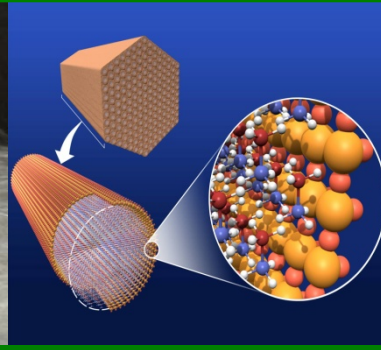
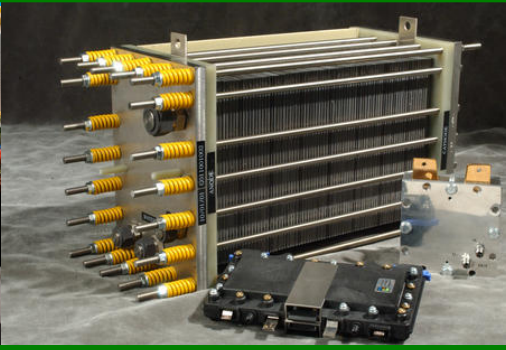




U.S. DEPARTMENT OF
ENERGY



Systems Analysis Program Area - Plenary Presentation -

Fred Joseck

Fuel Cell Technologies Office

*2016 Annual Merit Review and Peer Evaluation Meeting
June 6-10, 2016*

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 (ghg and petroleum reduction and water use) of hydrogen and fuel cells (on a life-cycle basis) for diverse applications.
- Socio-economic benefits (e.g., job creation).

Evaluate

- Targets, and impact of progress to targets for the near and long term.
- Fueling station costs for early vehicle penetration.
- Hydrogen for energy storage and as an energy carrier.

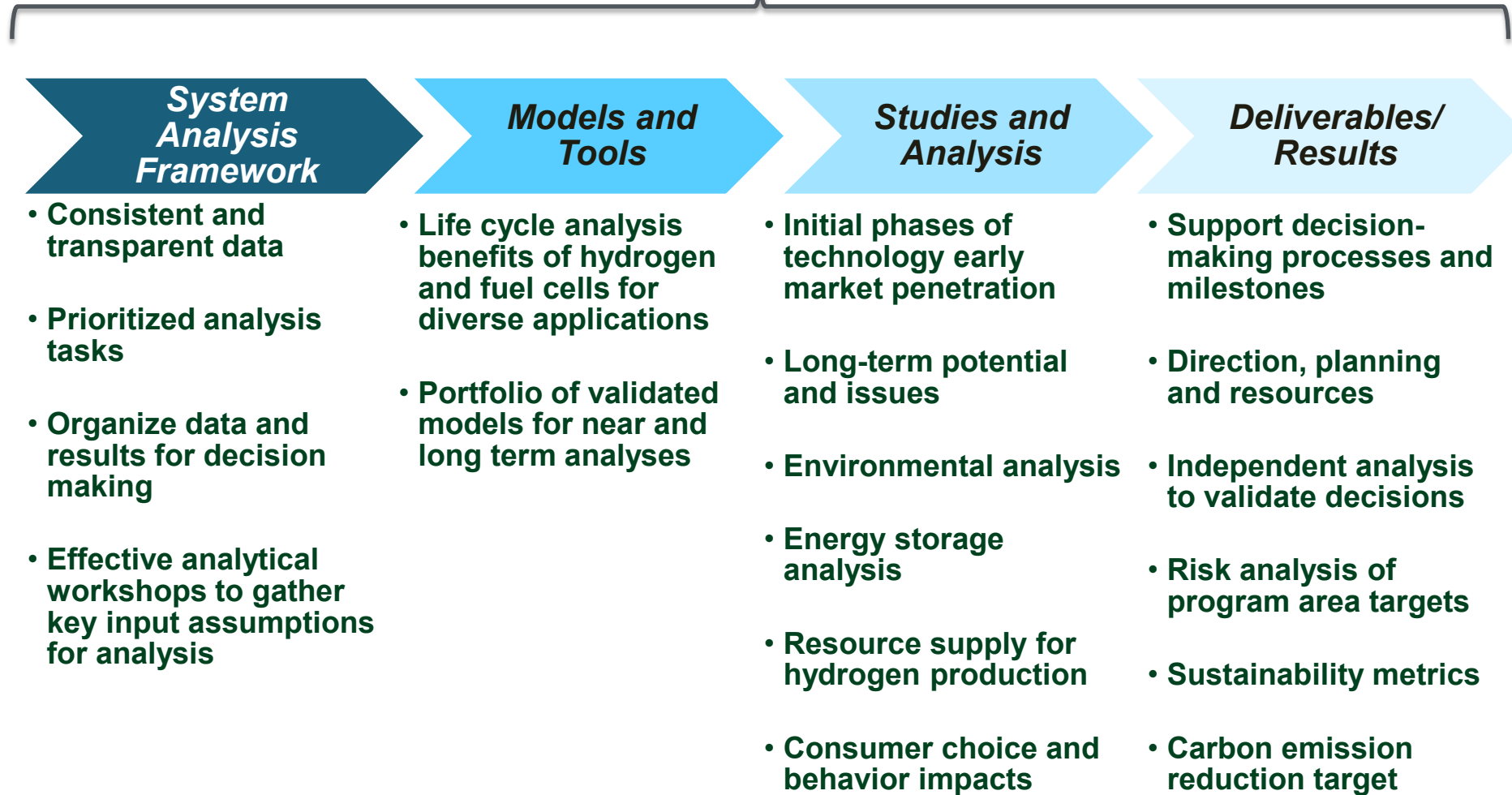
Develop

- Sustainability metrics for the Program.
- Carbon emission reduction-type target for the Program.

Integrate

- Consumer choice and behavior in program and market penetration analysis.

Partnerships with labs, industry, academia



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, and consumer choice/behavior.

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.

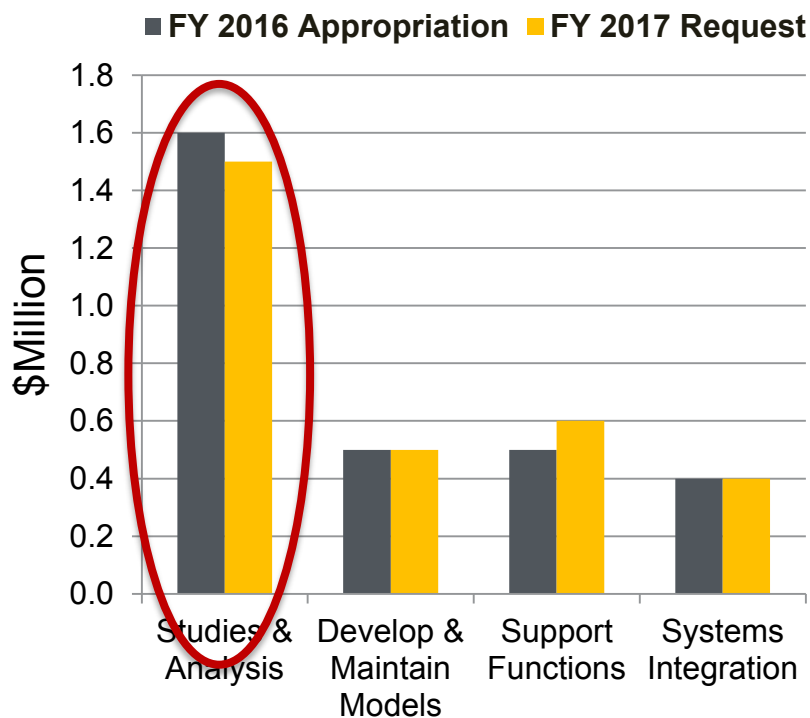
Coordination of Analytical Capability

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

Focus: Determine technology gaps, economic/jobs potential, and benefits of key technology advances; and quantify 2017 technology advancement.

FY 2016 Appropriation = \$3.0 M

FY 2017 Request = \$3.0 M



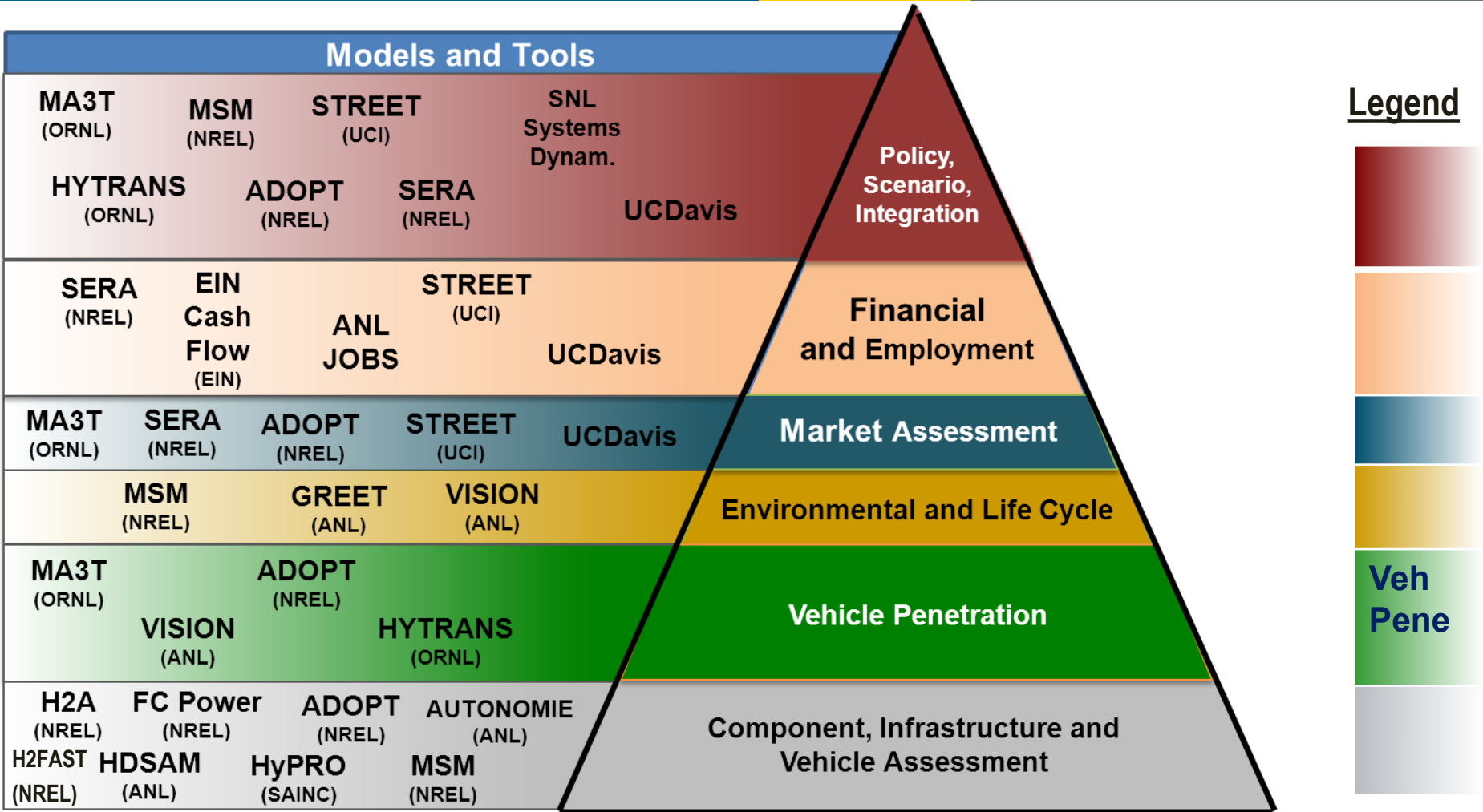
Emphasis

- Focus on life-cycle analysis of cost, greenhouse gas emissions, petroleum use, criteria emissions, and water use.
- Assessment
 - Gaps and drivers for early market infrastructure cost for transportation and power generation applications.
 - Business case assessment of infrastructure.
 - Impact of incentives and policies
 - Impact of targets on market penetration, job creation, return on investment, and opportunities for fuel cell applications in the near term.
- Development of a carbon reduction target and update of the H₂ cost target.
- Evaluation
 - Use of hydrogen for energy storage.
 - Sustainability framework and metrics.

* 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).

Systems Analysis Program at a Glance

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

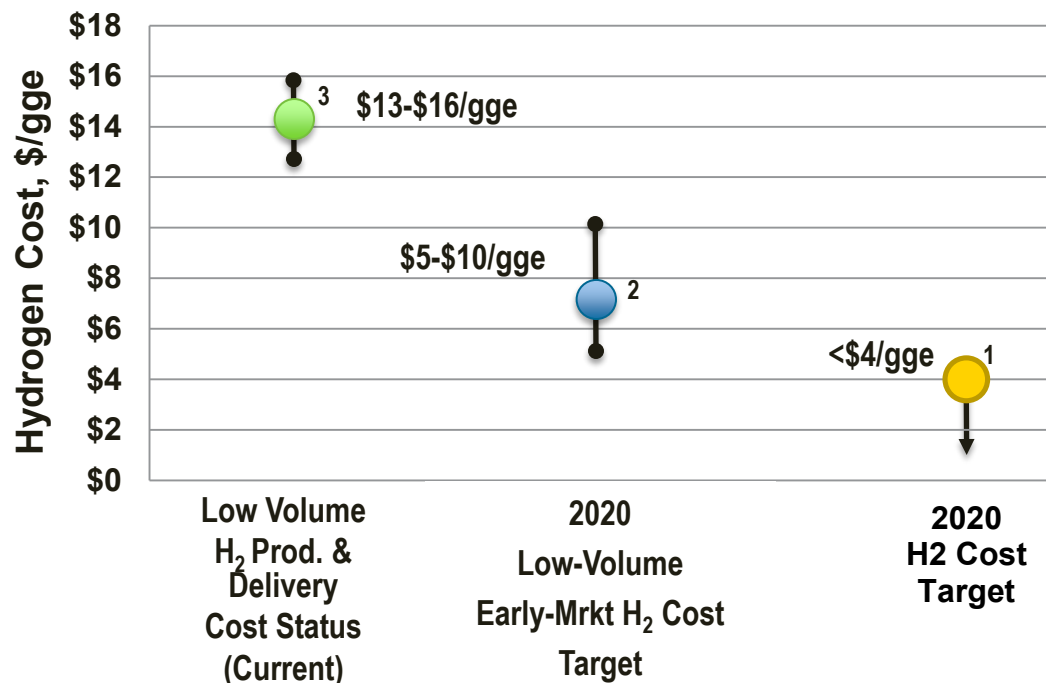


Model Fact Sheets: <http://www.energy.gov/eere/fuelcells/systems-analysis>

FY15-16 Highlights and Future Work

Current cost of low volume H₂ production and delivery ranges from \$13 – 16/gge.

Hydrogen Cost Status and Target



1 - Record 11007 Hydrogen Threshold Cost Calculation

2 - Record 15011 Low Volume Hydrogen Production and Delivery Cost Status

3 - Record 15012 Low-Volume Early-Market Hydrogen Cost Target

700 bar Hydrogen Fuel Cost

Production and Delivery Cost	Station and Dispensing Cost	Total Cost
\$6.00 - \$8.00/gge	\$6.50 - \$8.00/gge	\$12.50 - \$16.00/gge

Objective:

Assess the hydrogen cost for low volume production/delivery for current market applications for transportation fuel.

Basis and Notes:

- The cost of hydrogen is based on hydrogen produced at a central production site.
 - Delivery by gaseous or liquid truck within 200 miles at volumes of 500-1000 kg/month.
 - Production cost based on actual costs provided by industrial gas suppliers and end users.
- Hydrogen cost for compression, storage and dispensing is based on the results from H2FIRST Station Design Report.
- Selling price of H₂ in northern CA was \$13.59/gge (1/22/15) and \$15.00/gge in southern CA (2/25/15).

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

- Joint analysis project Vehicle and BioEnergy Technologies and U.S.DRIVE
- Vehicle life cycle cost assumptions with U.S. DRIVE “Cradle-to-Grave” Analysis

Common Assumptions

- 5-year ownership
- 14,200 miles per year
- 5% discount for annual fuel costs
- Resale value at 17.5% of new vehicle price

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

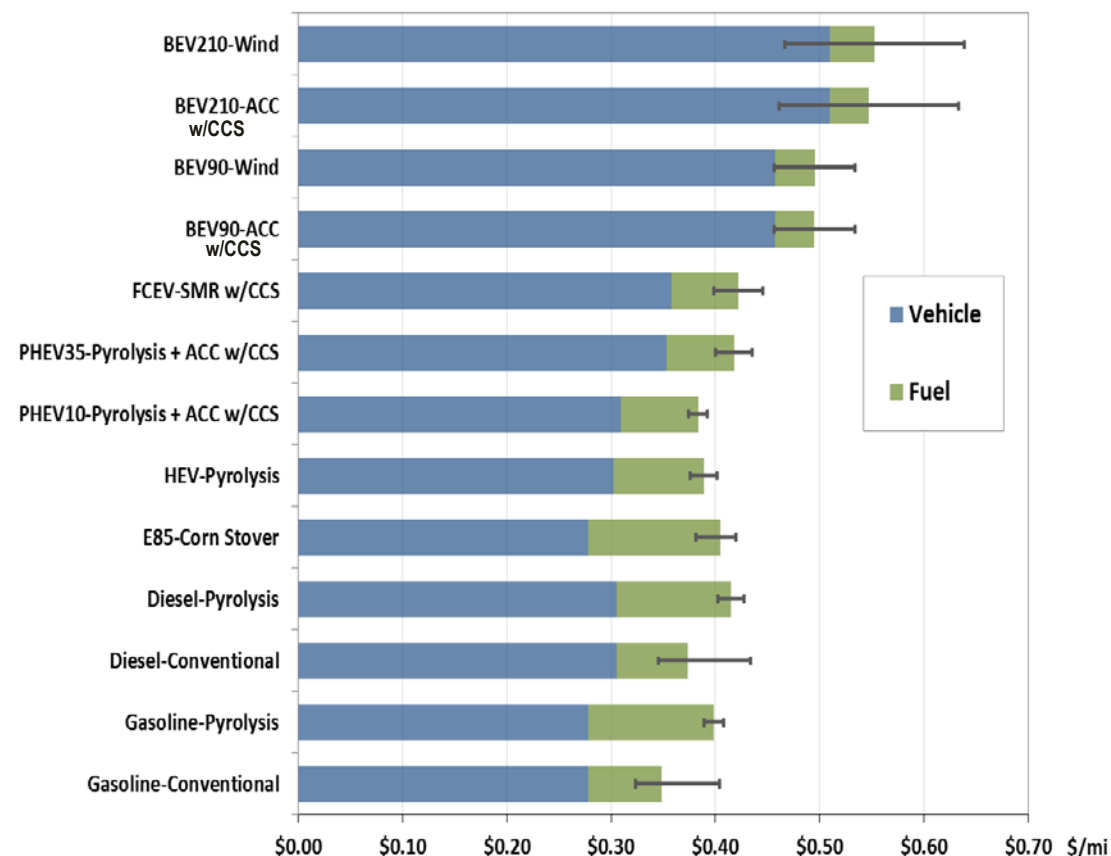
Veh.

Assess ★ **New Report** ★

Costs Based on 5-Year Life

Levelized Cost of Driving, HIGH VOLUME FUTURE TECH

Analysis Window = 5 years; discount rate = 5%

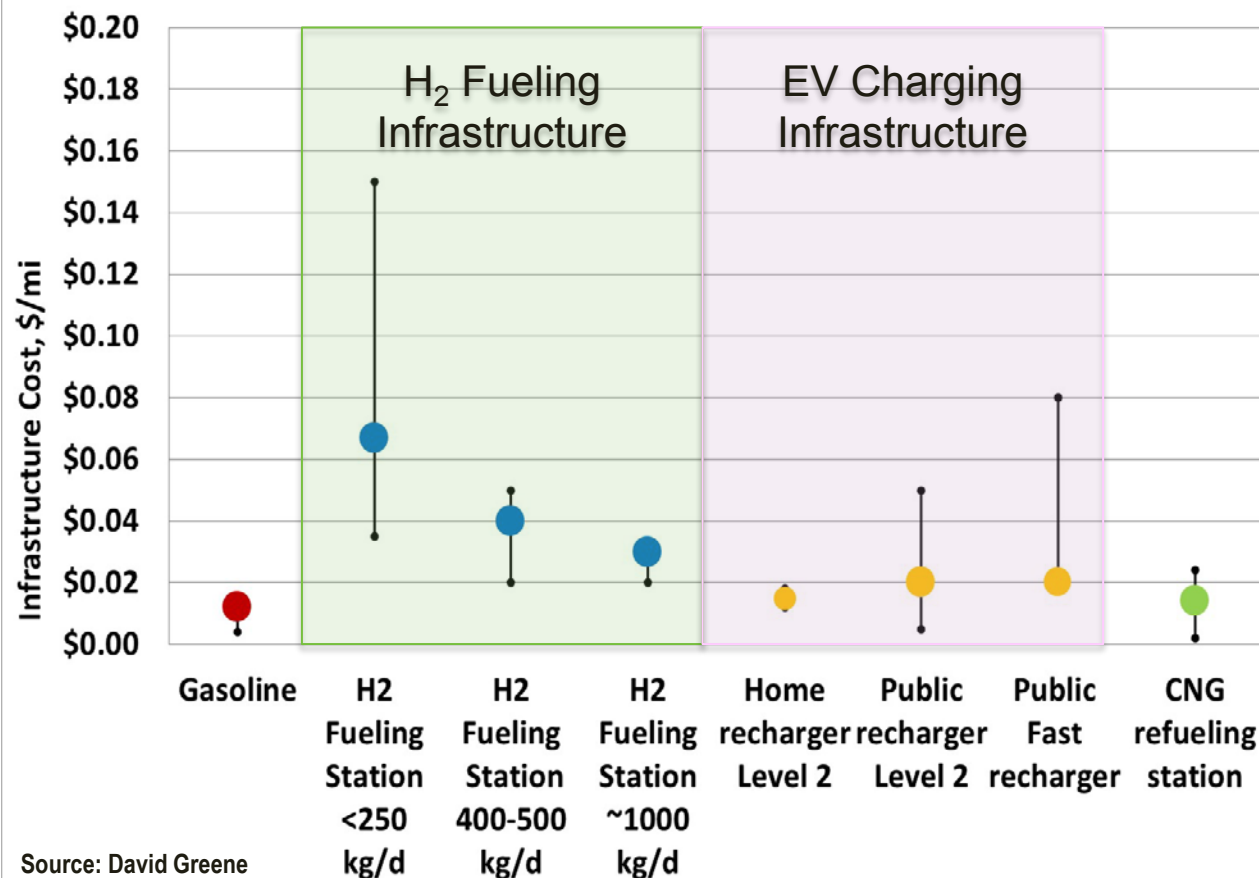


ANL Report url: <https://greet.es.anl.gov/publication-c2g-2016-report>

EV and H₂ infrastructure costs are similar on standardized cost per mile basis

Preliminary

Gasoline and Alternate Fuel Infrastructure Costs, \$/mi.



Goal: Determine infrastructure costs for alternative fuels

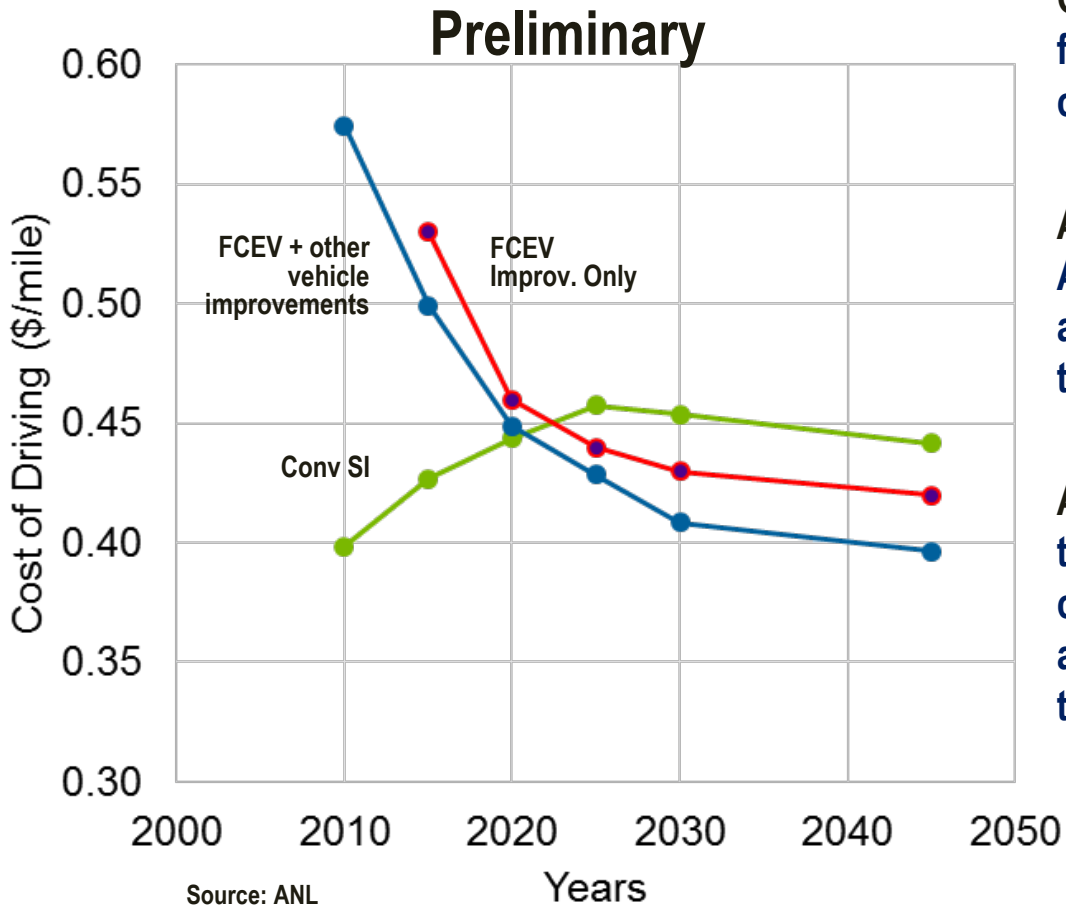
Approach: Utilize published data for infrastructure costs

Accomplishments: Researched and calculated infrastructure costs for conventional and alternative fueling infrastructure.

Assumptions:

- * Equip. amortized over 10 yrs. At 5.5%
- * Stations operate at 80% capacity
- * Costs in 2013\$
- * Taxes, station rent and insurance not included for alternative fuels
- * Refueling equip. costs, installation, operation and maintenance included

By achieving the 2020 FCTO targets, FCEVs could be competitive with conventional vehicles on a cost per mile basis by 2025-2030



Goal: Determine impact of H2 and fuel cell targets on FCEV cost compared to conventional vehicle

Approach: Utilize stakeholder input, ANL experts, GPRA and office assumptions and Autonomie model to develop vehicle cost comparisons

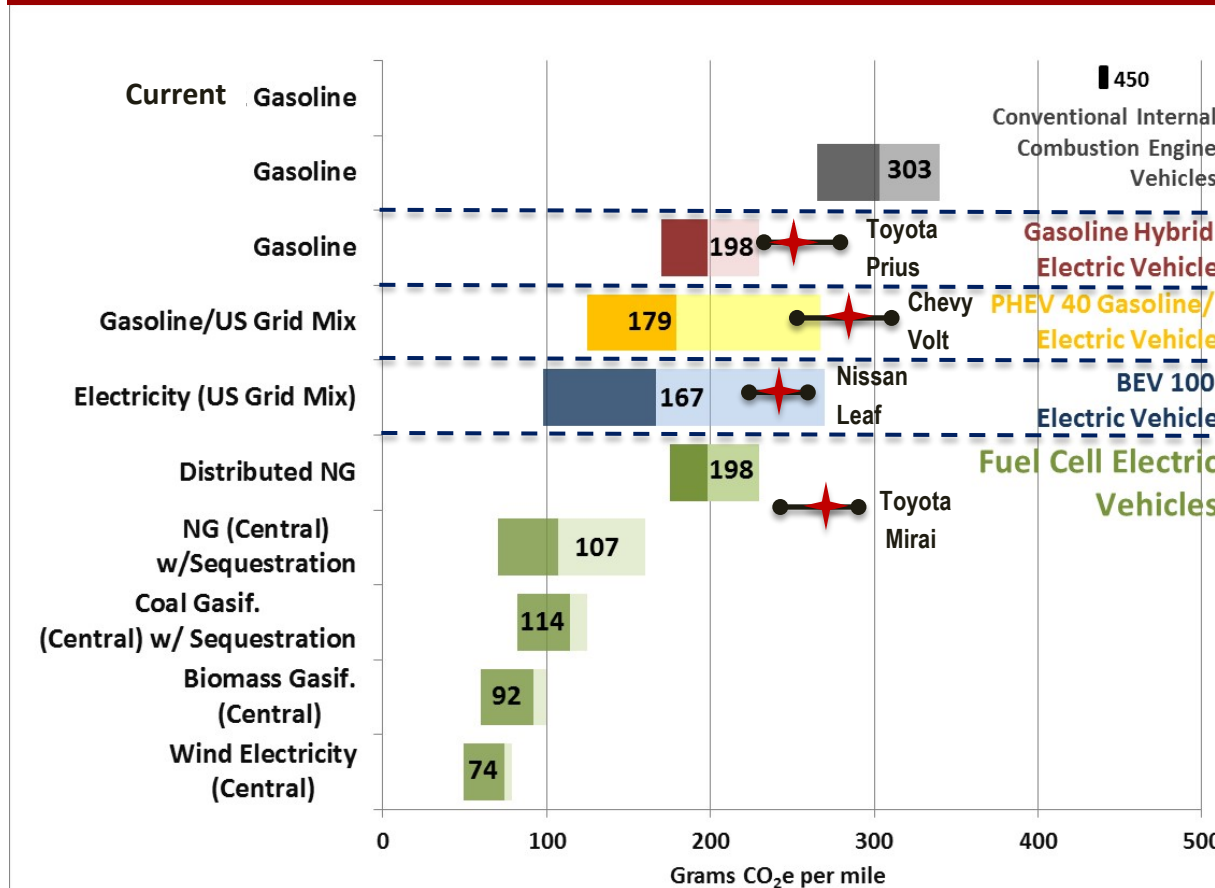
Accomplishments: Analysis showed that FCEVs could be commercially competitive on a cost basis by achieving the FCTO technology targets.

- Legend:**
- Conv. SI
 - FCEVs with only FCTO advances
 - FCEVs with FCTO + VTO advances

- Assumptions:**
- * Hydrogen fuel cost \$3.5/gge
 - * Platinum cost \$1,500/tr. oz
 - * Discount rate 7% at 5yrs.
 - * Hydrogen storage cost in 2020 \$10-\$13.5/kWh
 - * Fuel cell peak efficiency in 2020 60-66%
 - * Annual miles driven 14,000

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

Preliminary Lifecycle Analysis of Greenhouse Gases Emissions Future Mid-Size Car (Grams of CO₂-equivalent per mile)



- Multi-Office analysis with consistent assumptions and transparent approach

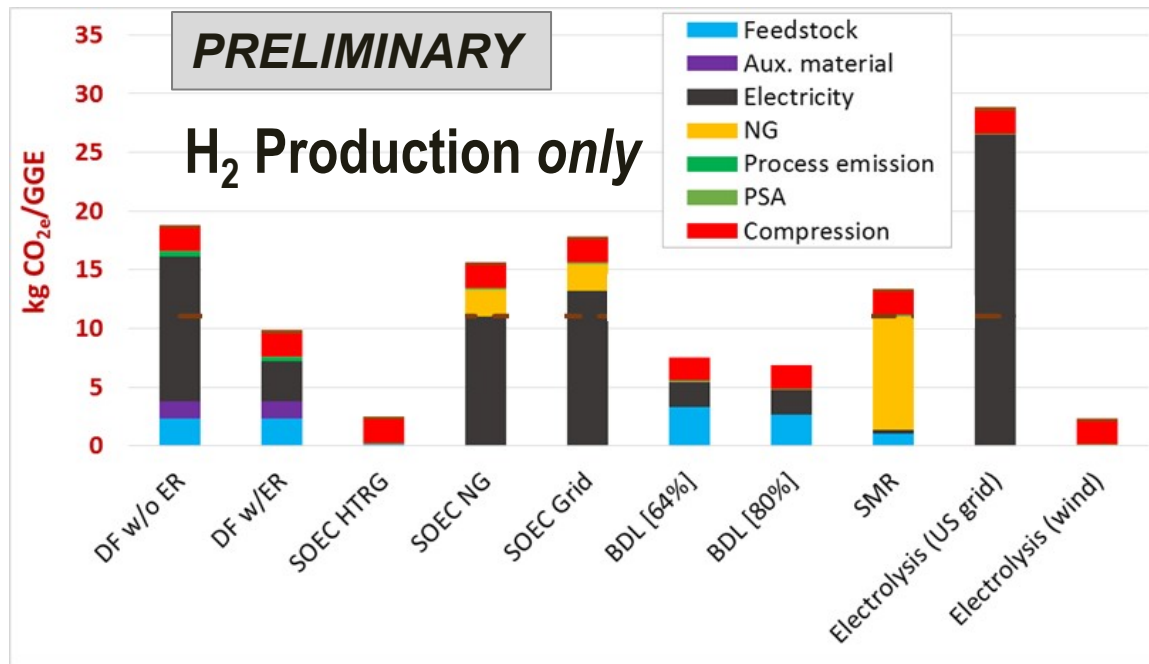
- Analysis included Vehicles Technologies and BETO Offices, and ANL.

- Analysis illustrates need for portfolio approach to reduce greenhouse gas emissions from conventional vehicle fleet

Legend
 Current vehicle model GHGs

Basis: U.S. DRIVE Cradle to Grave assumptions and ANL GREET Model

H₂ produced from renewable energy sources have the potential to have lower ghg emissions from the production portion of the pathway than US grid-based electrolysis and SMR-produced H₂



Goal: Understand GHG emissions of emerging renewable H₂ production pathways

Approach: Coordinate with the Hydrogen Production program and stakeholders and ANL with the GREET model to represent the emerging renewable technologies in the GREET model.

Accomplishments: ANL developed GREET modules for Dark Fermentation, SOEC and Biological Derived Liquids

Source: ANL GREET Model

Legend

DF – Dark Fermentation
SMR– Steam Methane Reforming
SOEC – Solid Oxide Electrolysis
HTRG – Hi Temp Gas-Cooled Reactor

BDL – Biological Derived Liquids
ER – Energy Recovery
NG – Natural Gas

Future work:

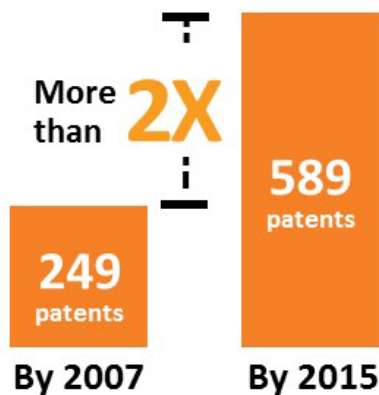
Continue developing modules for emerging renewable technologies of solar thermochemical, photobiological and photoelectrochemical

DOE funded R&D has led to more than **589** patents, **46** commercial hydrogen and fuel cell technologies and **68** emerging technologies.



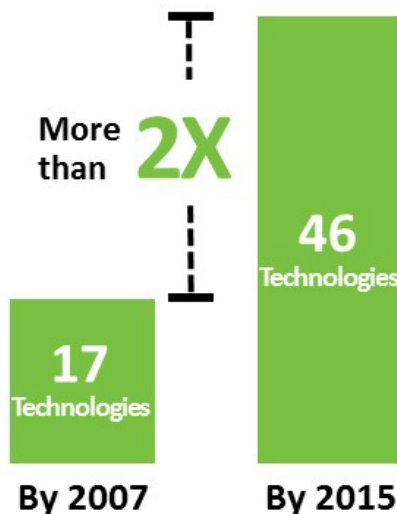
Innovation

Cumulative Number of Patents



Commercialization

Cumulative Number of Commercial Technologies Entering the Market



Jobs

From DOE-supported Commercial Technologies:

450 jobs average per year 

From ARRA-supported Technology Deployments

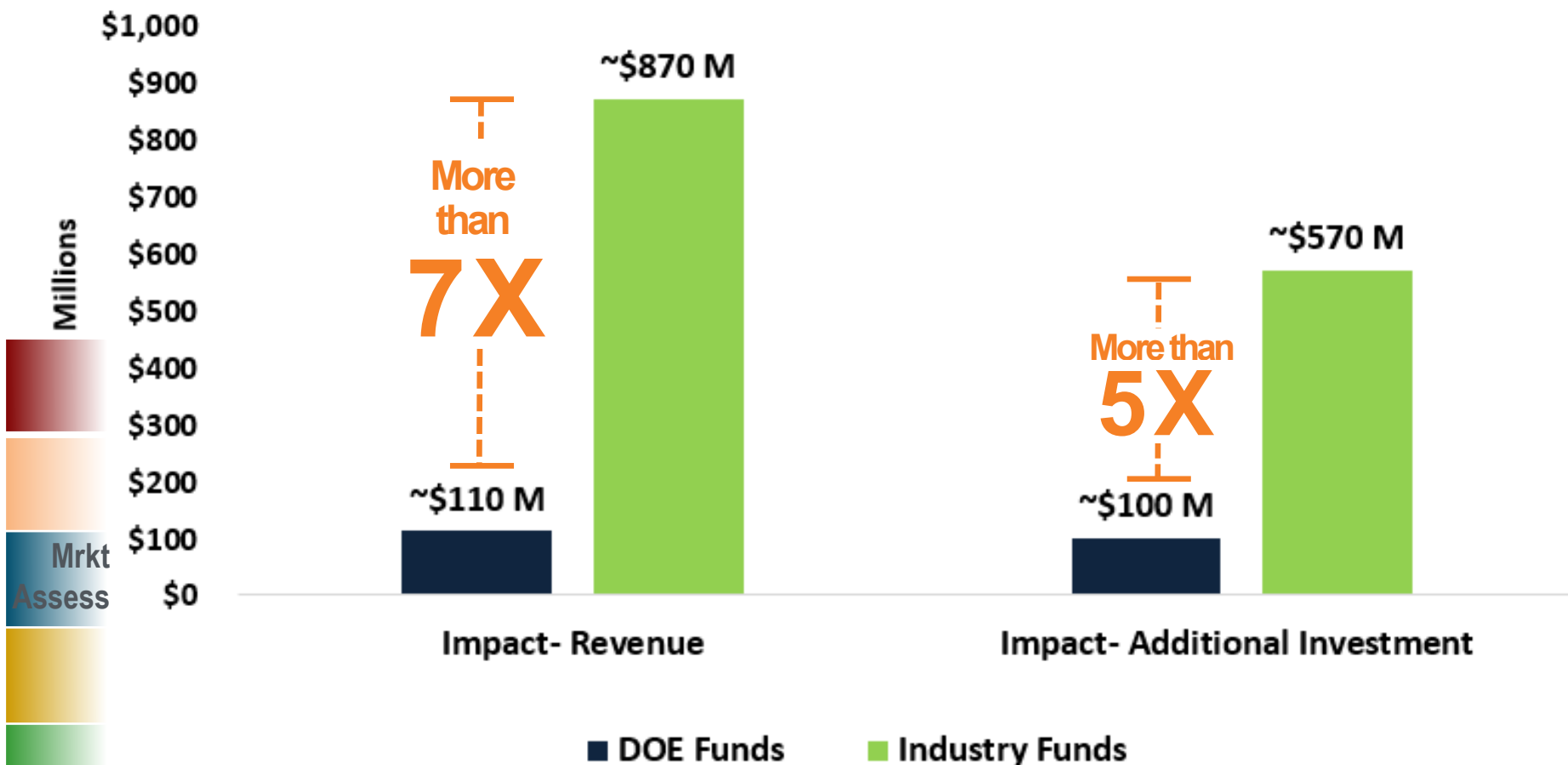
1,400 jobs created or sustained 

ARRA: American Recovery and Reinvestment Act

Examples of Commercial Technologies

- Catalysts
- Electrolyzers
- Fuel Cell System Components
- Tanks

Cumulative Impact of DOE Investment on Industry Revenues and Additional Investment*



* Based on a sample of companies that reported data to FCTO

Government funds catalyzing industry revenues and investment in H₂ & fuel cell industry

Expanded tool cash flow and ROI analysis capabilities for hydrogen fueling stations to include risk analysis, take-or-pay contracts, policy/incentives and more.

H2FAST: Hydrogen Fueling Financial Analysis Scenario Tool 

Overall Financial Performance Metrics

Leveraged, after-tax, nominal IRR	84.44%
Investor payback period	3 years
First year of positive EBITD	analysis year 3
After tax, nominal NPV @ 10% discount	\$ 666,724
Estimated break-even leveraged price (\$/kg)	7.60

Cumulative investor cash flow
Investor contribution + previous year investor contribution

All 1 station(s): Cumulative investor cash flow, (Millions)



Station(s) Information

Select interface type: Basic

Enter num

Multi-Station Inputs

Select station(s) to analyze: All Stations

H2FAST

Station Inputs

Long-Term Station Utilization (%): 70.0

OR

Vehicle Refills (refills/day): 26.25

Hydrogen per Refill (kg): 6.7

Hydrogen Price (\$/kg): 10

Total Capacity (kg/day): 250

Total Capital Cost (\$): 1,182,165

Total Installation Cost (\$): 295,541

O&M Costs (\$/yr): 36,056

Scenario Inputs

Capital Incentive (\$/station): 1,400,000

Initial Production Incentive (\$/station): 0

Annual Decrement of Production Incentive (\$/station): 0

Incidental Revenue (\$/year): 0

Cost of Delivered Hydrogen (\$/kg): 5.5

Cost of Electricity (\$/kWh): 0.12

Investor Net Cash Flow [\$ / year]



Investor Cumulative Cash Flow [\$]





NEW! Capabilities

- Evaluate up to 300 stations and assess finances for individually or as a cluster.
- Take-or-pay contract
- Multiple hydrogen feedstock source
- Risk/stochastic
- Low Carbon Fuel Standard (LCFS), RIN credits (policy decisions)

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
 - Probability distributions

Webinar and peer review held with H2USA stakeholders to discuss tool and model details.

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

Web-based online calculator and Excel spreadsheet versions available

Fin &
Employ

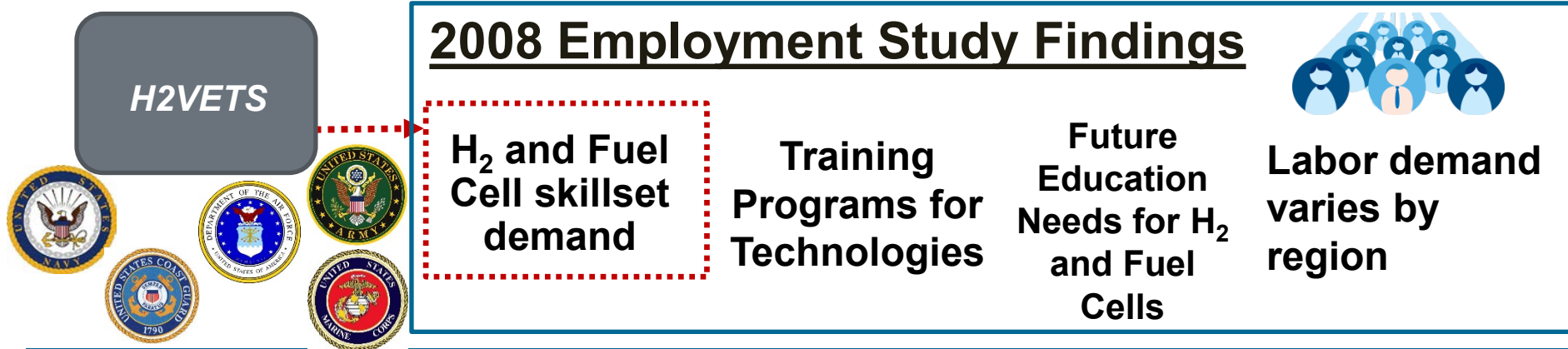
Employment Study

Goal: Determine labor demand, skill set gaps, and regional and national employment impacts of emerging hydrogen and fuel cell technologies with the 2008 Employment Study as the basis.

Approach: Utilize a scenario approach with the REMI model to evaluate the employment impacts.

Accomplishments:

- Conducted a stakeholder workshop to review and revise assumptions, gaps and scenarios of hydrogen demand and fuel cell technology market penetration
- Established a steering team to vet assumptions and modeling approach



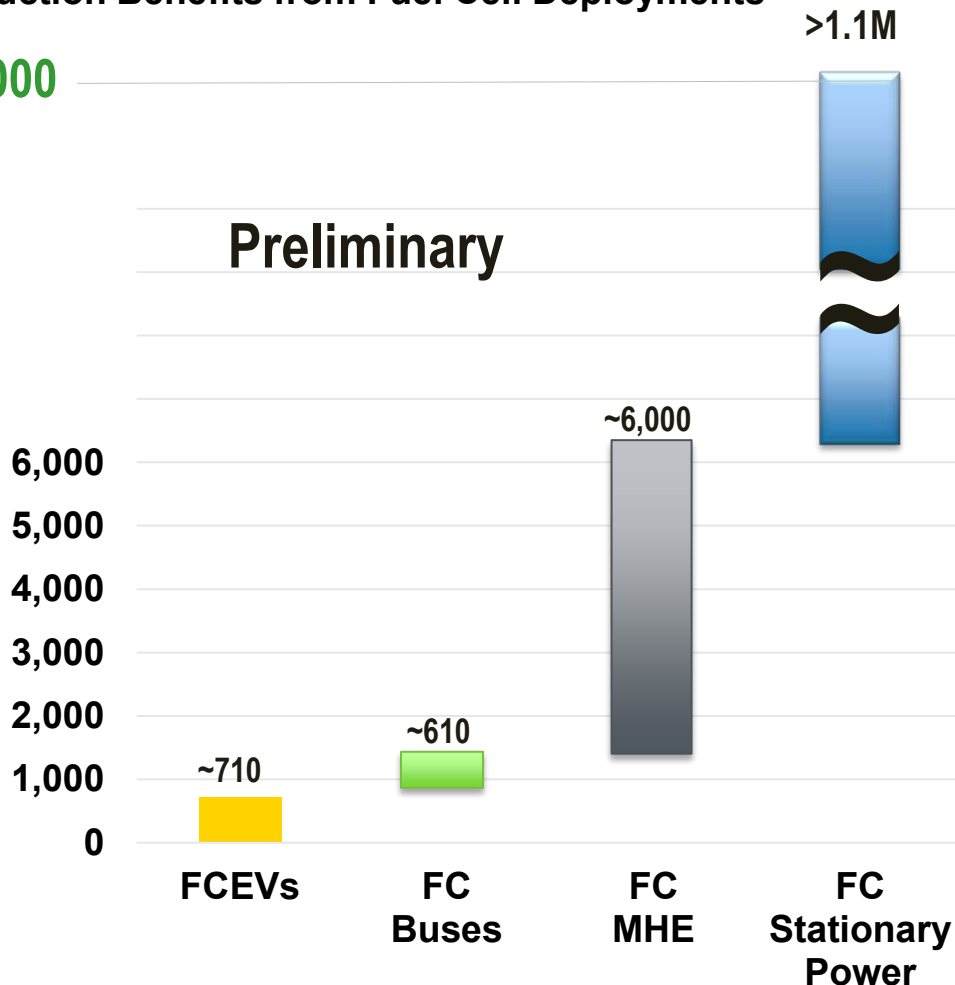
Future Work: Continue development of H2VETS and revision of employment study

Fuel cell deployments through 2014 resulted in the reduction of more than 1.1 million metric tons of GHG emissions and a savings of nearly 450,000 gallons of petroleum

GHG Emission Reduction Benefits from Fuel Cell Deployments

1,100,000

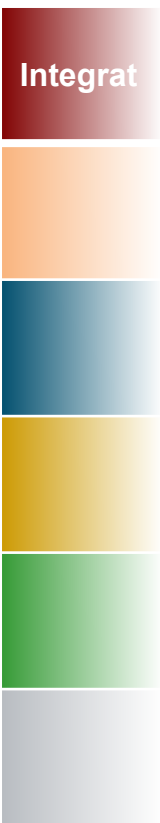
GHG Emissions Reduced, metric tonnes



Assumptions:

- Fuel cell deployments are a result of FCTO RD&D thru 2014.
- Fuel cells deployed:

FCEVs:	150
FC Buses:	11
FC Lift Trucks:	~6,700 units
FC Station:	203 MWs
- Benefits excluded govt. demonstration fleets and early research and pre-release vehicles.



Develop sustainability framework and metrics to gauge the renewable impacts of hydrogen and fuel cell technologies

Potential H₂ and Fuel Cell Technologies Sustainability Framework

Climate Change and Air Quality



Lifecycle analysis of GHG and criteria emissions

Employment Impacts



Employ. demand, skillset gaps and education

Land Use



Land use for renewable H₂ Production

Water Use and Resources

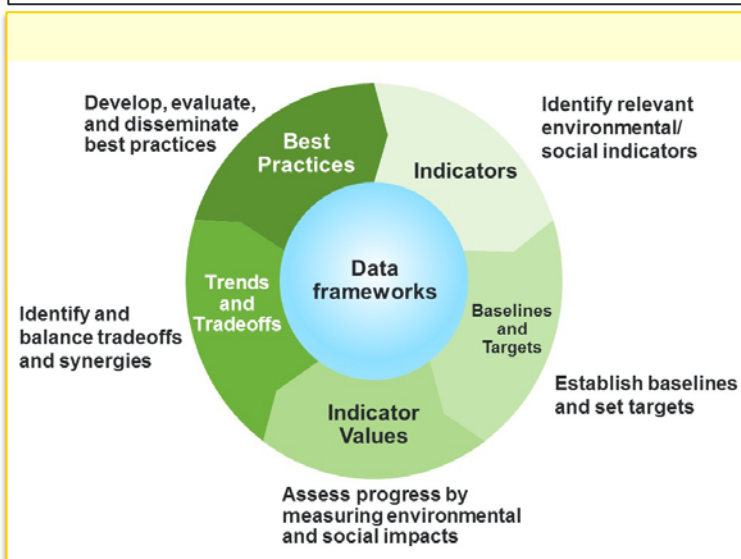


Water use H₂ Production

Goal: Sustainability framework and metrics for H₂ and fuel cell technologies

Approach: Engage stakeholders and sustainability experts to establish process and metrics

Sustainability Process



Accomplishment

- Conducted workshop with stakeholders and experts to understand sustainability, use of metrics and application

Complexity of the transition to alternative fuels and vehicles requires a comprehensive policy strategy addressing all the major barriers and targeted at areas of concentrated early adopters.

Vehicle Cost Incentives Findings

Financial

- Federal income tax credit increased sales by 3% to 20% in 2006
- Subsidies at time of purchase more valuable than tax credits
 - Factor of 10x
- Immediate rebate is worth about 2x more than tax credits
- Incentives >\$1,000 have a statistical impact on sales

Non-Financial

- HOV sticker is worth \$1,200-\$4,000 in CA
- HOV access increased sales in VA
- PEV sales
 - Increased from HOV access, exemption from emission testing and annual fee reductions
 - Unaffected by public charger availability, home charger subsidies, license fee exemptions

Cost of Refueling and Fuel Availability Findings

- Infrastructure capital and/or operating subsidies to obtain 3-5 yr. payback
- Fuel savings is statistically important to consumers
- Consumers willing to pay ~\$1,900 to obtain \$500 fuel savings (3-4 yr. payback)
- For H₂, fuel availability could translate into a vehicle cost penalty of \$4,000-\$16,000
- Recharging networks in San Francisco and Seattle valued at \$1,000 - \$2,000 per BEV
- Fuel availability is a major concern for first adopters until reaches 10% - 20%

Source: David Greene

Recent and Upcoming Activities

Emphasis

- Early market and infrastructure analysis
- Life-cycle analyses of cost, greenhouse gas emissions, petroleum use and criteria emissions, and water use.
- Assess programmatic impacts on market penetration, job creation, and return on investment.
- Evaluate sustainability framework and metrics for FCTO
- Develop carbon reduction target

FY 2016

- **FCTO technology performance and cost status**
- **GREET models for H₂ production technologies including PEC, STCH and photobiological**
- **Employment study, sustainability and H2VETS workshops**
- **Incentive and policy evaluation**

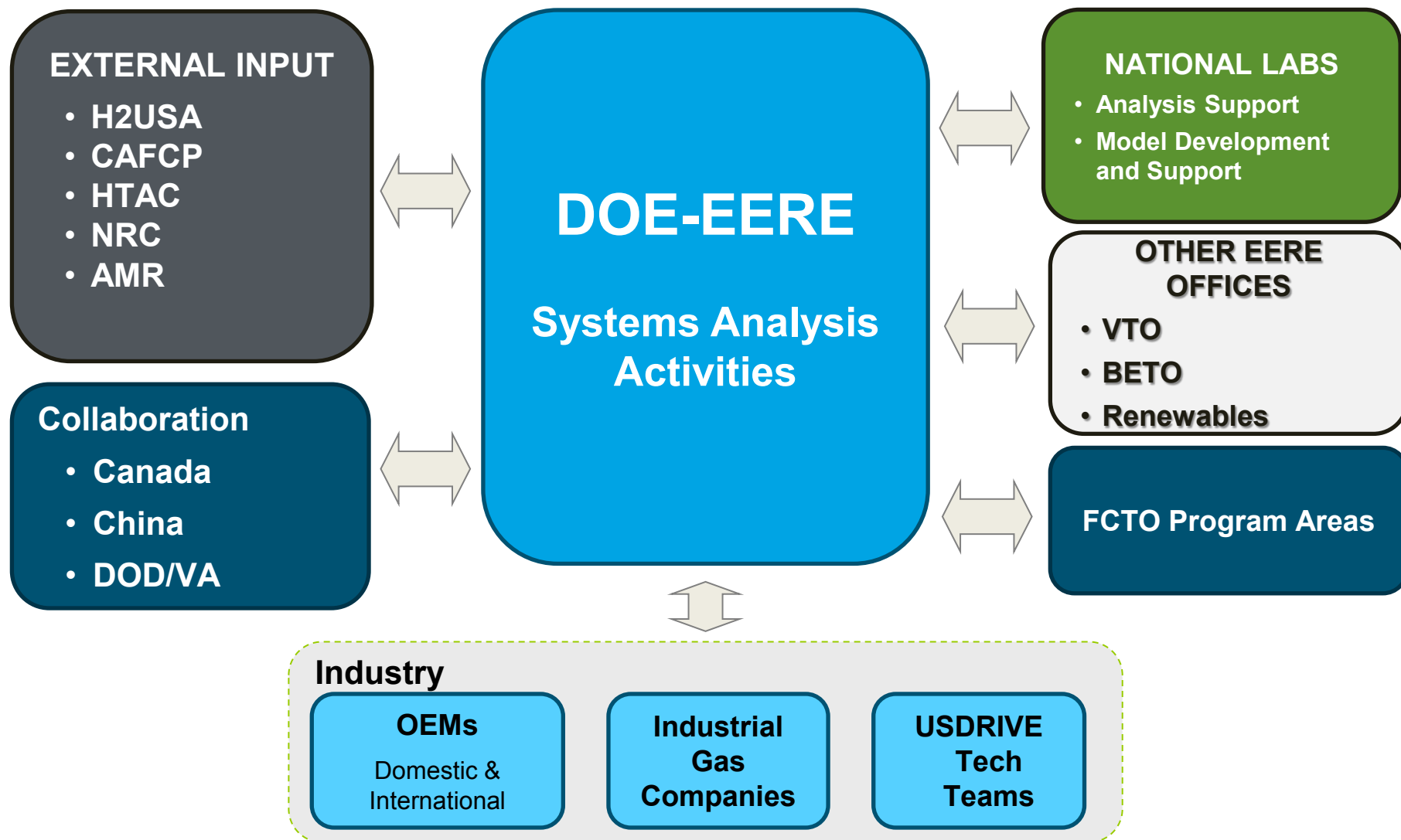
FY 2017

- **Gaps and drivers for early market infrastructure cost**
- **Carbon target for FCTO**
- **H2VETS tool and conduct pilot workshops**
- **Employment study - national employment impacts**
- **Sustainability metrics for FCTO**
- **GHGs for medium & heavy duty trucks**
- **Integrate consumer choice in vehicle market penetration**

FY 2018-2020

- **FCTO milestones and technology readiness goals—including risk analysis, independent reviews, financial evaluations, and environmental analysis**
- **Launch H2VETS tool**
- **Employment study update**
- **Sustainability for hydrogen and fuel cell technologies at the national and regional level**
- **Consumer choice and behavior**

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



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

2015 Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program

<http://energy.gov/eere/fuelcells/downloads/2015-pathways-commercial-success-technologies-and-products-supported-fuel>

MODELS

H2FAST Version 2

by NREL

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

<http://www.h2usa.org/H2FAST>

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

- 16009 – Life-Cycle Costs of Mid Size Lt-Duty Vehicles**
- 16007 - Water Consumption for Light-Duty Vehicles' Transportation Fuels**
- 16004 – Life-Cycle Greenhouse Gas Emissions and Petroleum Use for Current Cars**
- 16003 – GHG Emissions and Petroleum Use Reduction from Fuel Cell Deployments**
- 16002 – Environmental and Energy Security Benefits for APUs in Transportation Applications**
- 15012 - Low-Volume Early-Market Hydrogen Cost Target**

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

Reminder!

General Analysis Session

When: Wednesday @ 8:30AM – 2:15 PM

Session: 6

Infrastructure Analysis Session

When: Thursday 8:30AM - 5:15PM

Session: 7