U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

System Analysis Program Overview

Poster SA01

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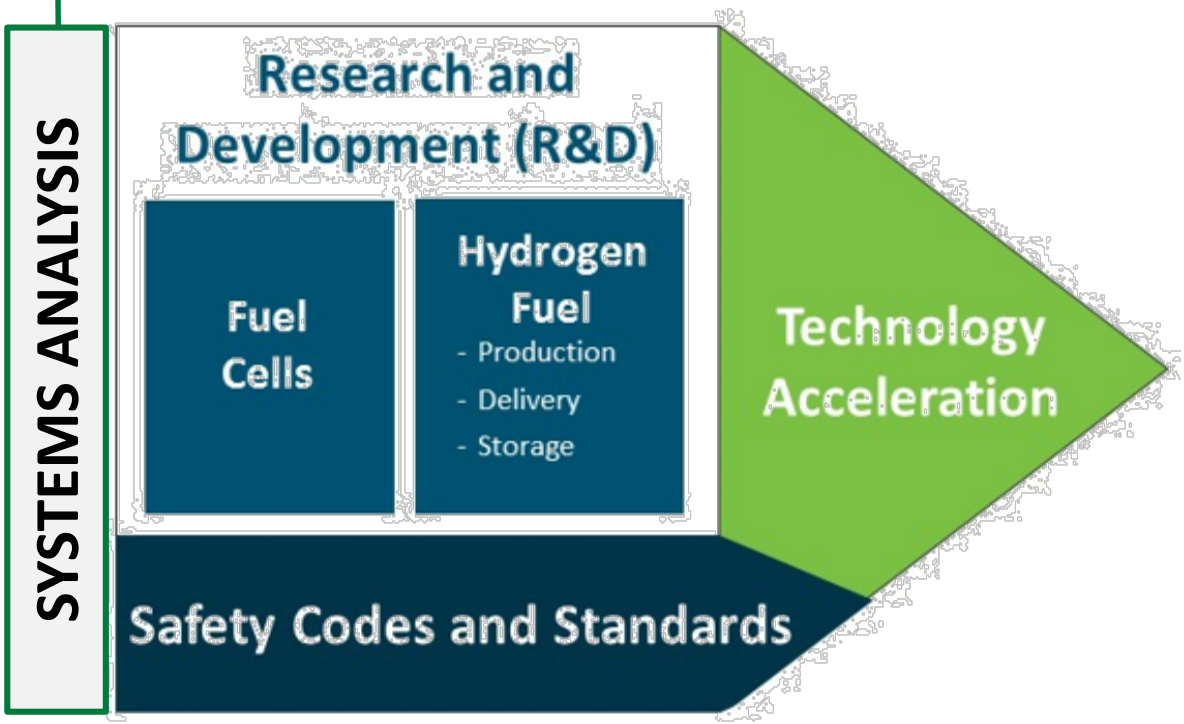
2018 Annual Merit Review

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

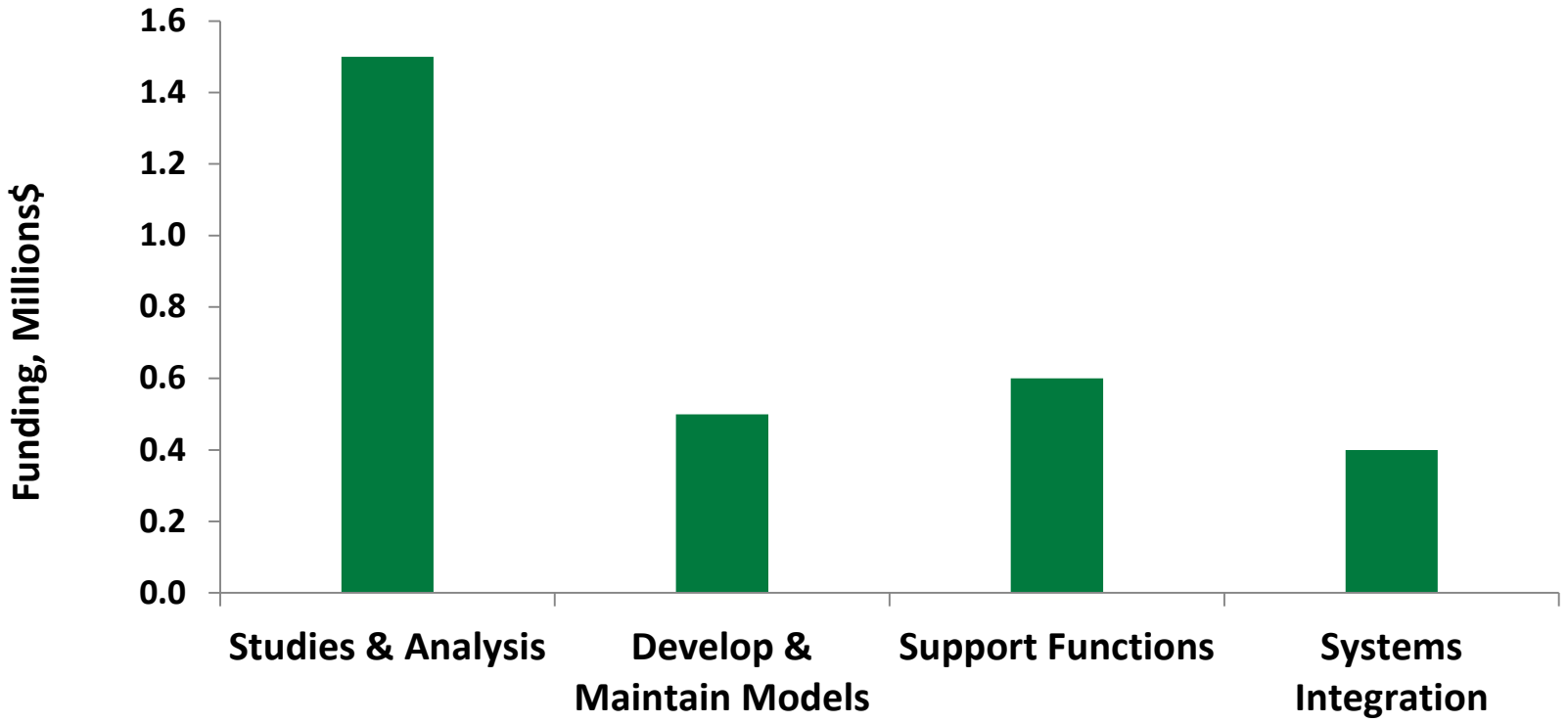
Estimate
- Potential value of early-stage R&D efforts

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

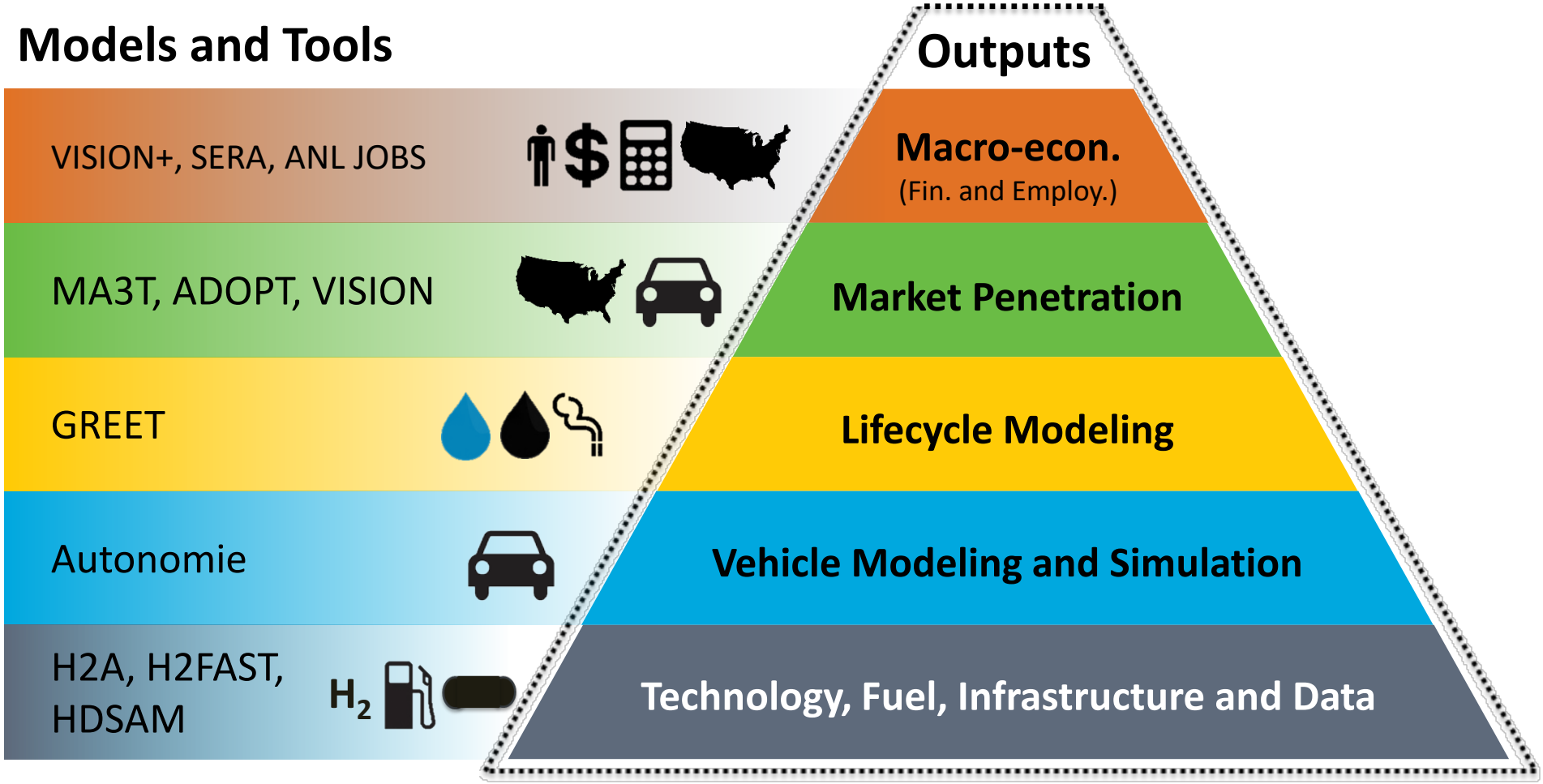
System Analysis Framework	*Models and Tools*	*Studies and Analysis*	*Deliverables/ Results*
• Consistent and transparent data	• Life cycle analysis benefits of hydrogen and fuel cells for diverse applications	• Initial phases of technology early market penetration	• Support decision-making processes and milestones
• Prioritized analysis tasks	• Portfolio of validated models for near and long term analyses	• Long-term potential and issues	• Direction, planning and resources
• Organize data and results for decision making		• Energy security analysis	• Independent analysis to validate decisions
• Effective analytical workshops to gather key input assumptions for analysis		• Energy storage analysis	• Risk analysis of program area targets
		• Resource supply for hydrogen production	• 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

Models: \ Analysis Type:	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:

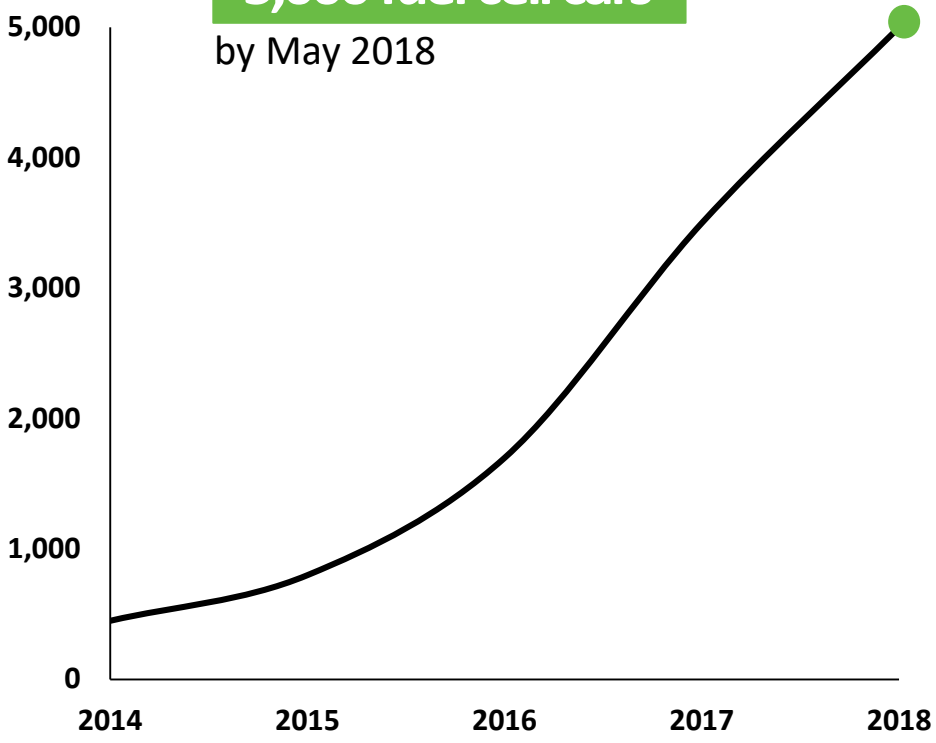
GPRA* Integrated Analysis	DATA	VEHICLE	Life Cycle	MARKET	MACRO
H2A, HDSAM and expert input					
Autonomie					
GREET					
MA3T					
VISION					

* Government Performance Results Act

Fuel Cell Cars and Stations Growth Over the Years

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

Nearly **5,000 fuel cell cars** by May 2018

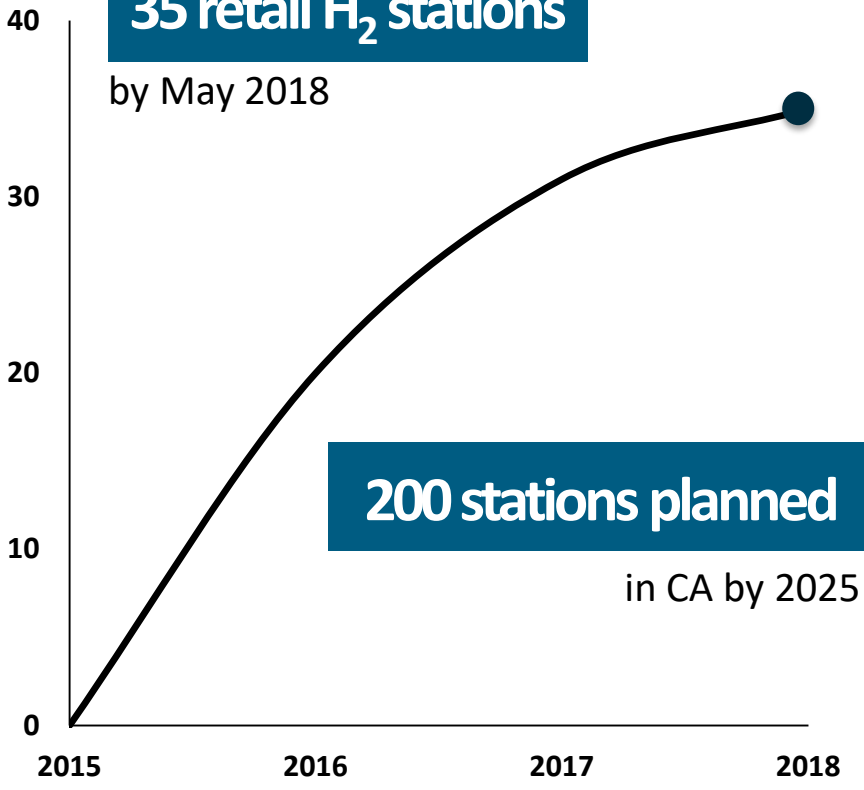


*Toyota Mirai, Hyundai Tuscan, Honda Clarity

Retail H_2 Stations in California

35 retail H_2 stations by May 2018

200 stations planned in CA by 2025

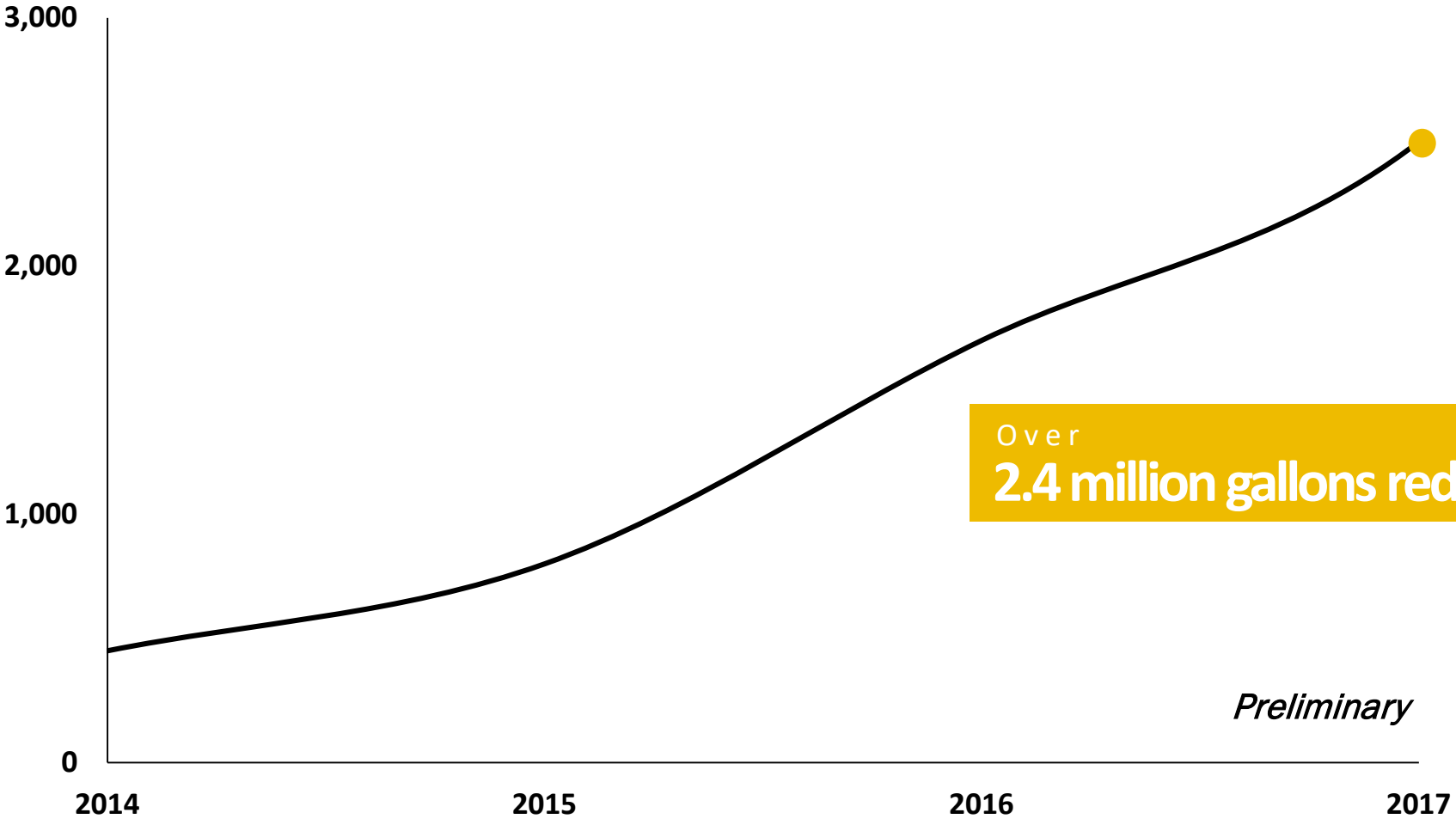


Sources: California Office of the Governor

H_2 and Fuel Cells Enable Energy Security Benefits

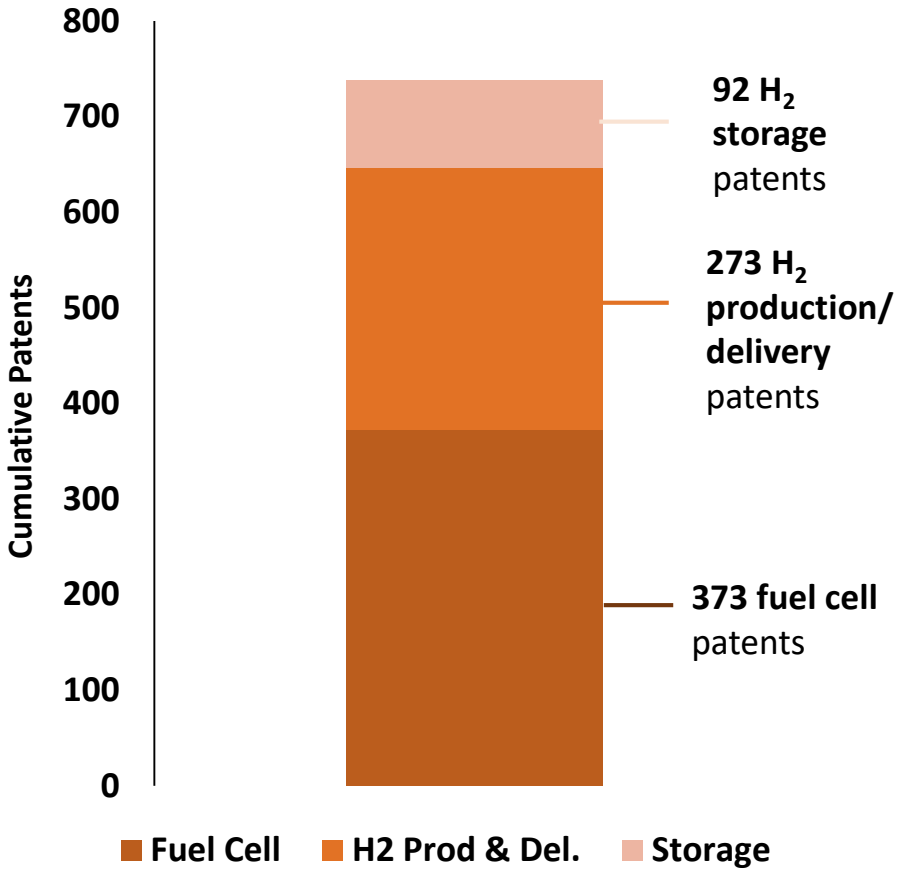
Petroleum Displacement

(cumulative, in thousands of gallons)



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

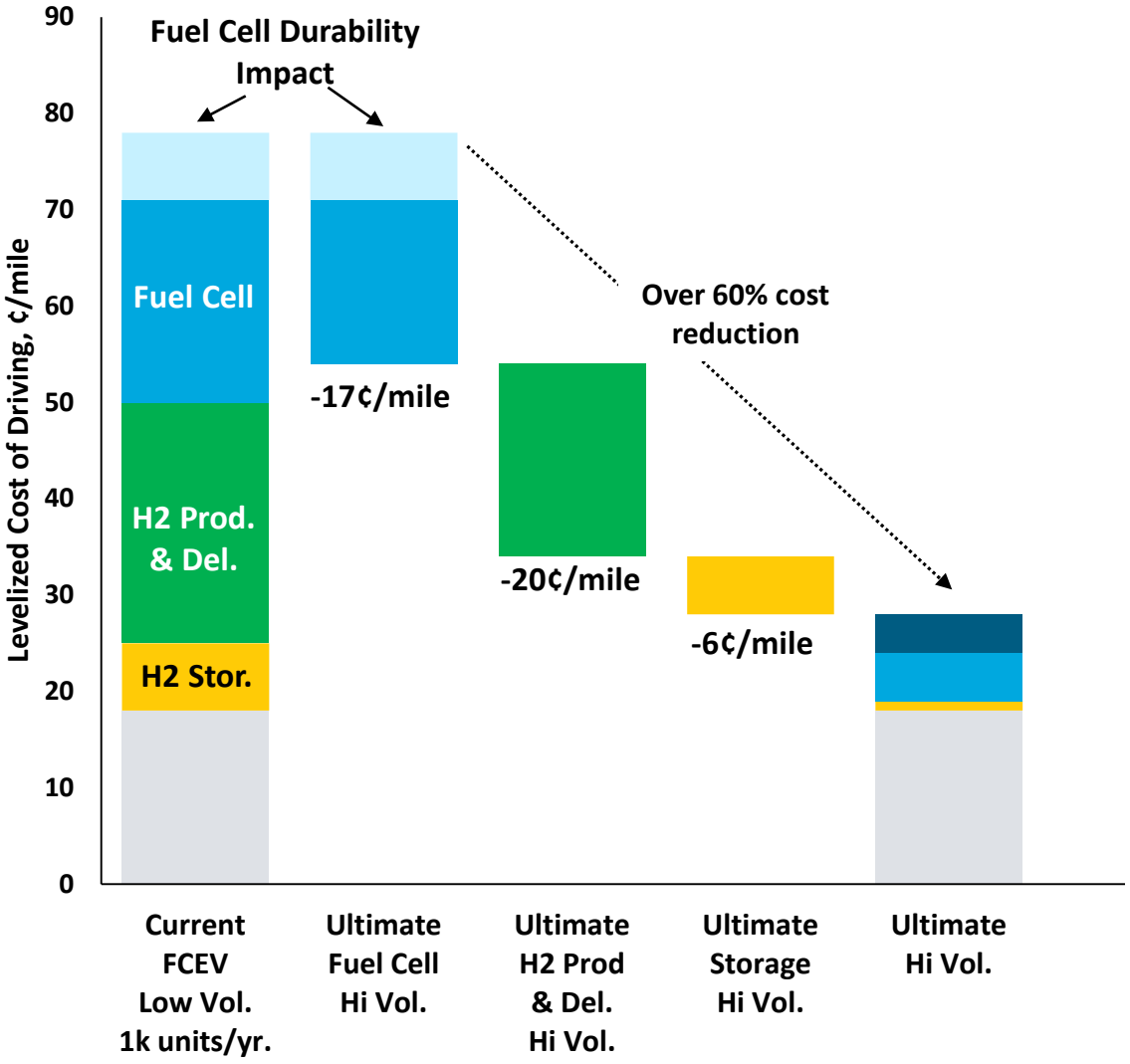
H_2 Storage

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

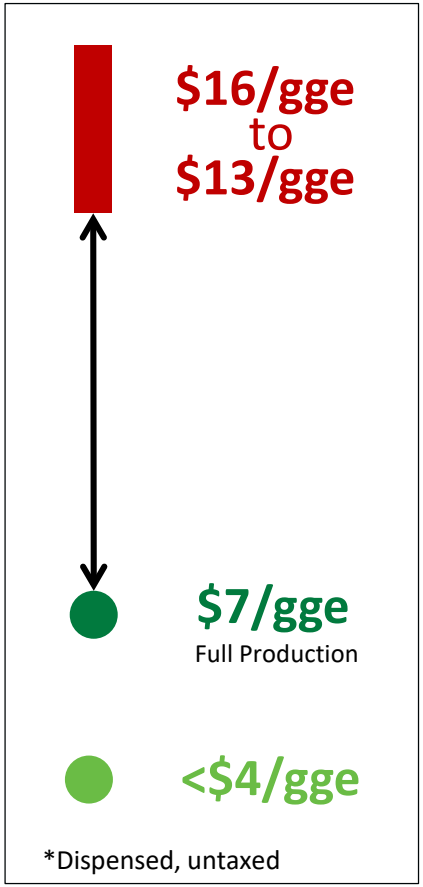
Lower onboard storage cost

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



Assumptions

Preliminary

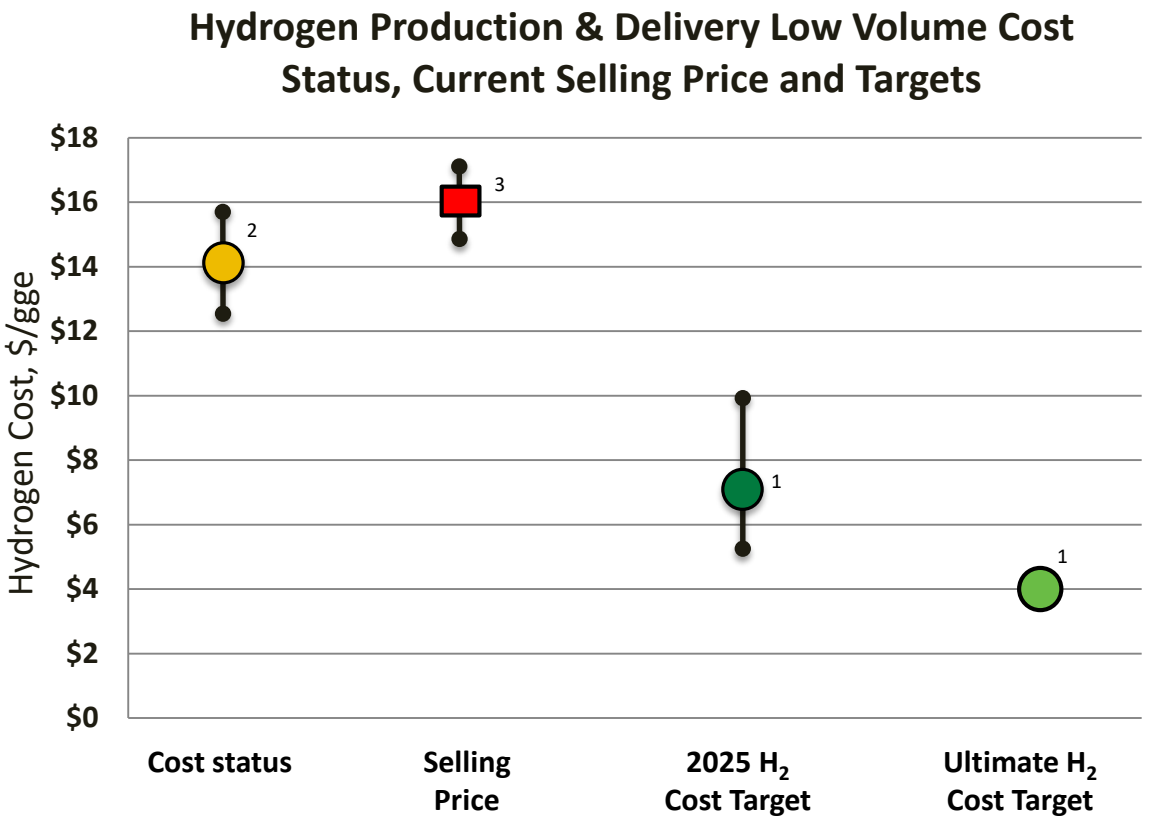
	H_2 R&D Cost Target	
	2025	Ultimate
H_2 R&D Cost Target	$7/gge	<$4/gge
Reference year $	2016$	2016$
Reference gasoline mid-size vehicle	ICEV	HEV
Reference fuel	Gasoline	Gasoline
Cost of gasoline (untaxed)[1]	$1.70-5.60/gge	$1.70-5.60/gge
Vehicle fuel on-road fuel economy[2]	30-39 mi./gge	44-60 mi./gge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

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

[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*

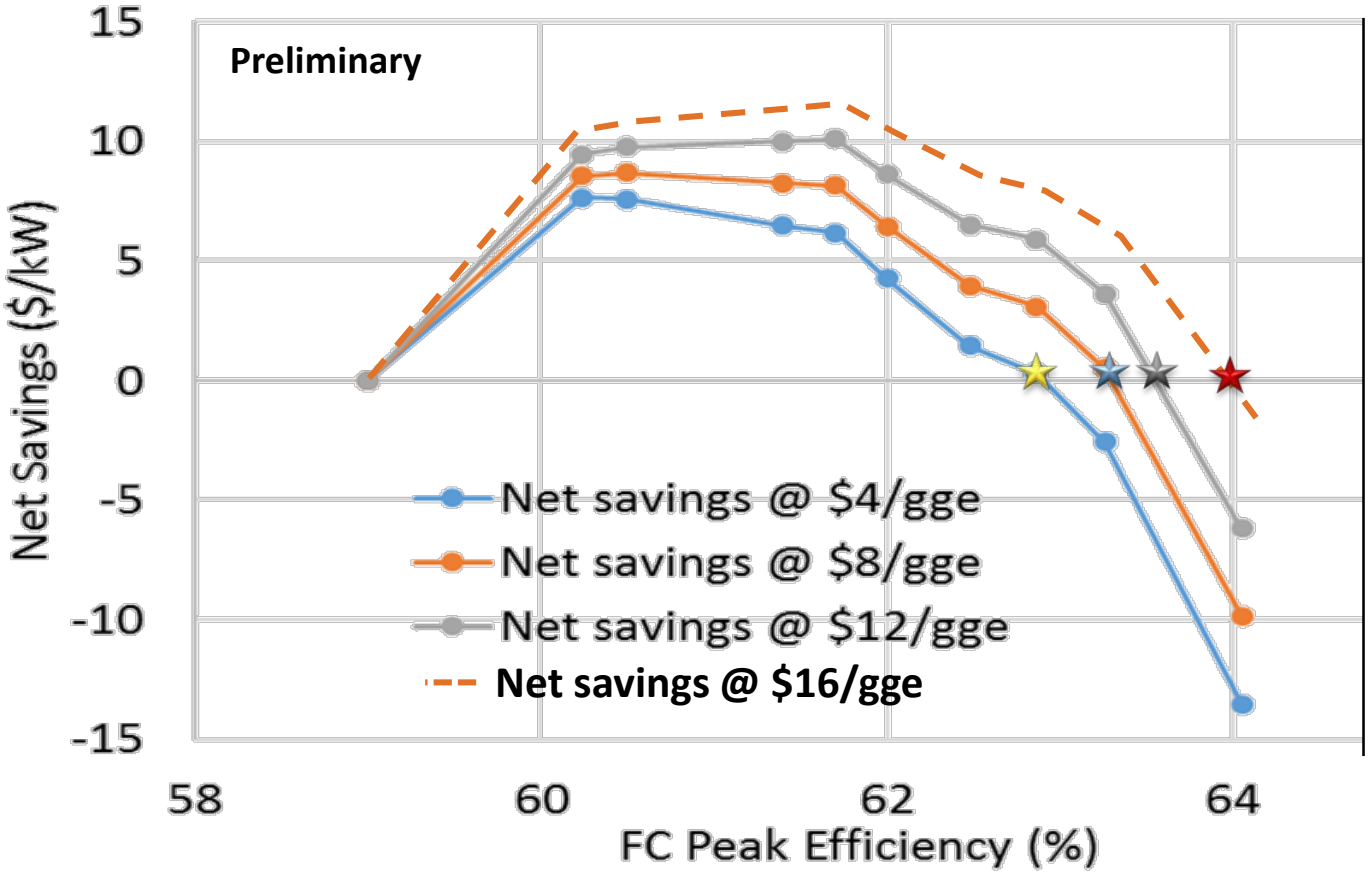
3 – California Air Resources Board AB 8 publication 2018

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

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

Assumptions

Range: 13,000 miles/yr.

BEV:

Battery cost: $165/kWhr

Electric price: $0.12/kWh

FCEV:

Fuel cell cost: $30/kW

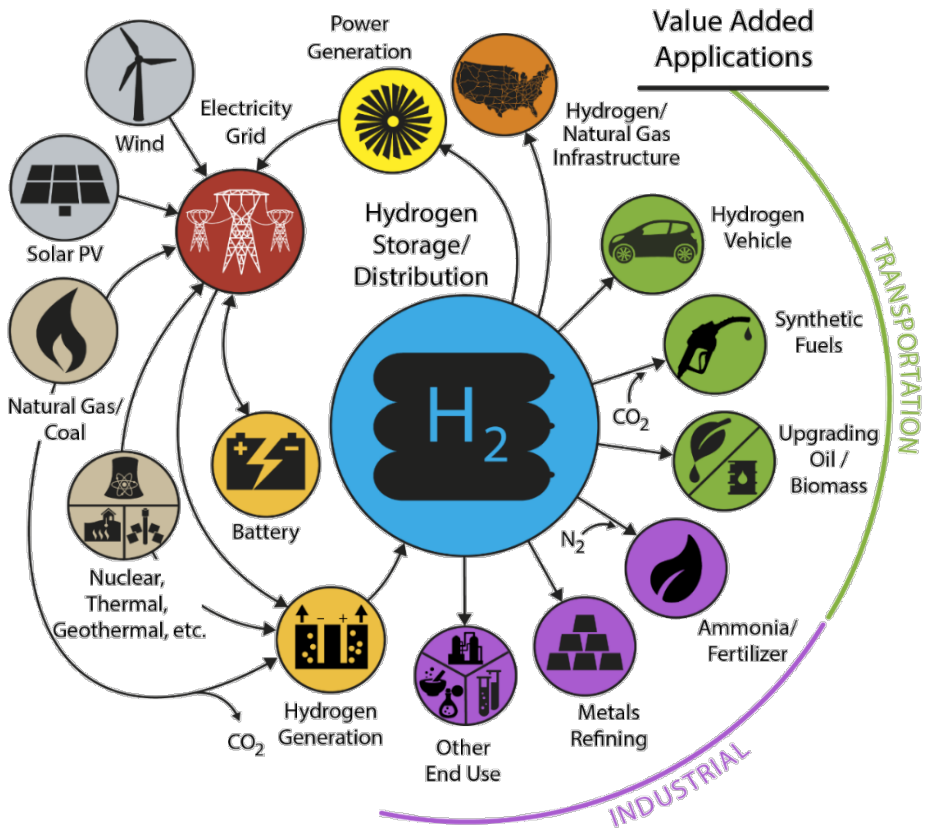
Storage: $8/kWh

Hydrogen cost: $2.50/gge

Discount rate: 7%

Vehicle ownership: 15 yrs.

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

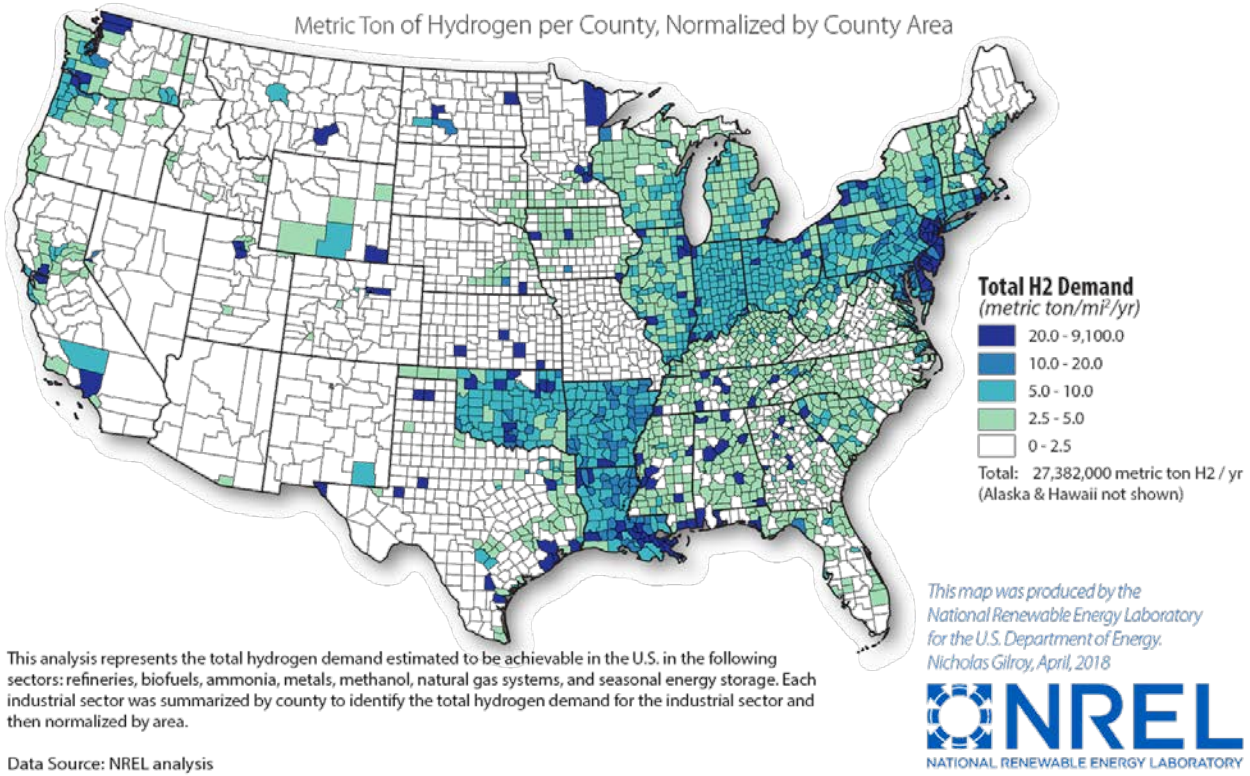
Estimated Technical Potential Hydrogen Demand

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



* 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)

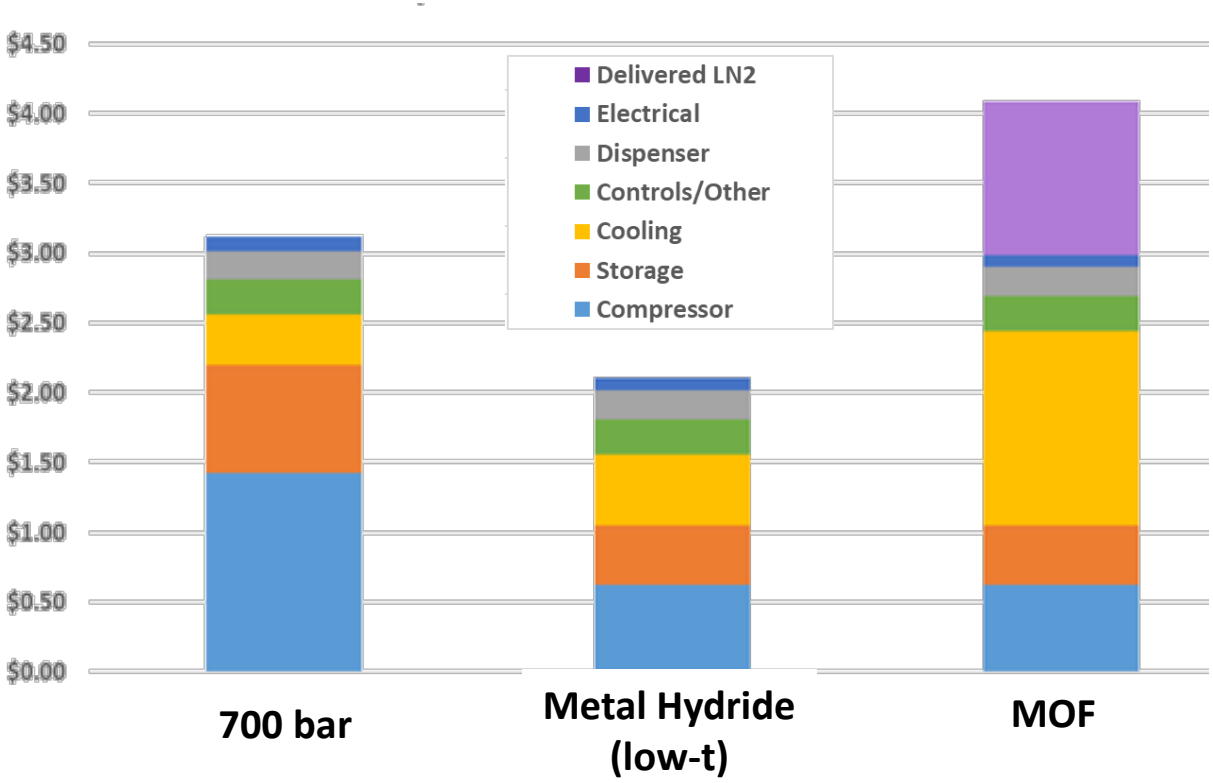
H_2 Delivery/MOF Onboard storage system

- 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

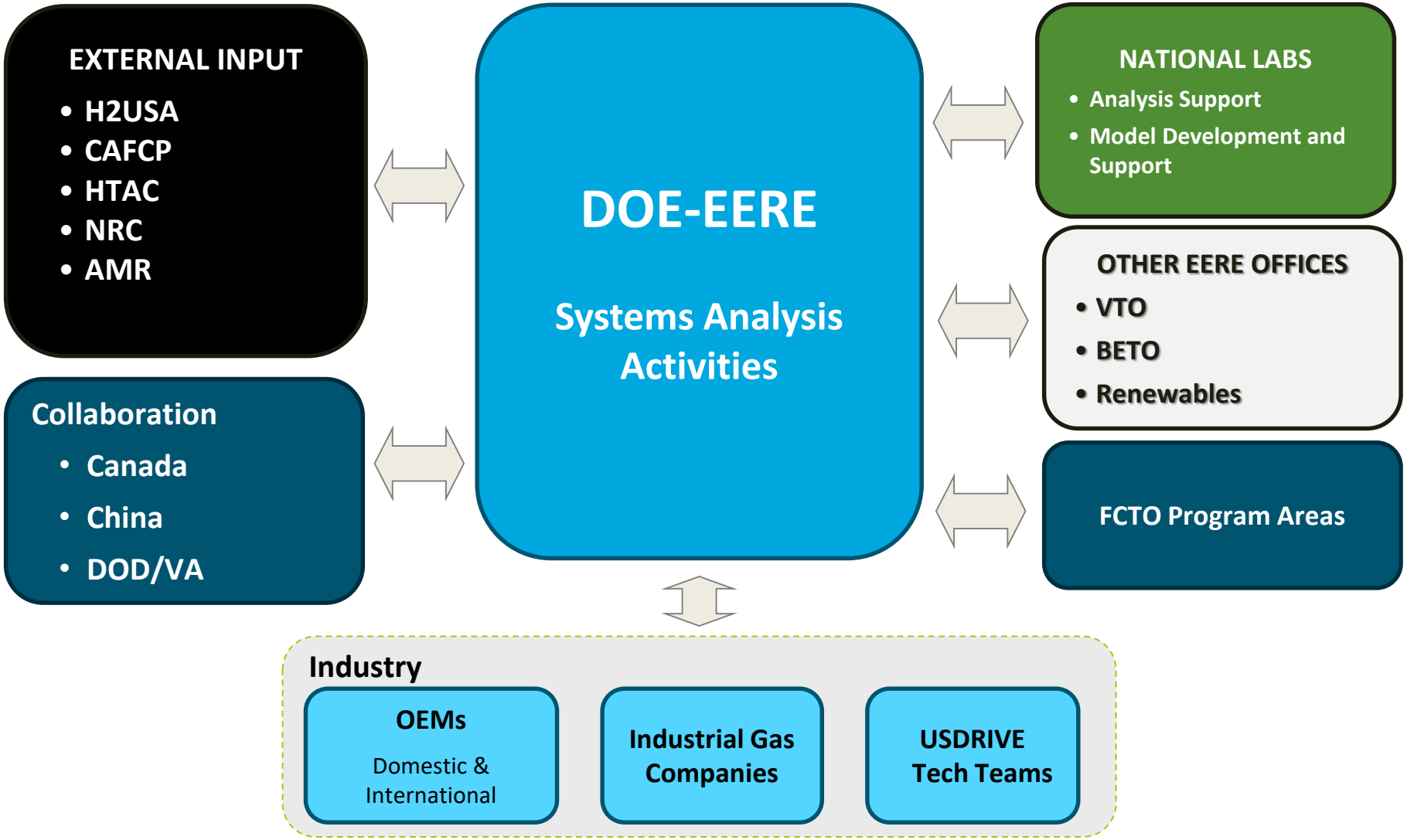
FY 2018 Emphasis:

- 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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