U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

System Analysis Program Overview

Poster SA01

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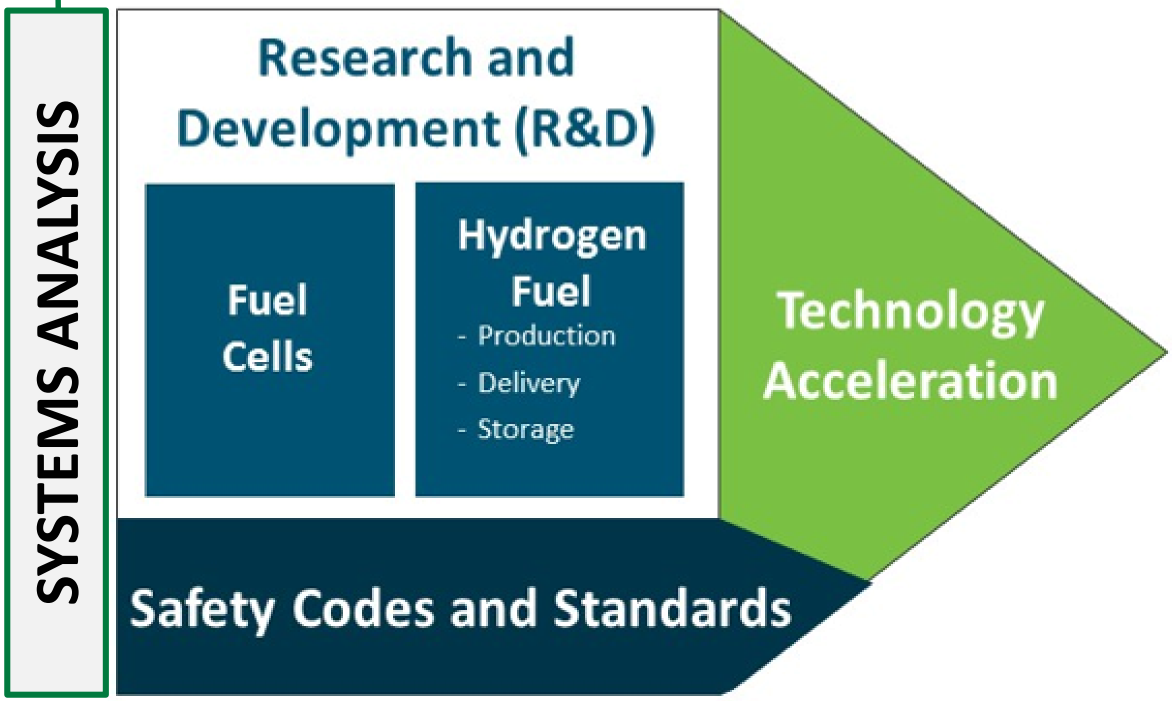
2018 Annual Merit Review

Washington, D.C. – June 13, 2018


Structure and Objectives

Systems Analysis Fit Within the Hydrogen and Fuel Cells Program

SA activities span across all focus areas and guide early-stage R&D and supporting efforts



Objectives

Evaluate
- Technologies and pathways
- Hydrogen supply and demand
- Energy security benefits

Guide
- Selection of R&D technology options

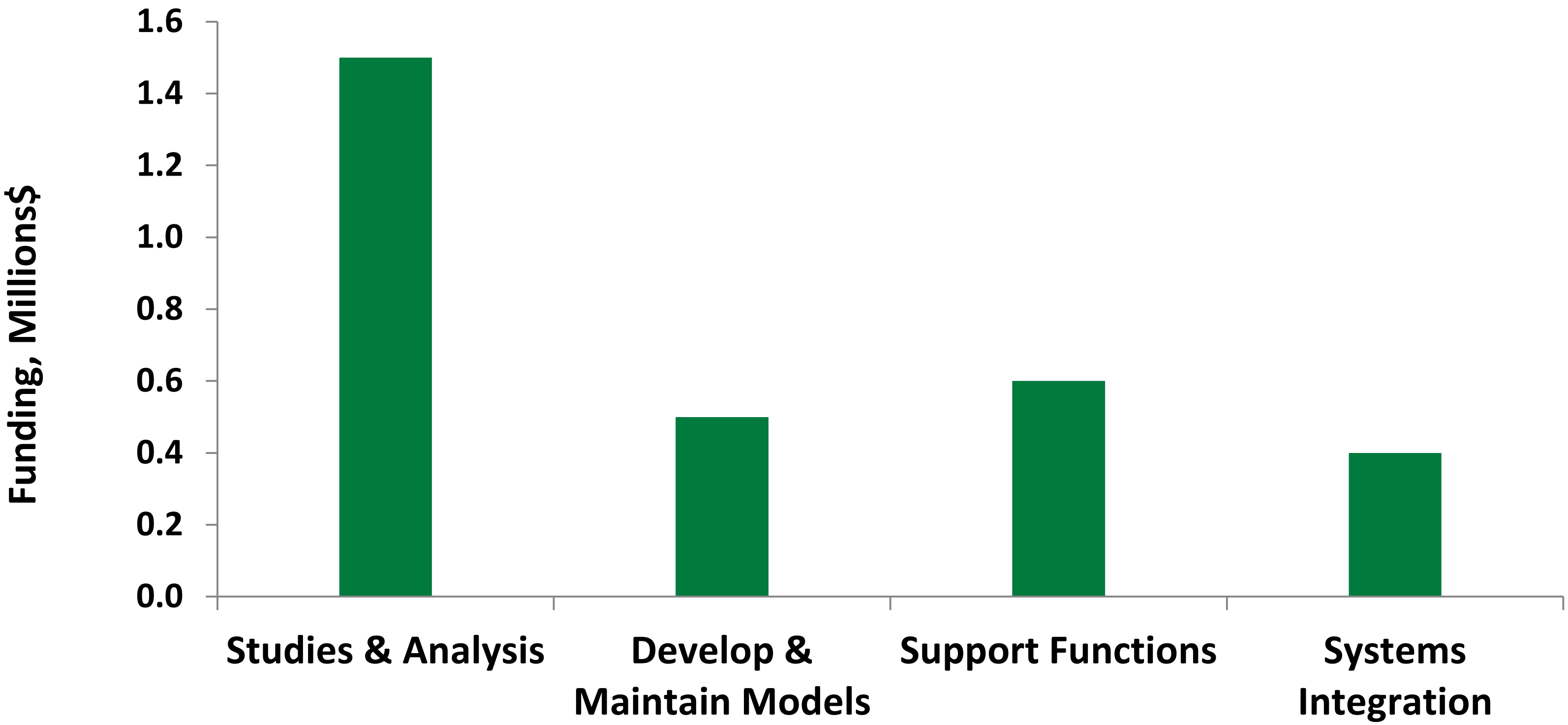
Estimate
- Potential value of early-stage R&D efforts

Identify
- Technology gaps including H2@scale

Budget – FY 2018 Appropriation

Total funding: $3.0 Million for FY 2018

Focus: Estimate and evaluate early-stage R&D gaps, impact and potential growth.



Strategy

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
- Energy security analysis
- Energy storage analysis
- Resource supply for hydrogen production

Deliverables/ Results

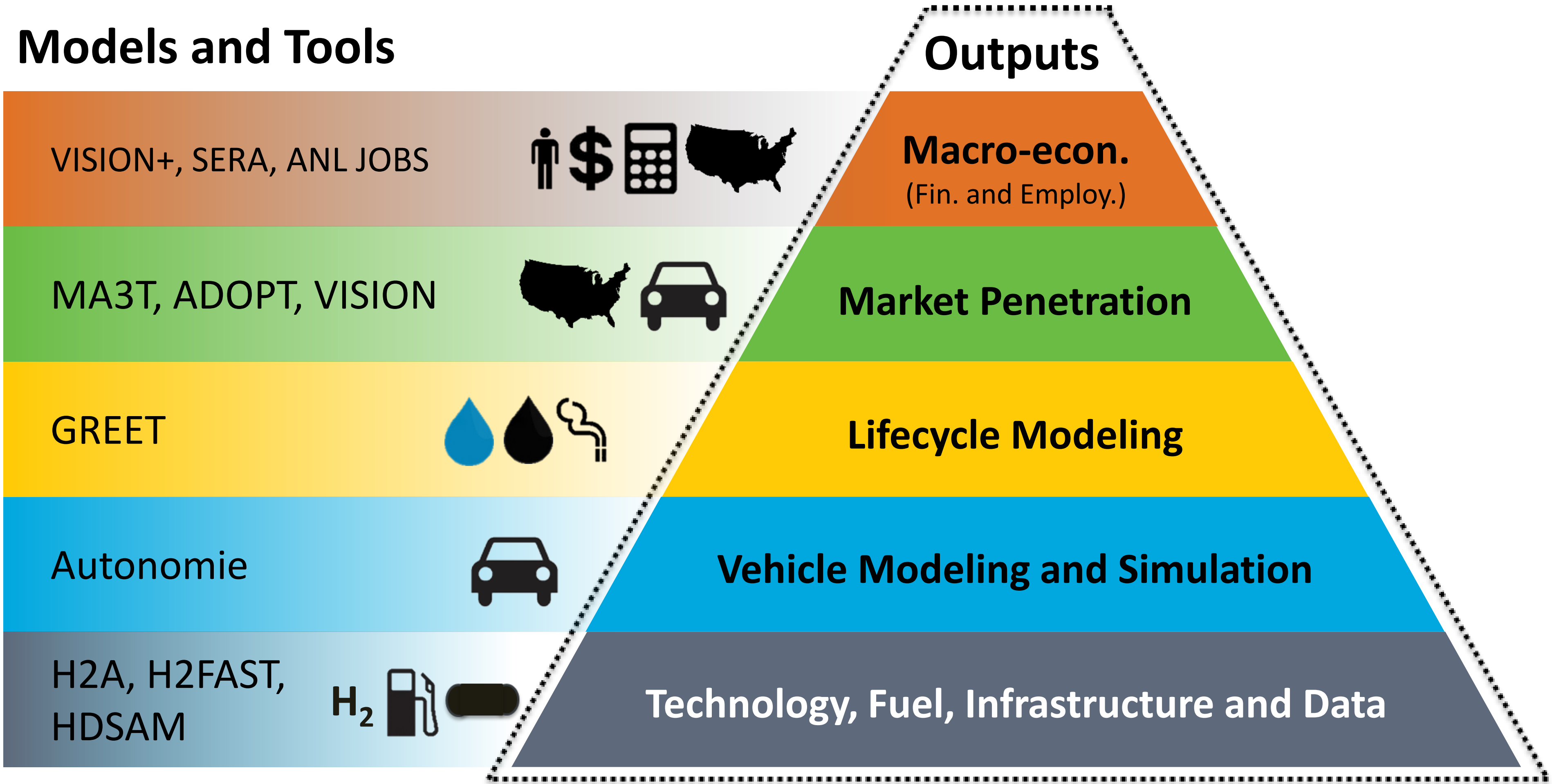
- Support decision-making processes and milestones
- Direction, planning and resources
- Independent analysis to validate decisions
- Risk analysis of program area targets
- Sustainability metrics

FCTO Program Collaboration and Input

Internal and External Peer Review

Model and Tool Portfolio

A versatile, comprehensive and multi-functional portfolio:



Model Description Factsheets Available at: www.energy.gov/eere/fuelcells/systems-analysis

FCTO Analysis Portfolio in Summary

Analysis Type: / Models:	Tech., H_2, Infras & Data	VEHICLE	Lifecycle	MARKET	MACRO
H2A					
HDSAM					
ORNL and HyARC databases					
Autonomie					
FASTSim					
GREET					
MA3T					
ADOPT					
SERA					
JOBS					
VISION					

- Covers the full analysis space and includes some redundancies (left figure)
- Some projects (figure below) span all categories for a truly integrated analyses

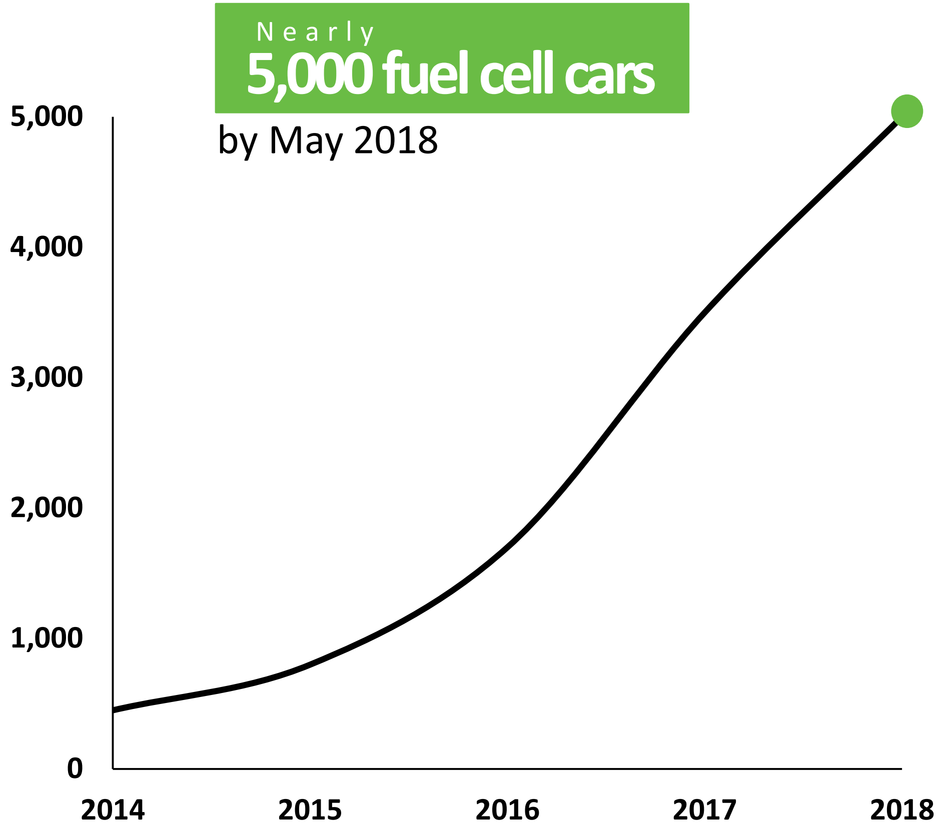
Project Example:

GPRA* Integrated Analysis	DATA	VEHICLE	Life Cycle	MARKET	MACRO
H2A, HDSAM and expert input					
Autonomie					
GREET					
MA3T					
VISION					

* Government Performance Results Act

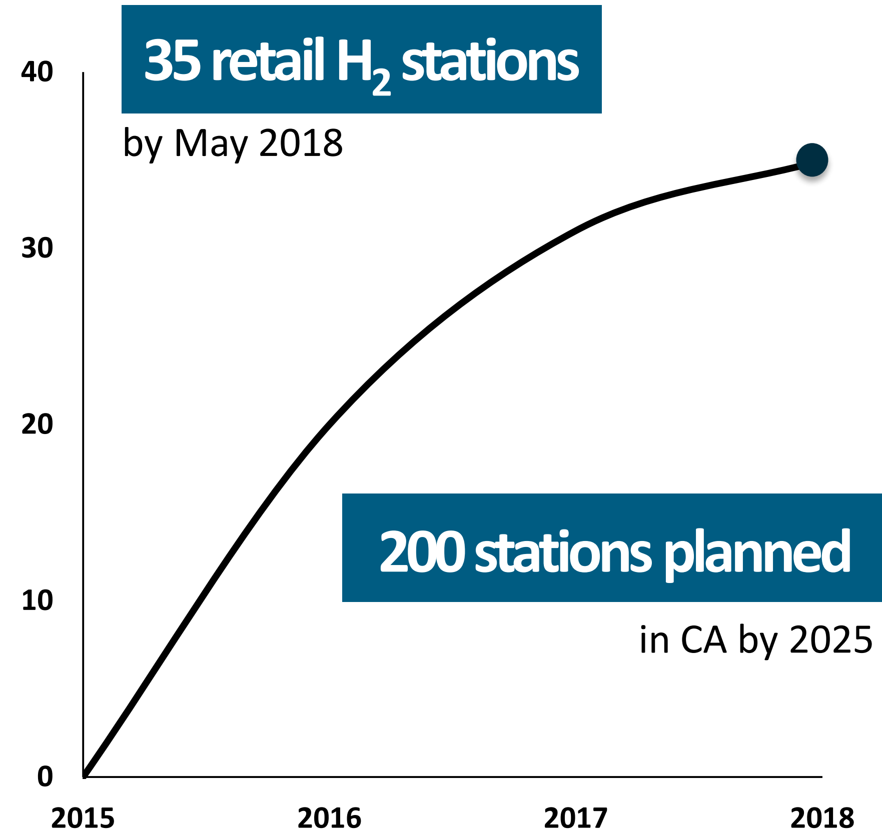
Fuel Cell Cars and Stations Growth Over the Years

Fuel Cell Car* Sales and Leases in the U.S.



*Toyota Mirai, Hyundai Tuscan, Honda Clarity

Retail H_2 Stations in California



Sources: California Office of the Governor

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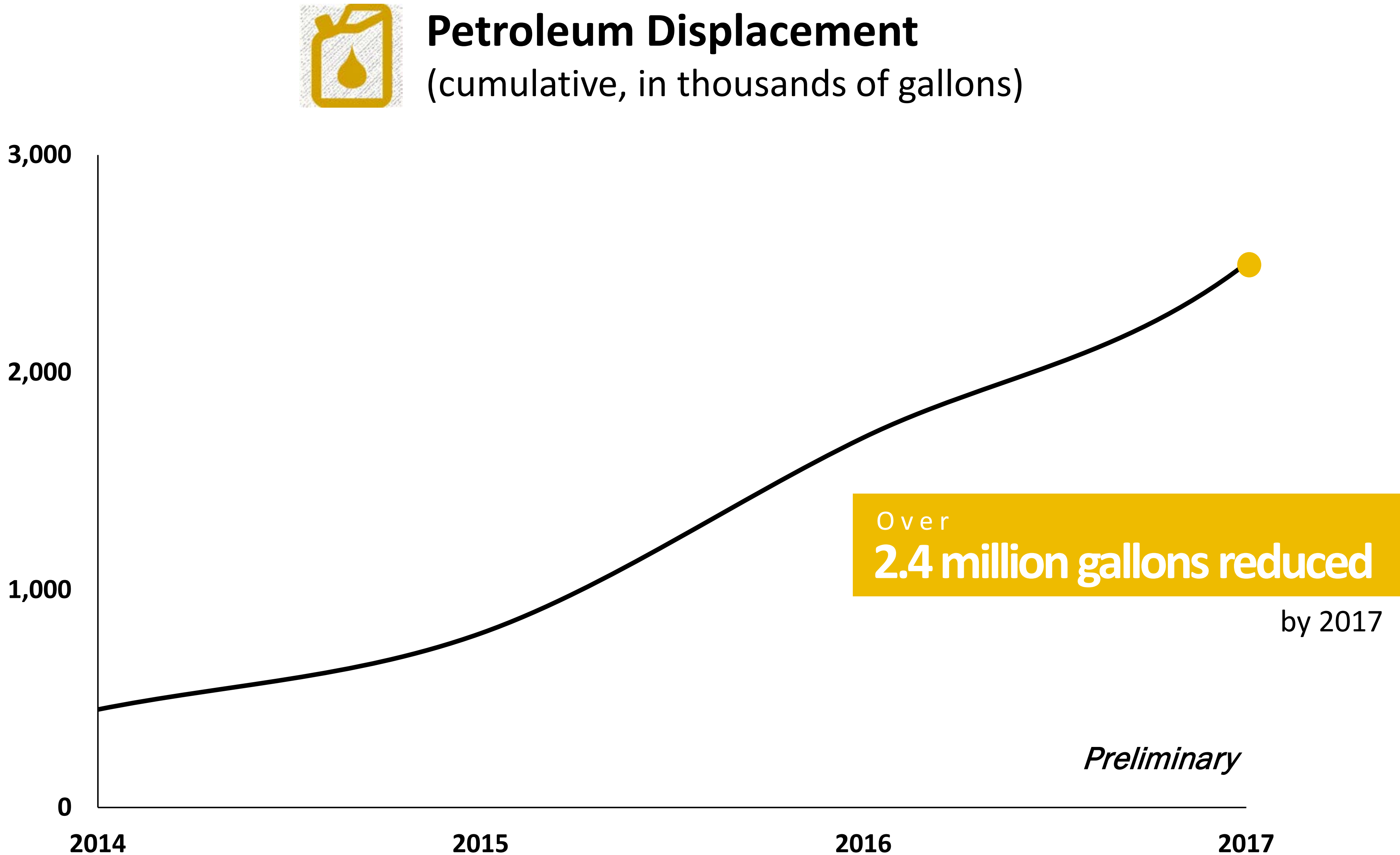
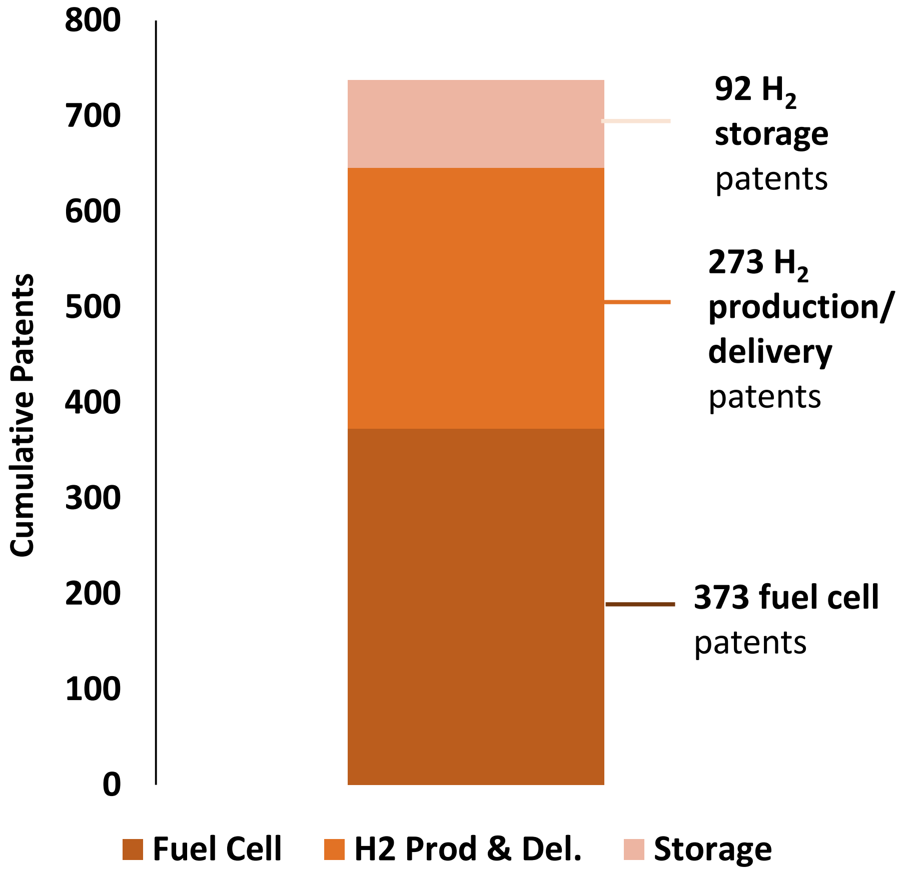
H_2 and Fuel Cells Enable Energy Security Benefits



DOE efforts have enabled early stage R&D innovation

Cumulative H_2 and fuel cell patents enabled by FCTO (2017)



738 patents

enabled by FCTO funds

Approx. **36%** of H_2 and fuel cell patents **come from National Labs**

FY 2017 – FY 2018 Highlights

Identified key cost areas to guide R&D portfolio

Fuel Cells

Bipolar Plates
Membranes
BOP
MEA Frames/Gaskets
GDLs

Focusing on…

Low and Non PGM Catalysts,

Alkaline Membranes

H_2 Station

Storage
Cooling
Dispensing
Other

Advanced Compression

Alternate Approaches

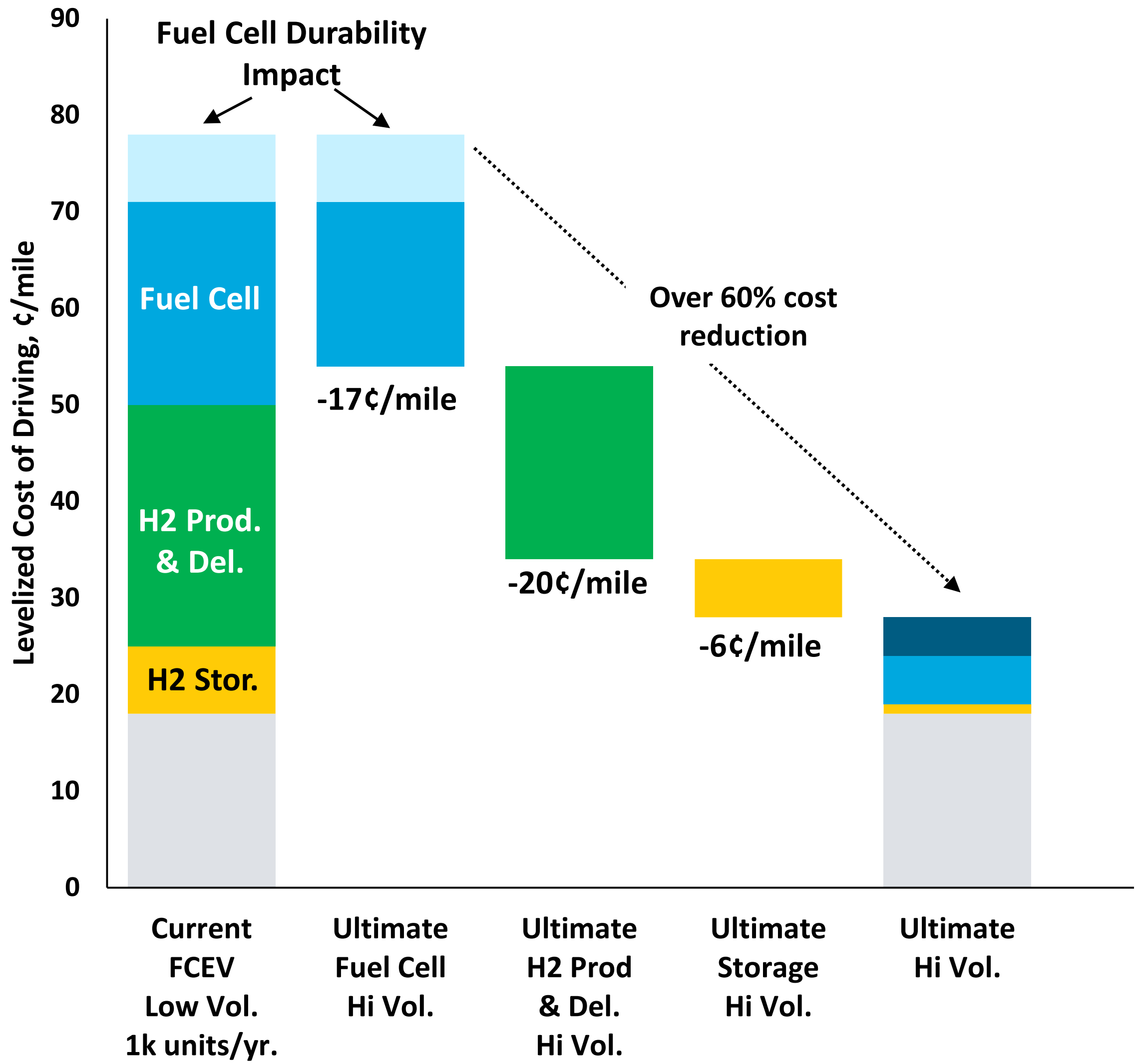
H_2 Storage

BOP/Assembly
Other processing
Resin

Low Cost Carbon Fiber (CF)

Long term Materials Approaches

Identified Fuel Cell Car Cost Reduction Pathways



Early R&D Needs and Status*

Lower fuel cell cost

Now	Ultimate***
$79/KW	$30/KW

Lower hydrogen cost

Now	Ultimate
$16/gge**	$4/gge

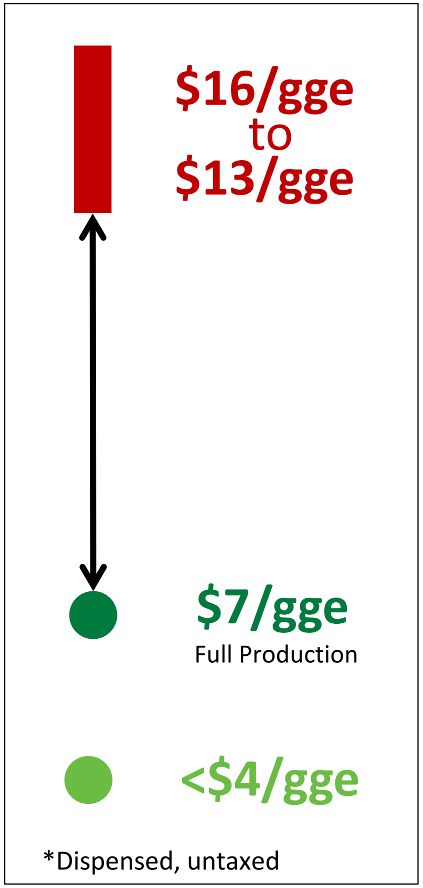
Lower onboard storage cost

Now	Ultimate***
$35/kWh	$8/kWh

*At 1K units/year
**gallon of gasoline equivalent
*** at 500,000/yr.

Updated hydrogen R&D cost target

Hydrogen R&D Cost* Target



Ultimate H_2 R&D Cost Target · 2025 H2 R&D Cost Target · Low-Volume Current Status

Assumptions

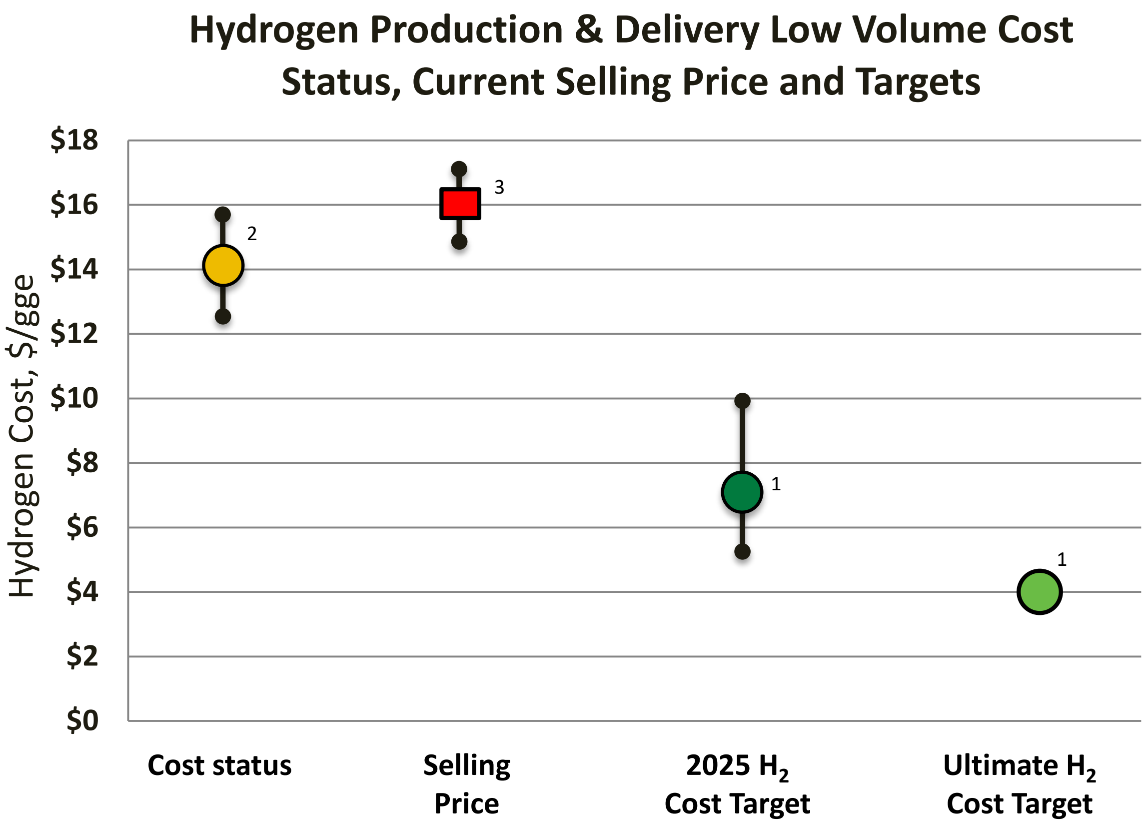
Preliminary

	H_2 R&D Cost Target	
	2025	**Ultimate**
H_2 R&D Cost Target	$7/gge	<$4/gge
Reference year $	2016$	2016$
Reference gasoline mid-size vehicle	ICEV	HEV
Reference fuel	Gasoline	Gasoline
Cost of gasoline (untaxed)[1]	$1.70-5.60/gge	$1.70-5.60/gge
Vehicle fuel on-road fuel economy[2]	30-39 mi./gge	44-60 mi./gge
FCEV on-road fuel economy[2]	62-87 mi./gge	62-87 mi./gge
FCEV incremental cost vs ICEV[2]	$0.00-0.03/mi.	
FCEV incremental cost vs HEV[2]		$0.00-0.04/mi.

[1] EIA 2017 Annual Energy Outlook

[2] Elgowainy et. Al., 2016. Cradle-to-Grave Lifecycle Analysis of U.S. Light Duty Vehicle-Fuel Pathways. Argonne National Lab.

Identified H_2 Low Volume Cost Status and Targets



1 – Draft Record 11007 *Hydrogen R&D Cost Target*

2 - Record 15012 *Low-Volume Early-Market Hydrogen Cost Target*

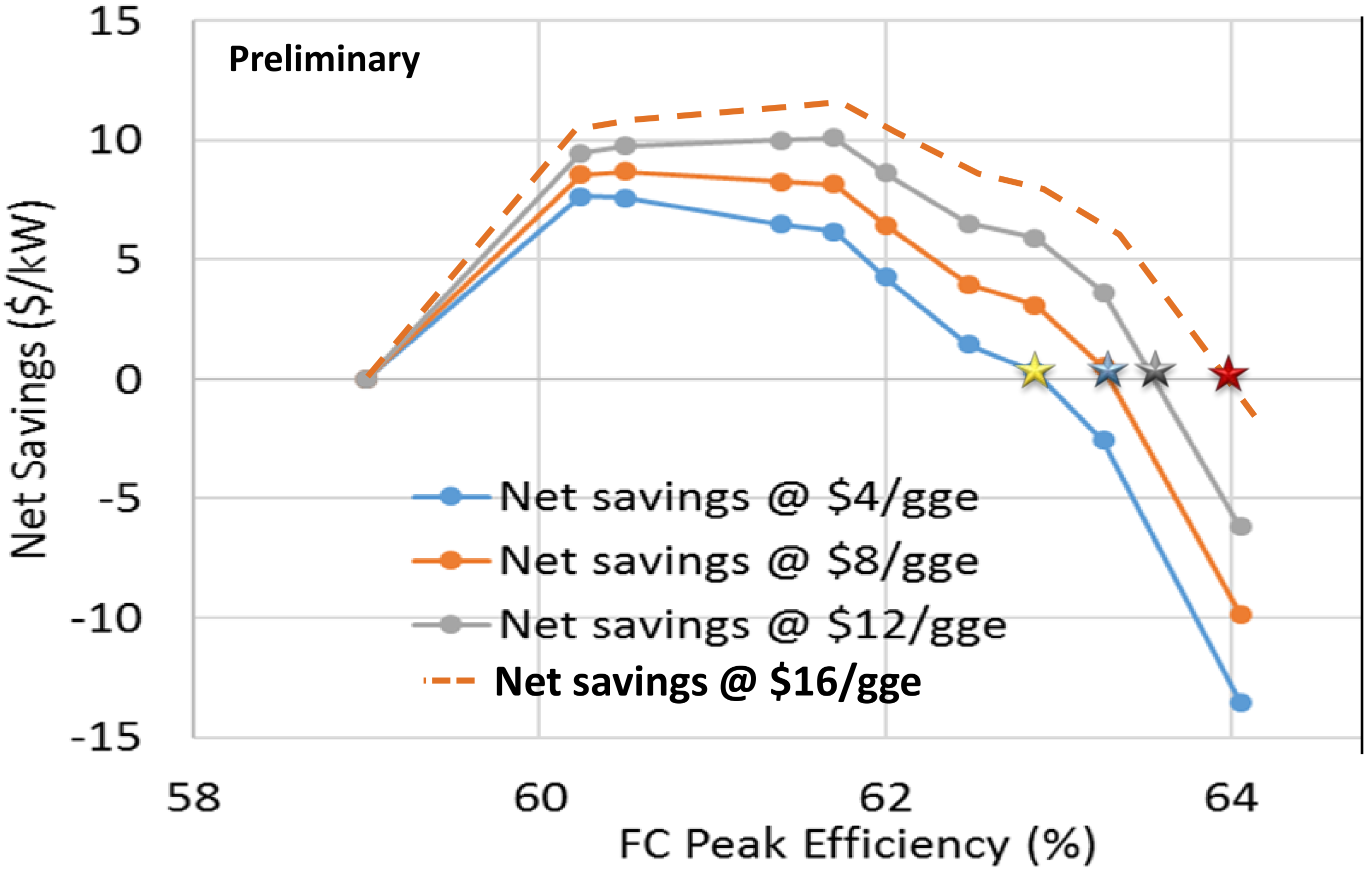
3 – California Air Resources Board AB 8 publication 2018

Assumptions

- **Hydrogen central production** is assumed
  - 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**.
- **\$15-\$16.80/gge. is current selling price** range for retails stations in CA (12/2017).

Identified Cost Savings of Higher FC Efficiency

Maximum Cost Saving Benefits Occur for Fuel Cell Systems Designed for ~60 to 62% Peak Efficiency



- For H_2 cost of $16/gge, breakeven is close to 64% peak efficiency.
- By achieving H_2 cost target of $4/gge, breakeven is ~63% peak efficiency.

Results shown for midsize sedan

Source: ANL

Evaluated and Compared Total Cost of Ownership (TCO)

Various fuel cell car models show increasing cost benefits for driving ranges over 150 miles

Year 2040: FCEV minus BEV-X Total Cost of Ownership

Green shows where FCEVs are more cost effective

	50 mi.	100 mi.	150 mi.	200 mi.	250 mi.	300 mi.	350 mi.
Two-seaters	$0.05	$0.01	-$0.03	-$0.07	-$0.11	-$0.15	-$0.19
Minicompacts	$0.05	$0.02	-$0.01	-$0.04	-$0.07	-$0.10	-$0.13
Subcompacts	$0.05	$0.02	-$0.01	-$0.04	-$0.07	-$0.11	-$0.14
Compacts	$0.04	$0.01	-$0.02	-$0.05	-$0.09	-$0.12	-$0.15
Midsize Cars	$0.05	$0.01	-$0.03	-$0.06	-$0.10	-$0.13	-$0.17
Large Cars	$0.04	$0.01	-$0.02	-$0.06	-$0.09	-$0.12	-$0.16
Small Station Wagons	$0.05	$0.01	-$0.03	-$0.07	-$0.11	-$0.15	-$0.19
Pass Van	$0.03	-$0.01	-$0.06	-$0.11	-$0.15	-$0.20	-$0.24
SUV	$0.03	-$0.02	-$0.08	-$0.14	-$0.19	-$0.25	-$0.30
Small Pickup	$0.06	$0.02	-$0.02	-$0.07	-$0.11	-$0.15	-$0.19

Assumptions

Range: 13,000 miles/yr.

BEV:

Battery cost: $165/kWhr

Electric price: $0.12/kWh

FCEV:

Fuel cell cost: $30/kW

Storage: $8/kWh

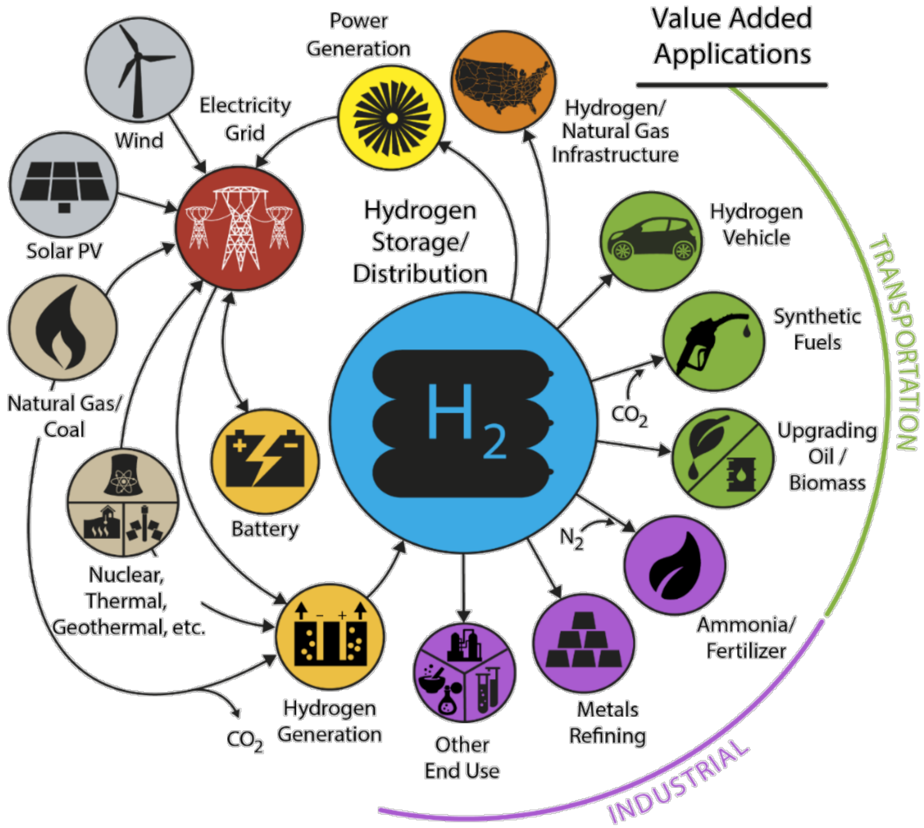
Hydrogen cost: $2.50/gge

Discount rate: 7%

Vehicle ownership: 15 yrs.

Source: *Market Segmentation of Light-Duty Battery Electric and Fuel Cell Electric Vehicles*
www.sciencedirect.com/science/article/pii/S0968090X18300056

Initiated H2@Scale Analysis



*Illustrative example, not comprehensive
Source: NREL

Example of Activities

- ✓ Initial Step (Complete)
- Identify potential demand
- Examine supply resources
- Identify impact potential
- Identify infrastructure issues

In-depth Analysis (FY17-18)

- Evaluated H_2 price requirements
- Identified supply options and costs
- Examined 3 scenarios
- Performed stage-gate review

Additional analysis (FY18)

- Evaluated regional scenarios
- Examined economic inertia and externalities
- Performed spatial analysis

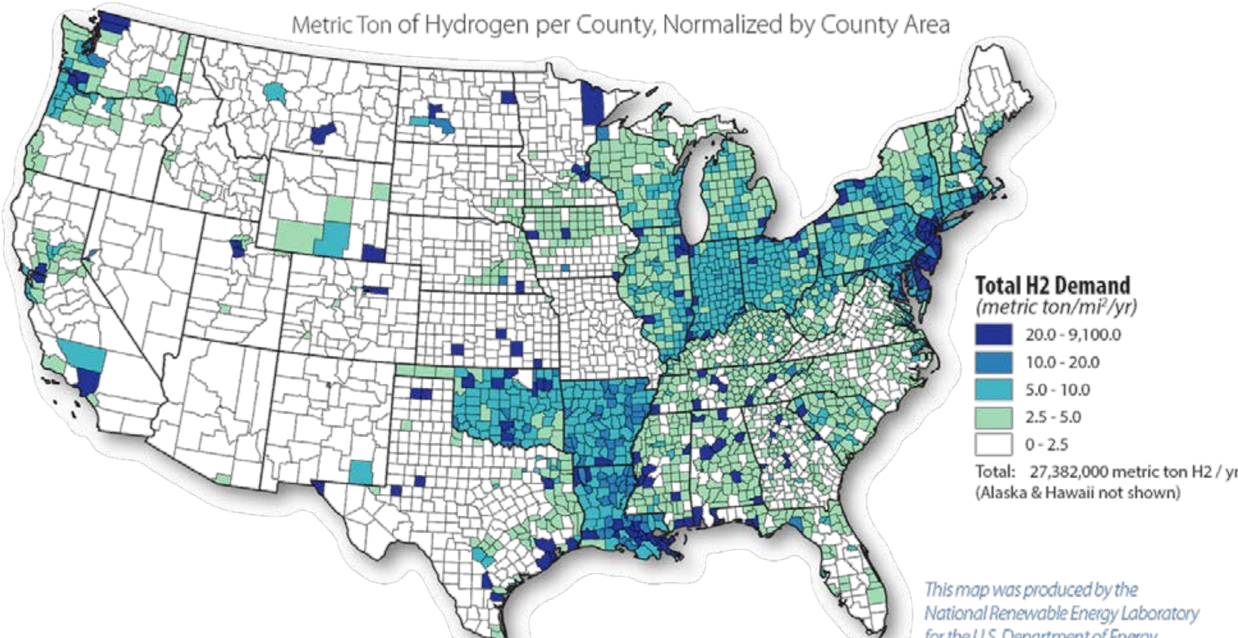
Estimated Technical Potential Hydrogen Demand

Nearly 90 MMT/year in potential hydrogen demand. Coming from light duty vehicles, natural gas, ammonia and metals industries; and the energy storage sector.

Technical Potential
(MMT*/yr.)

Refineries & CPI§	8
Metals	6
Ammonia	5
Methanol	1
Biofuels	1
Natural Gas	7
Light Duty Vehicles	28
Other Transport	3
Electricity Storage	28
Total	**87**

Represented in map



This analysis represents the total hydrogen demand estimated to be achievable in the U.S. in the following sectors: refineries, biofuels, ammonia, metals, methanol, natural gas systems, and seasonal energy storage. Each industrial sector was summarized by county to identify the total hydrogen demand for the industrial sector and then normalized by area.

Data Source: NREL analysis

* MMT: Million metric tonnes

§ CPI: Chemical Processing Industry not including metals, ammonia, methanol, or biofuels

Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

Integrated H_2 Delivery and On-Board Storage Analysis

Coordinated approach allows **to identify issues associated with coupling refueling infrastructure options with onboard storage technologies**

Findings (Preliminary)

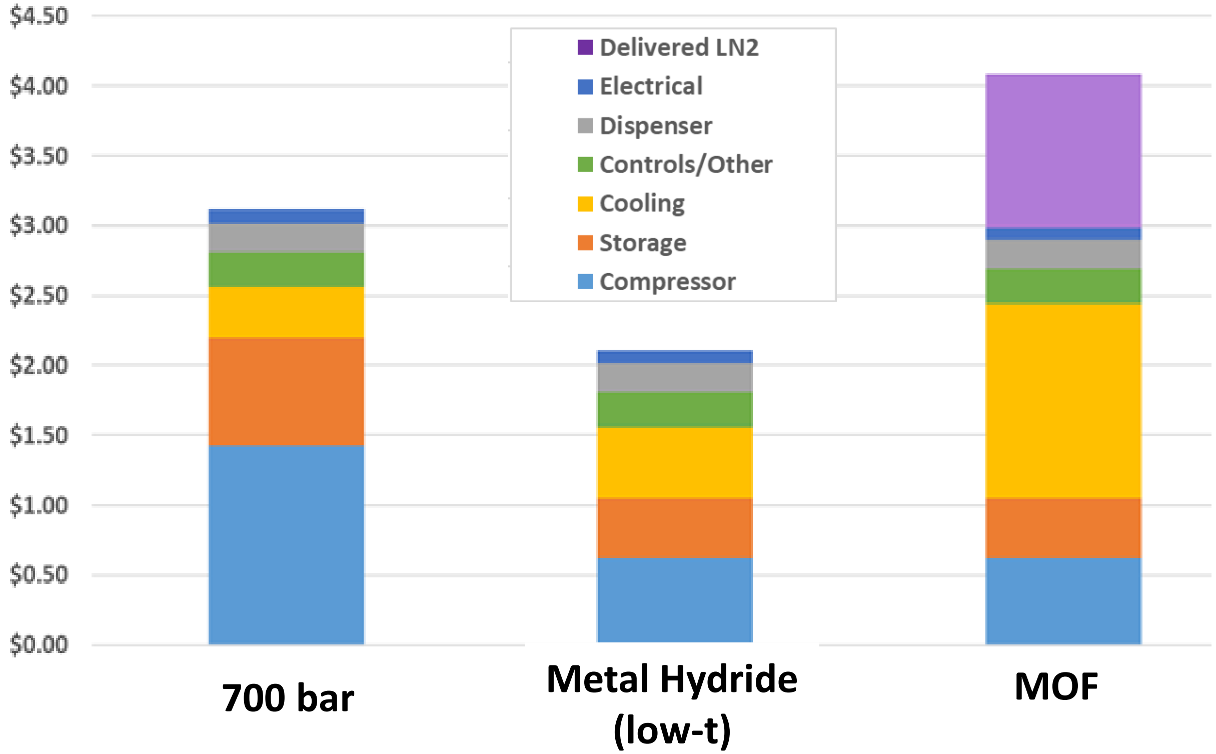
H_2 Delivery/MOF Onboard storage system

- Delivering LN2 for onsite cooling is EXPENSIVE
- *Future work:* Consider LH_2 pathway for MOF

H_2 Delivery/Metal Hydride Onboard storage system

- Potential to reduce the delivery/storage costs

Delivery & Dispensing Cost [2016$/kg H_2]



Assumptions:
1000 kg/day station Capacity, 0.8 Capacity factor, 20 bar H_2 supply, 4 dispensers

Recent and Upcoming Activities Summary

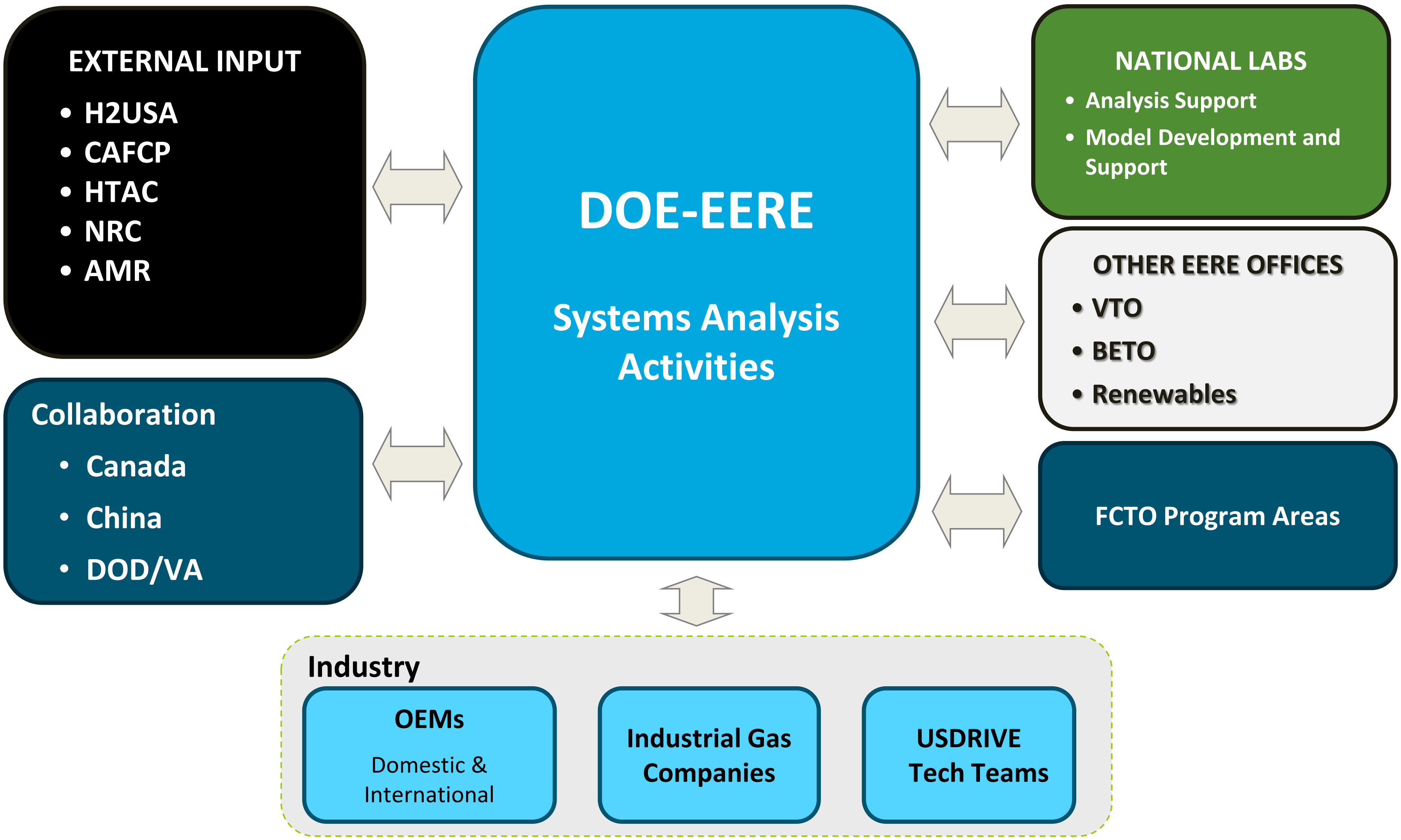
FY 2018 Emphasis:

- Early-stage and infrastructure R&D
- Life-cycle analysis of cost, petroleum and water use
- Program impacts on energy security and prosperity
- Sustainability Framework and FCTO metrics

FY 2018 – 2019 Activities:

- Identify gaps and drivers for early stage infrastructure R&D
- Assess early stage R&D impact on energy security
- Integrate analysis to ensure optimization
- Assess targets and metrics for medium and heavy duty trucks
- Conduct H2@scale analysis

Collaborations span national and international entities



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