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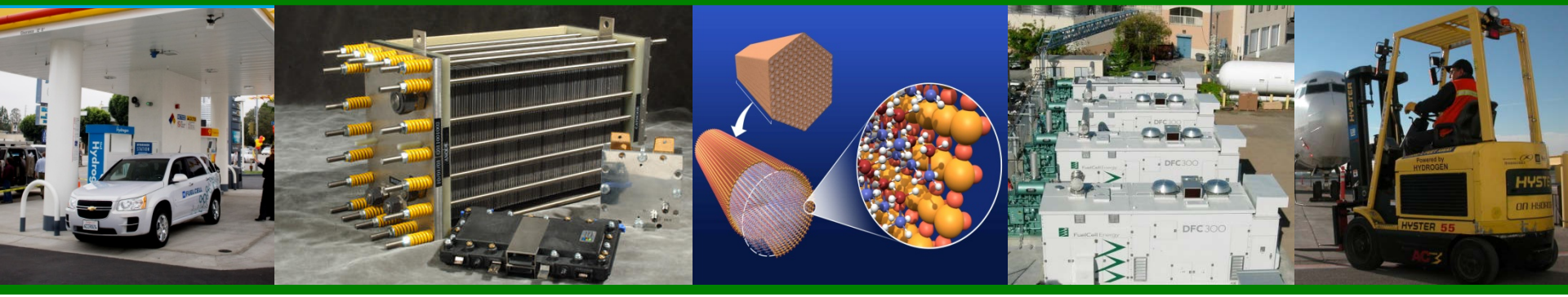

Systems Analysis Program Area
- Plenary Presentation -

Fred Joseck

Fuel Cell Technologies Office

2016 Annual Merit Review and Peer Evaluation Meeting

June 6-10, 2016

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 (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.

Strategy

Support a strong foundation of data, build relevant analytical models and execute insightful integrated analyses

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Partnerships with labs, industry, academia

System Analysis Framework

- Consistent and transparent data
- Prioritized analysis tasks
- Organize data and results for decision making
- Effective analytical workshops to gather key input assumptions for analysis

Models and Tools

- Life cycle analysis benefits of hydrogen and fuel cells for diverse applications
- Portfolio of validated models for near and long term analyses

Studies and Analysis

- Initial phases of technology early market penetration
- Long-term potential and issues
- Environmental analysis
- Energy storage analysis
- Resource supply for hydrogen production
- Consumer choice and behavior impacts

Deliverables/ Results

- Support decision-making processes and milestones
- Direction, planning and resources
- Independent analysis to validate decisions
- Risk analysis of program area targets
- Sustainability metrics
- Carbon emission reduction target

Internal and External Peer Review

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, 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.

Budget

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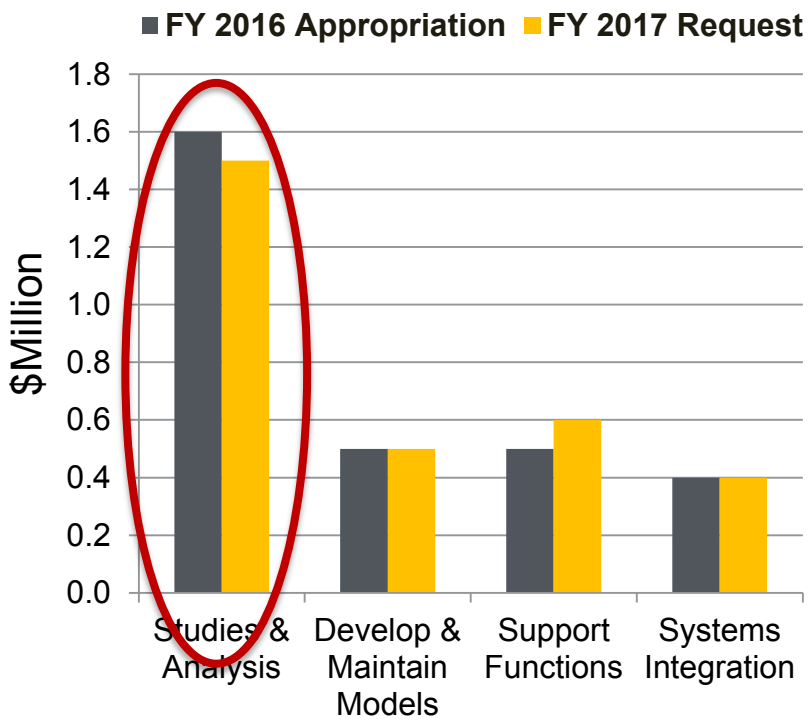
Focus: Determine technology gaps, economic/jobs potential, and benefits of key technology advances; and quantify 2017 technology advancement.

FY 2016 Appropriation = $3.0 M

FY 2017 Request = $3.0 M



* 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

- 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 H_2 cost target.
- Evaluation
  - Use of hydrogen for energy storage.
  - Sustainability framework and metrics.

Systems Analysis Program at a Glance

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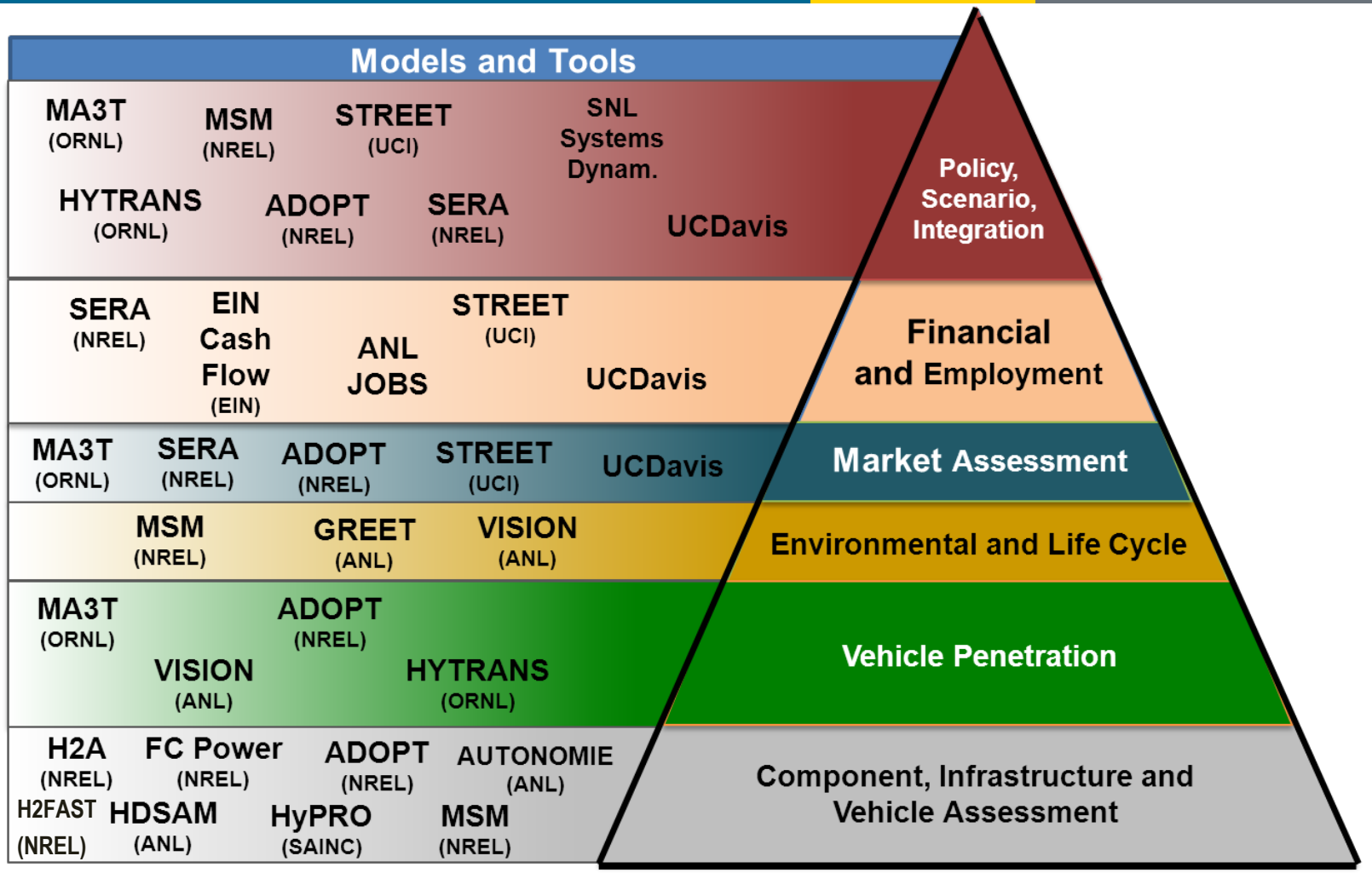
DOE's Fuel Cell Technologies Office model and tool portfolio is versatile, comprehensive and multi-functional.



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

FY15-16 Highlights and Future Work

FY15-16 Highlights: Current Cost of Hydrogen

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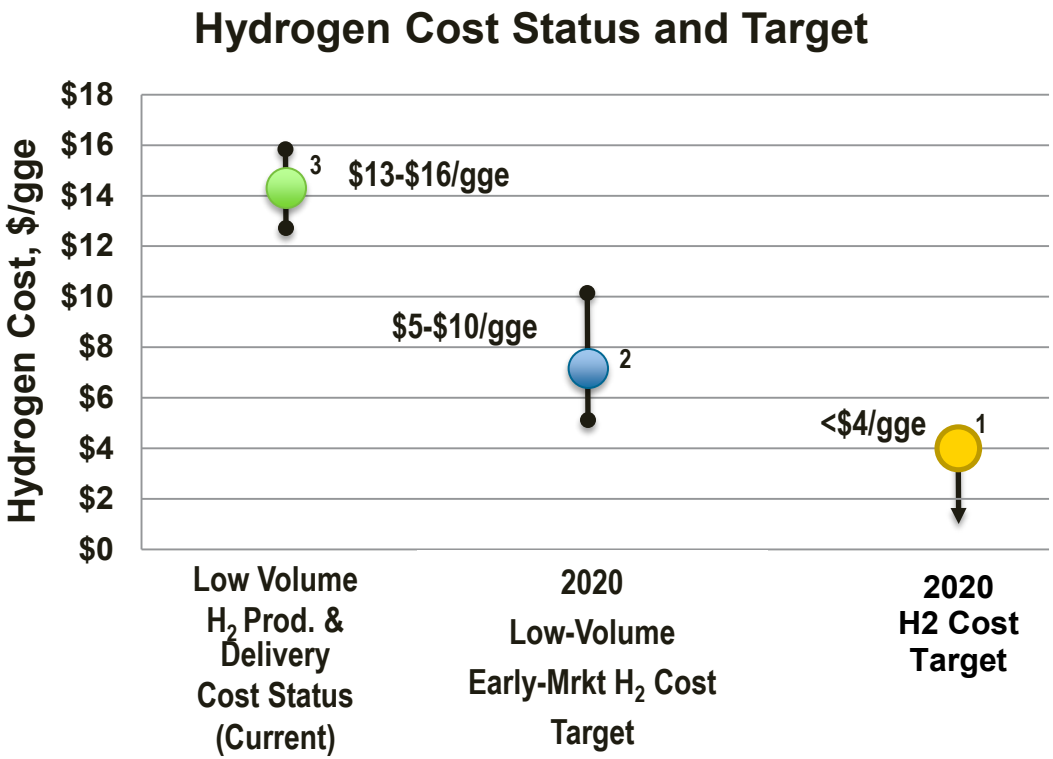
Current cost of low volume H_2 production and delivery ranges from $13 – 16/gge.



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 H_2 in northern CA was $13.59/gge (1/22/15) and $15.00/gge in southern CA (2/25/15).

Infra

Component, Infrastructure and Vehicle Assessment
FY15-16 Highlights: 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 Vehicle and BioEnergy Technologies and U.S.DRIVE**
- **Vehicle life cycle cost assumptions with U.S. DRIVE "Cradle-to-Grave" Analysis**

Common Assumptions

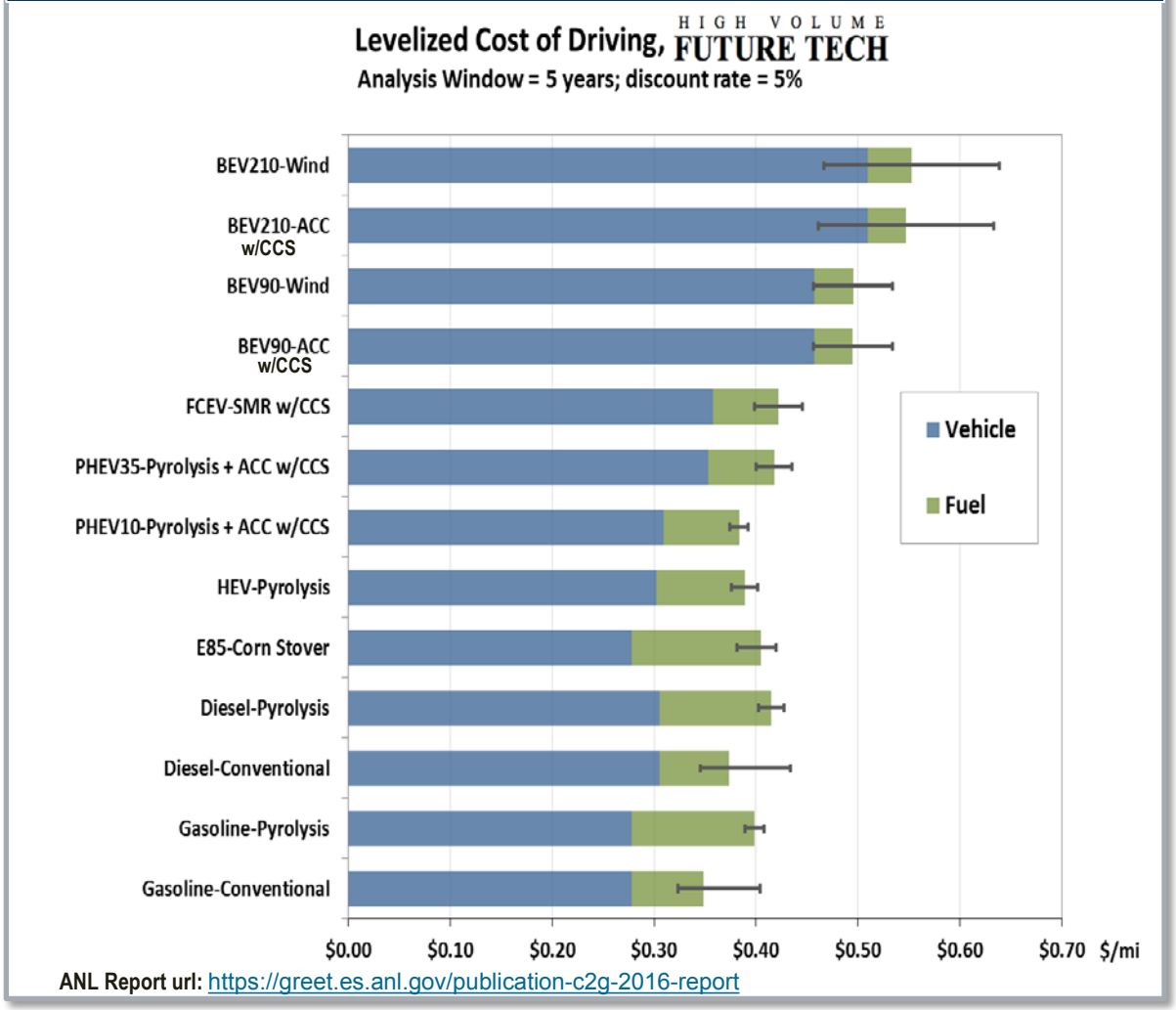
- 5-year ownership
- 14,200 miles per year
- 5% discount for annual fuel costs
- Resale value at 17.5% of new vehicle price

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



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

Source: ANL Report: Cradle-to-GraveLifecycle Analysis of U.S. Light Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025-2030) Technologies

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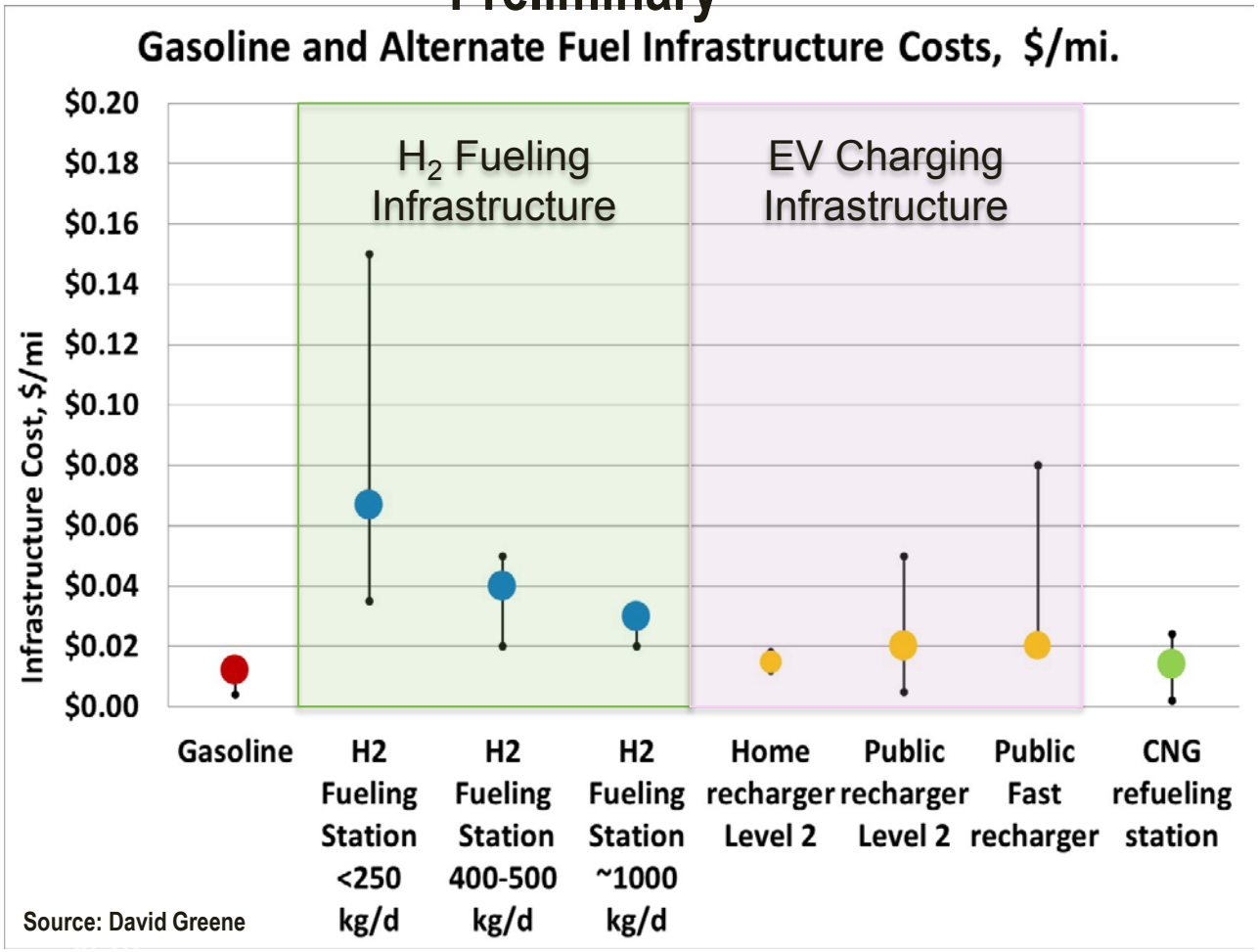
EV and H_2 infrastructure costs are similar on standardized cost per mile basis

Preliminary



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.

Infra

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

FY15-16 Highlights: Impact of FCTO Targets on Vehicle Cost

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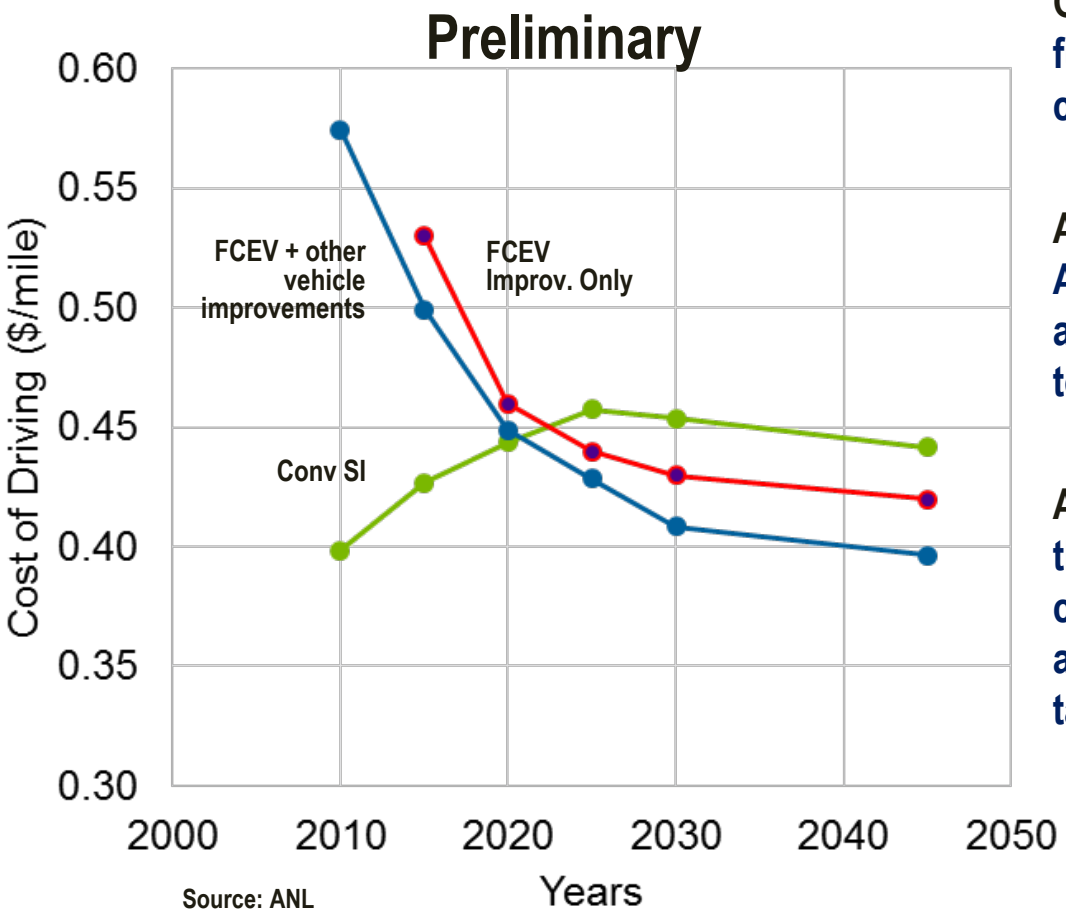
By achieving the 2020 FCTO targets, FCEVs could be competitive with conventional vehicles on a cost per mile basis by 2025-2030



Source: ANL

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

FY15-16 highlights: Lifecycle Analysis of Light-Duty Vehicle GHG Emissions

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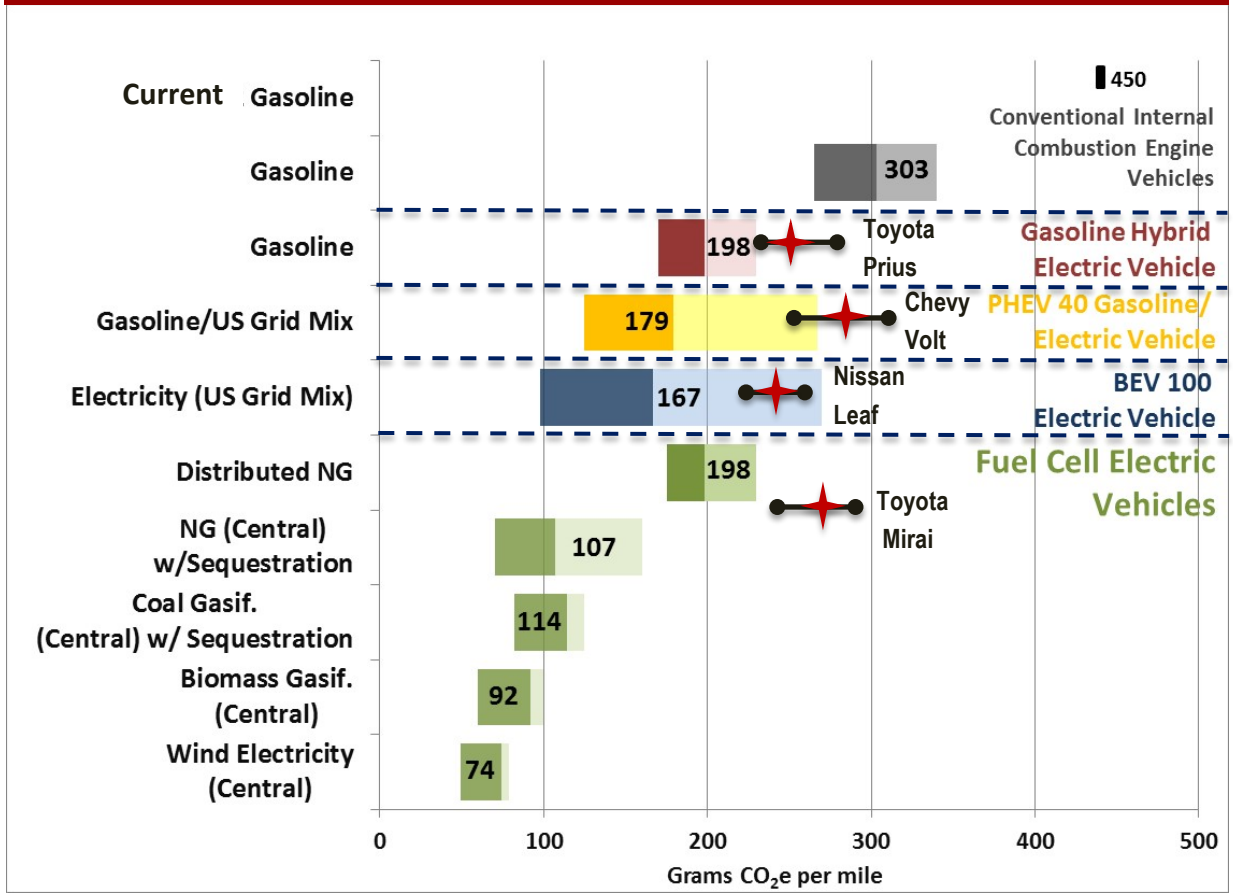
DOE is pursuing a portfolio of technologies with the potential to significantly reduce greenhouse gas emissions from light-duty vehicles

Preliminary Lifecycle Analysis of Greenhouse Gases Emissions Future Mid-Size Car (_Grams of CO_2-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

Environmental and Life Cycle Analysis

FY15-16 highlights: GHG Emission Analysis of Emerging Production Pathways

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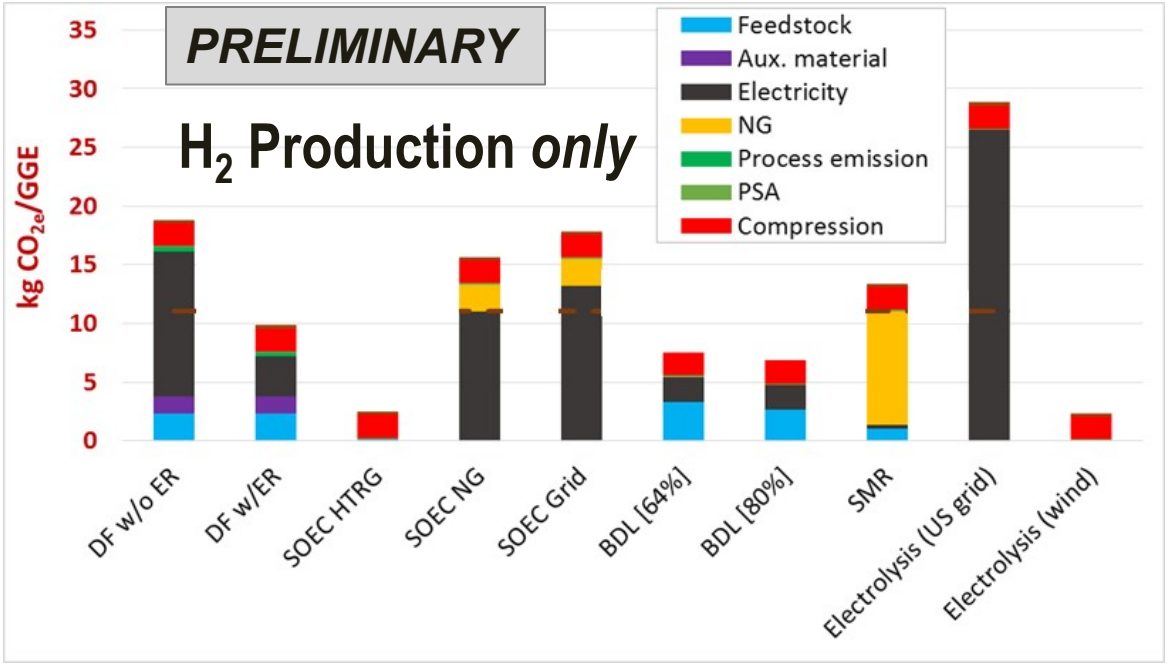
H_2 produced from renewable energy sources have the potential to have lower ghg emissions from the production portion of the pathway than US grid-based electrolysis and SMR-produced H_2



Goal: Understand GHG emissions of emerging renewable H_2 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

Market Assessments
FY15-16 highlights: Patents, Commercial & Emerging Technologies

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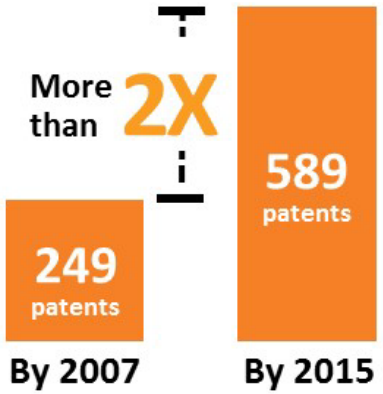
DOE funded R&D has led to more than 589 patents, 46 commercial hydrogen and fuel cell technologies and 68 emerging technologies.

Market Assess

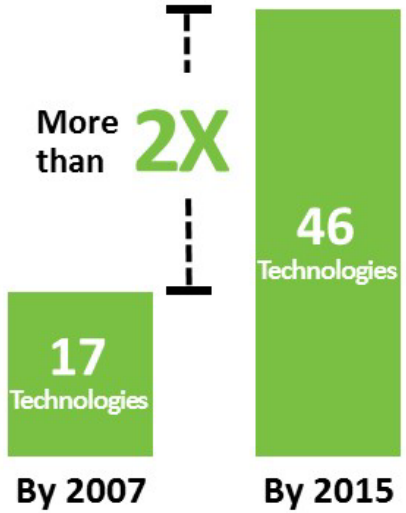
Innovation

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

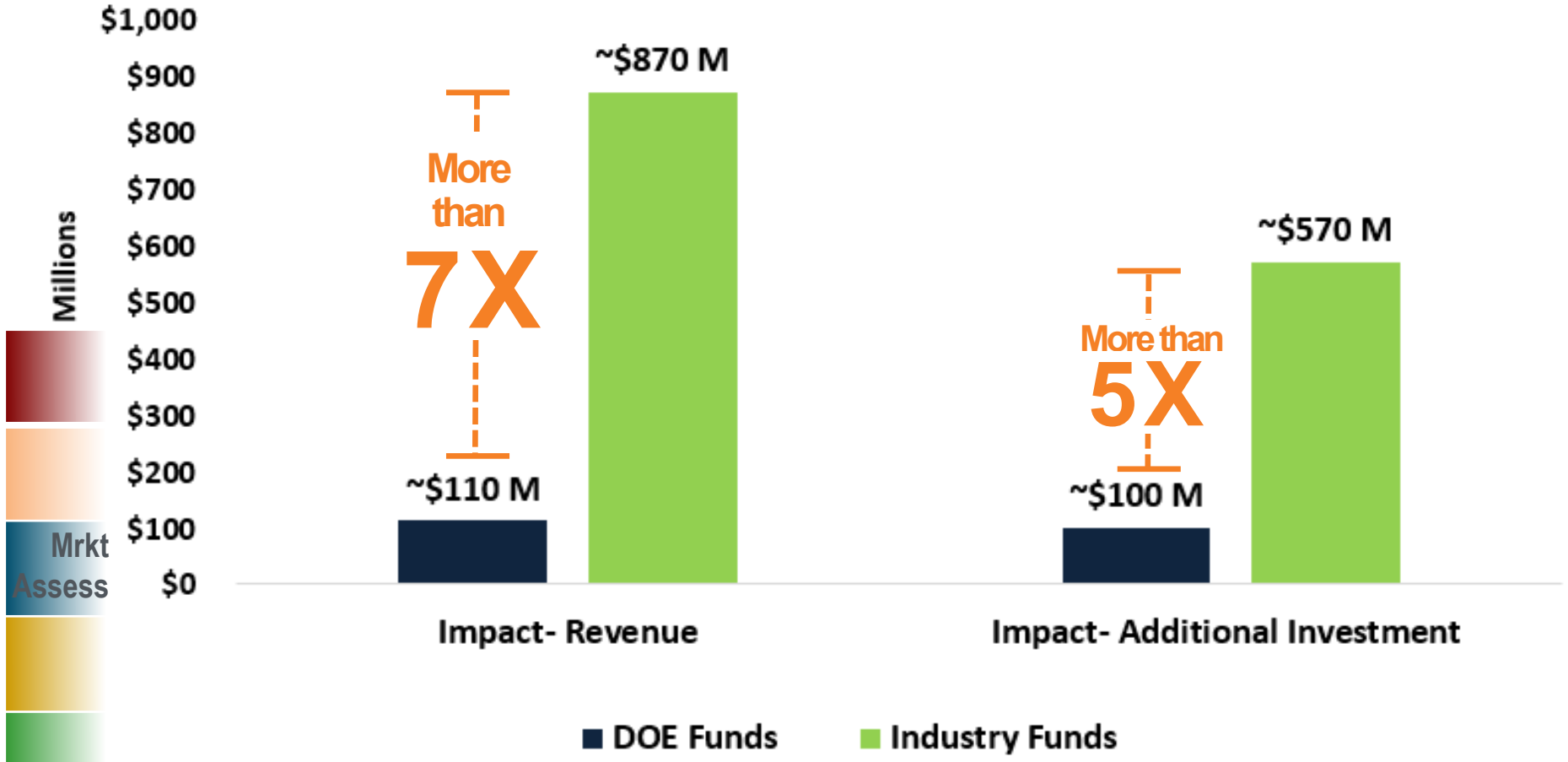
ARRA: American Recovery and Reinvestment Act

Examples of Commercial Technologies

- Catalysts
- Electrolyzers
- Fuel Cell System Components
- Tanks

Source: Pacific Northwest National Laboratory, http://energy.gov/eere/fuelcells/downloads/2015-pathways-commercial-success-technologies-and-products-supported-fuel

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 H_2 & fuel cell industry

Financial and Employment Analysis

FY15-16 Highlights: Hydrogen Financial Analysis Scenario Tool (H2FAST) Update

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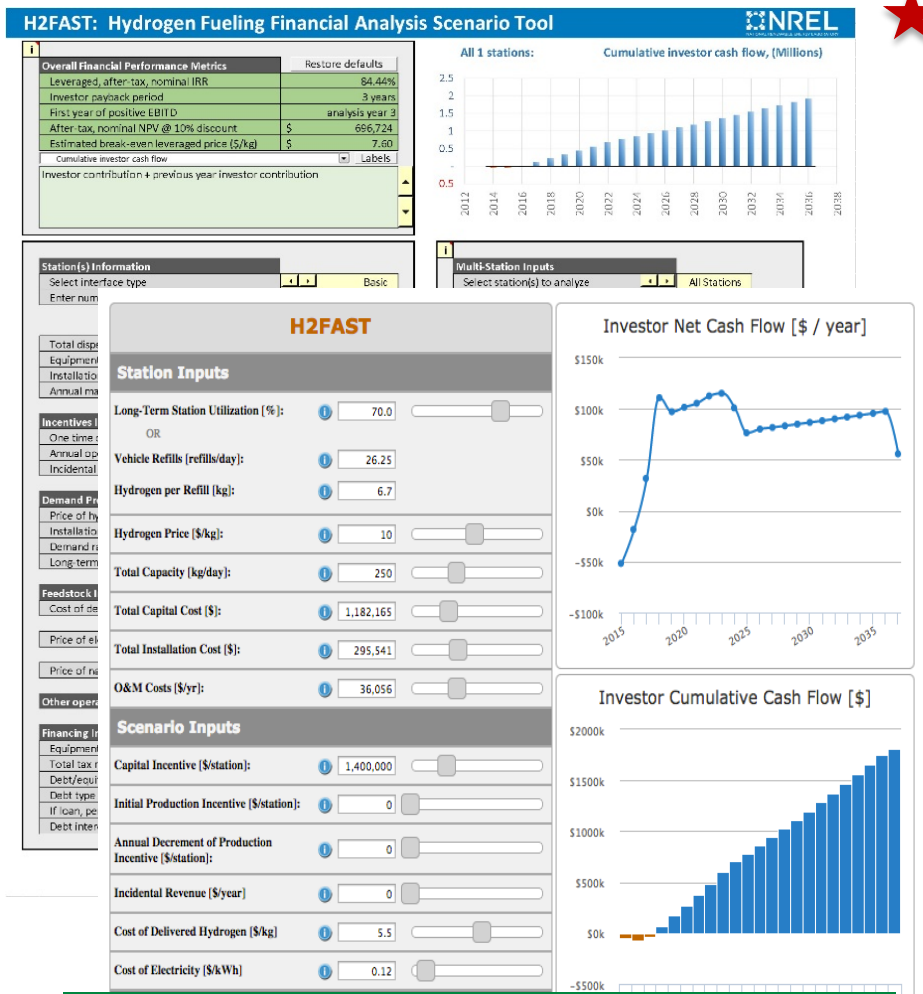
*Expanded tool **cash flow and ROI analysis capabilities** for hydrogen fueling stations to include risk analysis, take-or-pay contracts, policy/incentives and more.*



Web-based online calculator and Excel spreadsheet versions available

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

Source: NREL

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

H2VETS

2008 Employment Study Findings

- H_2 and Fuel Cell skillset demand
- Training Programs for Technologies
- Future Education Needs for H_2 and Fuel Cells
- Labor demand varies by region

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

FY15-16 Highlights: Benefits from FCTO RD&D and Fuel Cell Deployments

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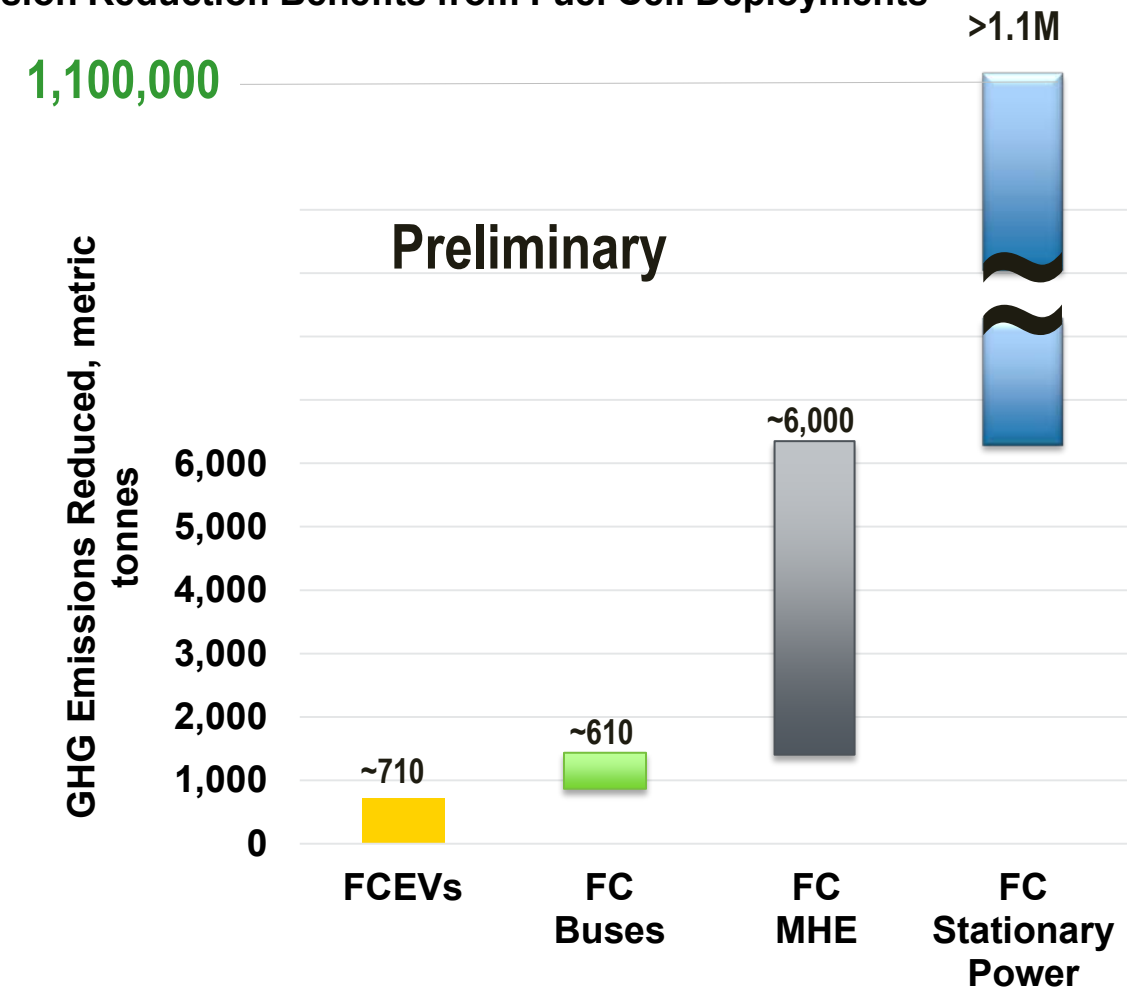
Fuel cell deployments through 2014 resulted in the reduction of more than 1.1 million metric tons of GHG emissions and a savings of nearly 450,000 gallons of petroleum

GHG Emission Reduction Benefits from Fuel Cell Deployments



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 H_2 and Fuel Cell Technologies Sustainability Framework

Climate Change and Air Quality	Employment Impacts	Land Use	Water Use and Resources
			
Lifecycle analysis of GHG and criteria emissions	Employ. demand, skillset gaps and education	Land use for renewable H_2 Production	Water use H_2 Production

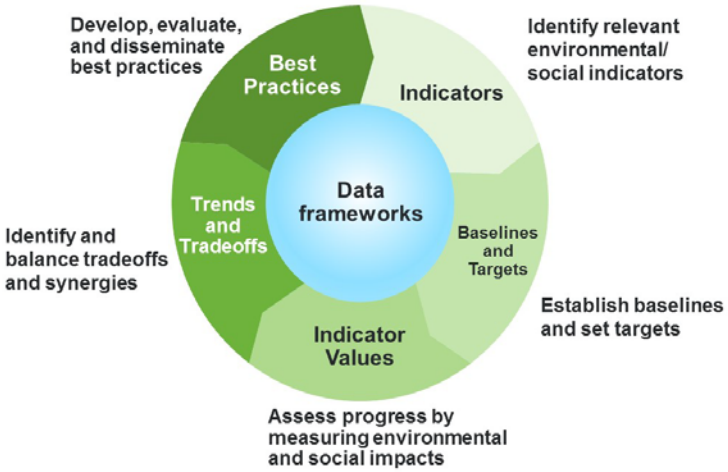
Accomplishment

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

Goal: Sustainability framework and metrics for H_2 and fuel cell technologies

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

Sustainability Process



Source: DOE BioEnergy Technologies Office

Policy, Scenario and Integration Analysis

FY15-16 Highlights: Incentives and Policy Analysis

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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.

Integrat

Vehicle Cost Incentives Findings

Financial

- Federal income tax credit increased sales by 3% to 20% in 2006
- Subsides 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 H_2, 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

Future Work: Assess incentives/policies through consumer choices on vehicle penetration

Recent and Upcoming Activities

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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	FY 2017	FY 2018-2020
• **FCTO technology performance and cost status** • **GREET models for H_2 production technologies including PEC, STCH and photobiological** • **Employment study, sustainability and H2VETS workshops** • **Incentive and policy evaluation**	• **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**	• **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**

Collaborations

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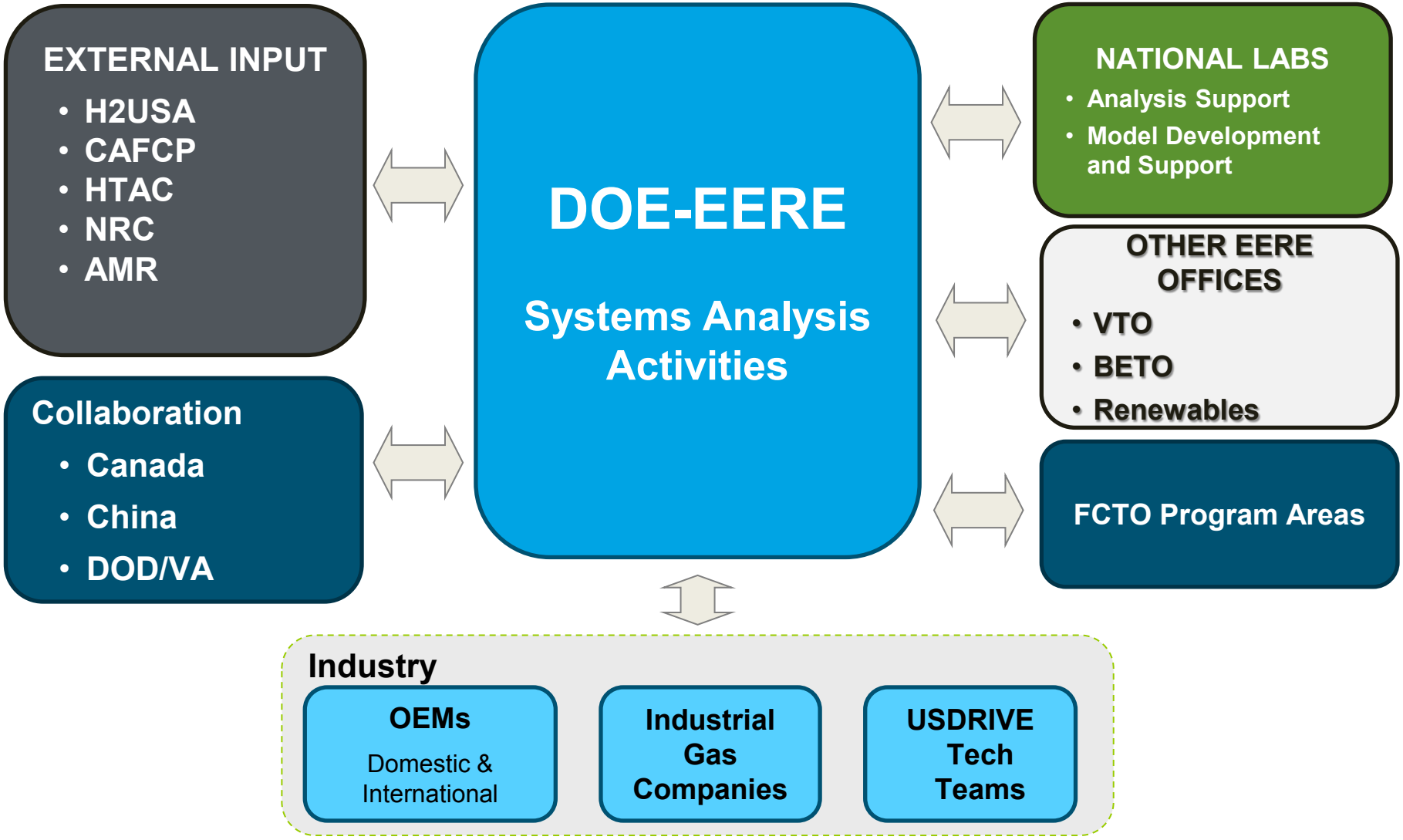
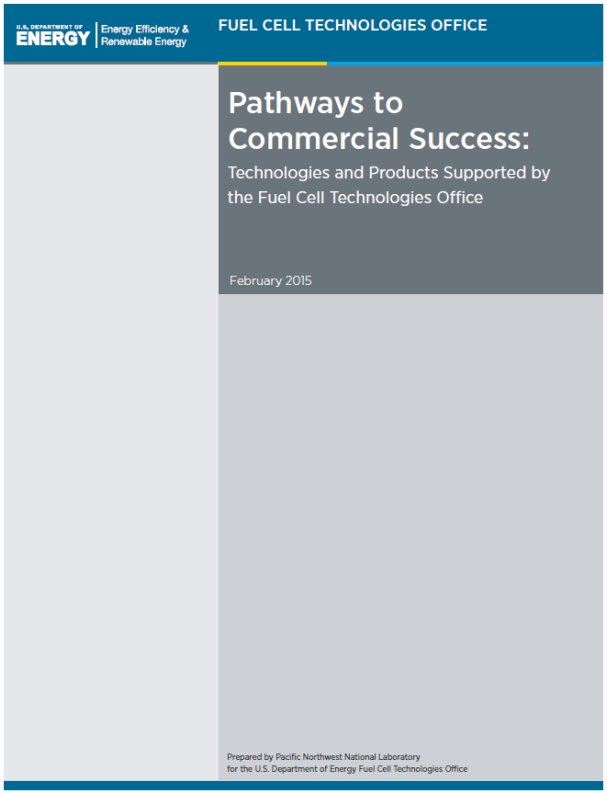
Analysis and peer review input coordinated among national and international organizations.



Key Model, Report and Record Releases



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

Contacts

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For more information contact:

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John Stevens Post Doc University at California Berkeley (New team member)	Vanessa Trejos Support Contractor 202-586-5153 vanessa.trejos@ee.doe.gov

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