriers, policy and next steps for encouraging HES
  - Workshop proceedings are available

- **Power-to-Gas project - Clean Energy Dialogue U.S./Canada Collaboration**
  - Understand geographic & environmental circumstance where power-to-gas makes sense
  - Simulate Power-to-gas systems
    - Scenario based approach
    - Simulate behavior, financial and possibly environmental performance
    - Canadian Nuclear Laboratories and National Research Council Canada working on Power-to-Gas standalone software module
    - EPRI working on integrating Hydrogen into a simplified version of energy storage valuation tool
    - NREL is supporting with some inputs and project review
  - This project is expected to conclude in August 2015.



Source: http://www.nrel.gov/docs/fy15osti/62518.pdf

Recent and Upcoming Activities

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- Diverse portfolio and expanded capability of models developed by Systems Analysis are enabling analysts to address barriers to technology development and commercialization.
- Emphasis on ***early market*** and ***infrastructure analysis*** :
  - Comprehensive approach to evaluate portfolio of fuel cell applications for light duty transportation, stationary generation, back-up power, material handling equipment, and the electric sector to realize economic, environmental and societal benefits.
- Continue life-cycle analyses of cost, greenhouse gas emissions, petroleum use and criteria emissions, and impacts on water use.
- Continue to enhance existing models and expand analyses.
- Assess programmatic impacts on market penetration, job creation, return on investment, and opportunities for fuel cell applications in the near term.

FY 2015	FY 2016	FY 2017-2020
Provide analysis of FCTO 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 FCTO technology performance and cost status and potential to enable use of fuel cells for a portfolio of commercial applications	Provide analysis of FCTO milestones and technology readiness goals—including risk analysis, independent reviews, financial evaluations, and environmental analysis—to identify technology and risk mitigation strategies
Complete development of station financial analysis tool, H2FAST	Complete the development of GREET models for future hydrogen production technologies such as PEC, STCH and photobiological.	Revise the Ultimate H_2 cost target and compare the status of various hydrogen pathways
Complete development of Interim H_2 cost target and compare the status of various hydrogen pathways	Complete the life cycle analysis of cost, ghg and petroleum use of multiple fuel/vehicle pathways.	Continue to assess gaps and drivers for early market infrastructure cost.
Complete H_2 infrastructure workshops to identify investment gaps		

Collaborations

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

EXTERNAL INPUT
- H2USA
- CAFCP
- HTAC
- NAS
- AMR

International Collaboration
- Canada

DOE-EERE

Systems Analysis Activities

NATIONAL LABS
- Analysis Support
- Model Development and Support

OTHER EERE OFFICES
- VTO
- BETO
- Renewables

FCTO Program Areas

Industry

OEMs
Domestic & International

Industrial Gas Companies

USDRIVE Tech Teams

Key Model, Report and Record Releases

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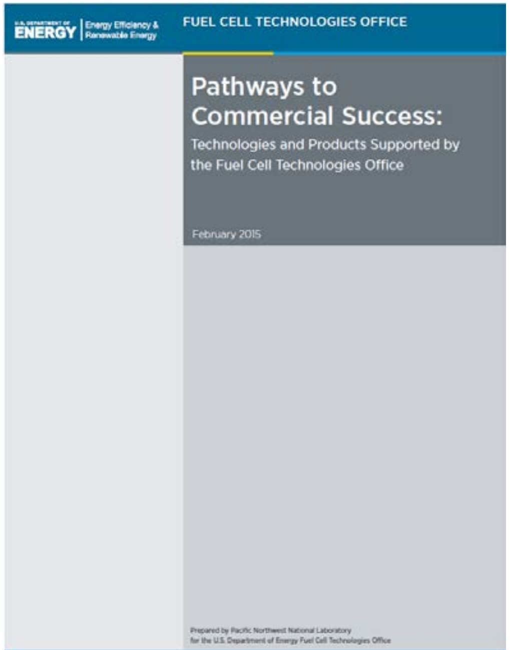
ENERGY | Energy Efficiency & Renewable Energy

FUEL CELL TECHNOLOGIES OFFICE

Pathways to Commercial Success:

Technologies and Products Supported by the Fuel Cell Technologies Office

February 2015

Prepared by Pacific Northwest National Laboratory for the U.S. Department of Energy Fuel Cell Technologies Office

PUBLICATIONS

2014 Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program

http://energy.gov/eere/fuelcells/downloads/2014-pathways-commercial-success-technologies-and-products-supported-fuel

MODELS

H2FAST

by NREL

http://www.nrel.gov/hydrogen/h2fast/

http://www.h2usa.org/H2FAST

RECORDS

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

14013- Interim Hydrogen Cost Target

http://hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf

14017-Well-to-Wheels Greenhouse Gas Emissions for Methanol to Hydrogen Pathways*

14004 - Water Consumption for Light-Duty Vehicles' Transportation Fuels*

* Records in process

Contacts

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http://energy.gov/eere/fuelcells/fuel-cell-technologies-office

Reminder!

General Analysis Session

When: Tuesday after Plenary @ 11AM

Location: Crystal City Marriott

Infrastructure Analysis Session

When: Thursday

Location: Crystal City Marriott