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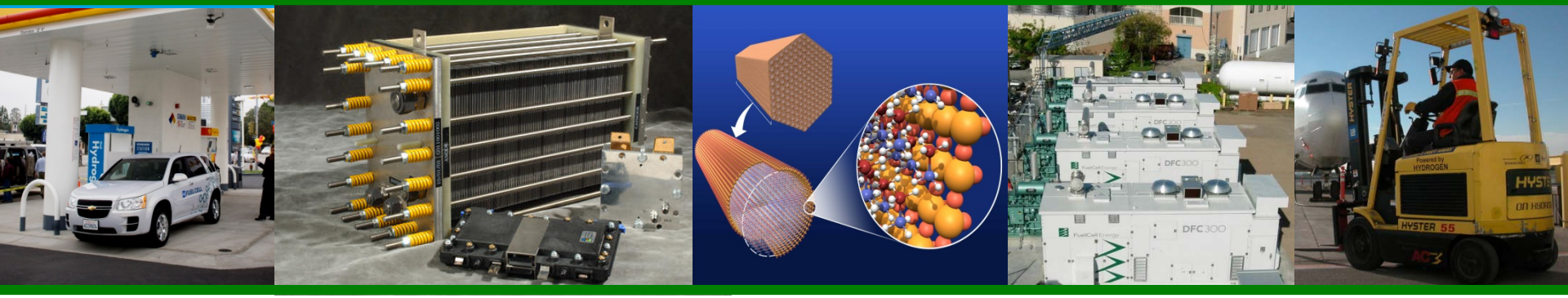

Systems Analysis Program Area
- Plenary Presentation -

Fred Joseck

Fuel Cell Technologies Office

2017 Annual Merit Review and Peer Evaluation Meeting

June 6, 2017

Systems Analysis Program Objectives & Goals

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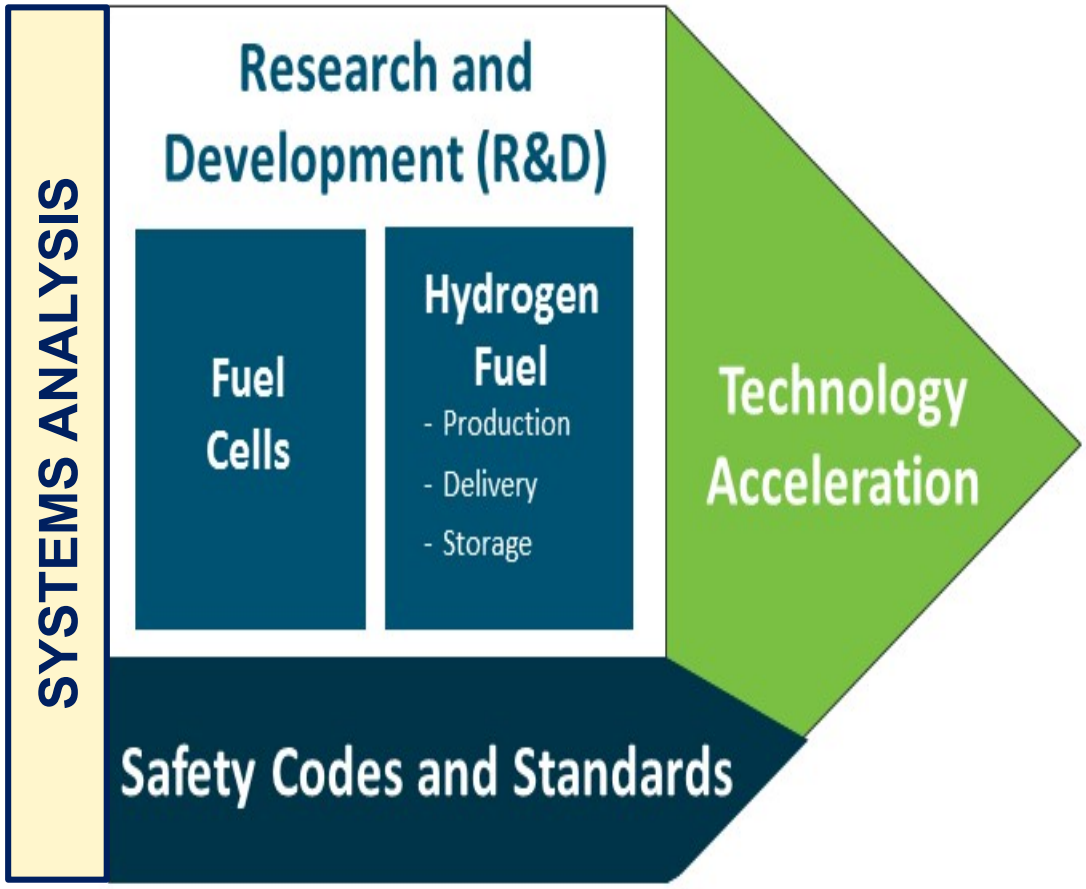
DOE Hydrogen and Fuel Cells Sub-Programs



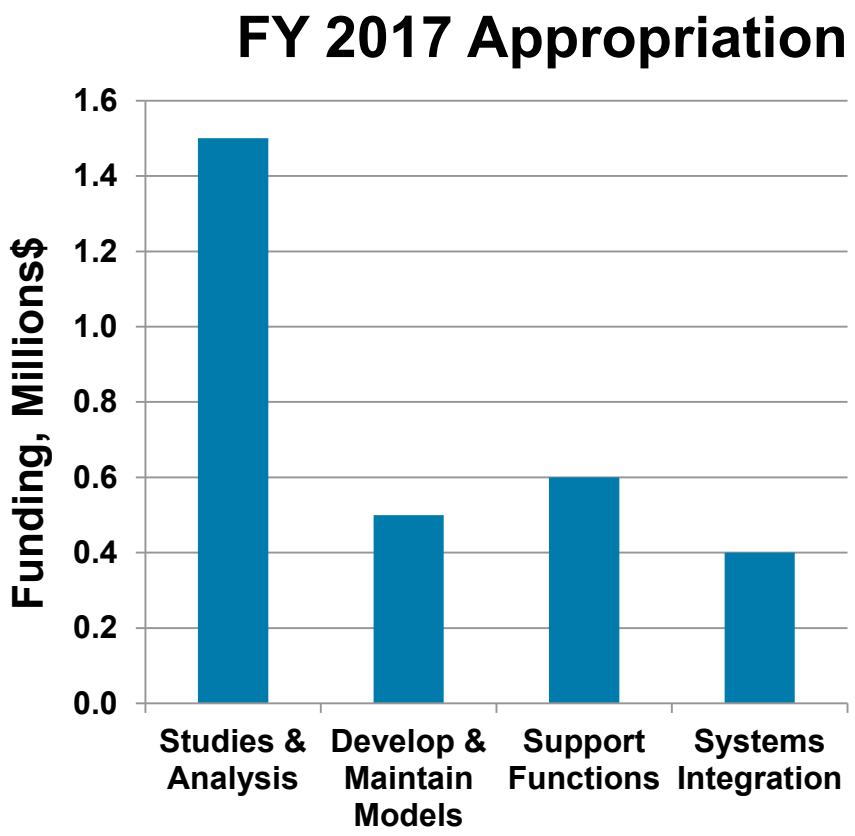
Objectives

Through system-level approach and analysis-

- *Evaluate technologies and pathways,*
- *Guide selection of RD&D technology approaches/options,*
- *Estimate potential value of RD&D efforts and targets, and*
- *Evaluate energy security and socio-economic benefits of the program targets.*

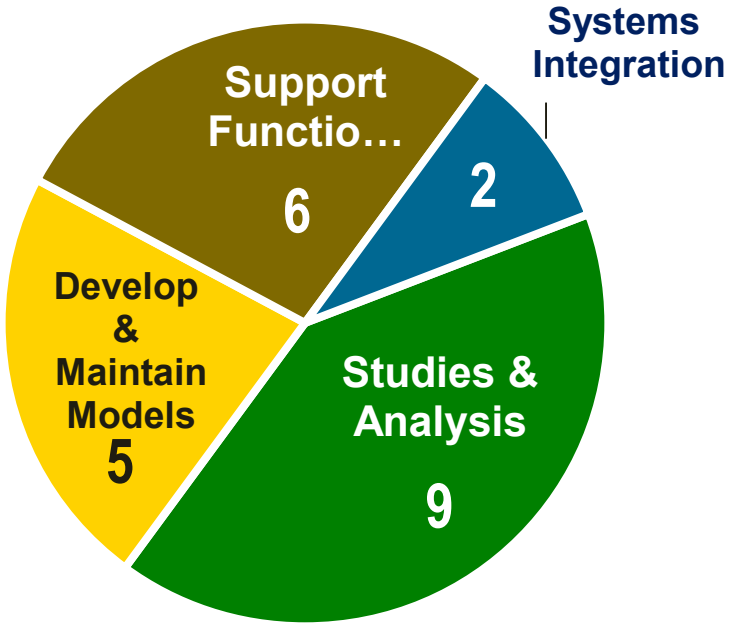
Systems Analysis Budget

FY 2017 Appropriation = $3.0 M



Focus: Determine technology gaps, evaluate impacts of early stage R&D and estimate benefits of energy security and economic/job growth from key technology advances.

Number of Activities by Focus Area



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
- Energy security 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

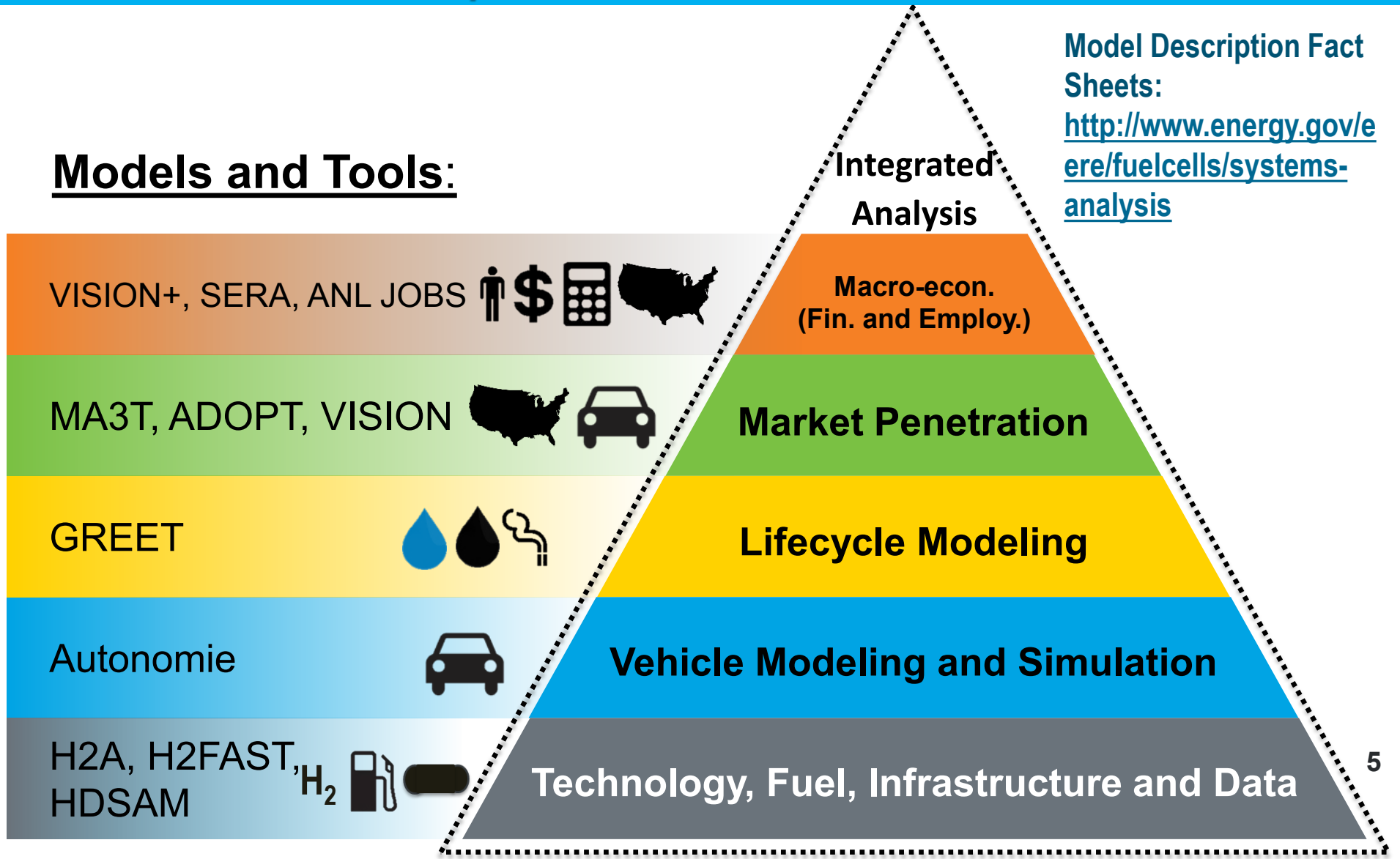
FCTO Program Collaboration and Input

Internal and External Peer Review

Systems Analysis Program at a Glance

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

Models and Tools:



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

FCTO Analysis Portfolio in Summary

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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					

- The FCTO analysis portfolio (left) covers the full analysis space and includes some redundancies
- Some projects (e.g., GPRA, below) span all categories for a truly integrated analyses

Example:

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

* Government Performance Results Act

Hydrogen Infrastructure: Production Sites in the U.S.

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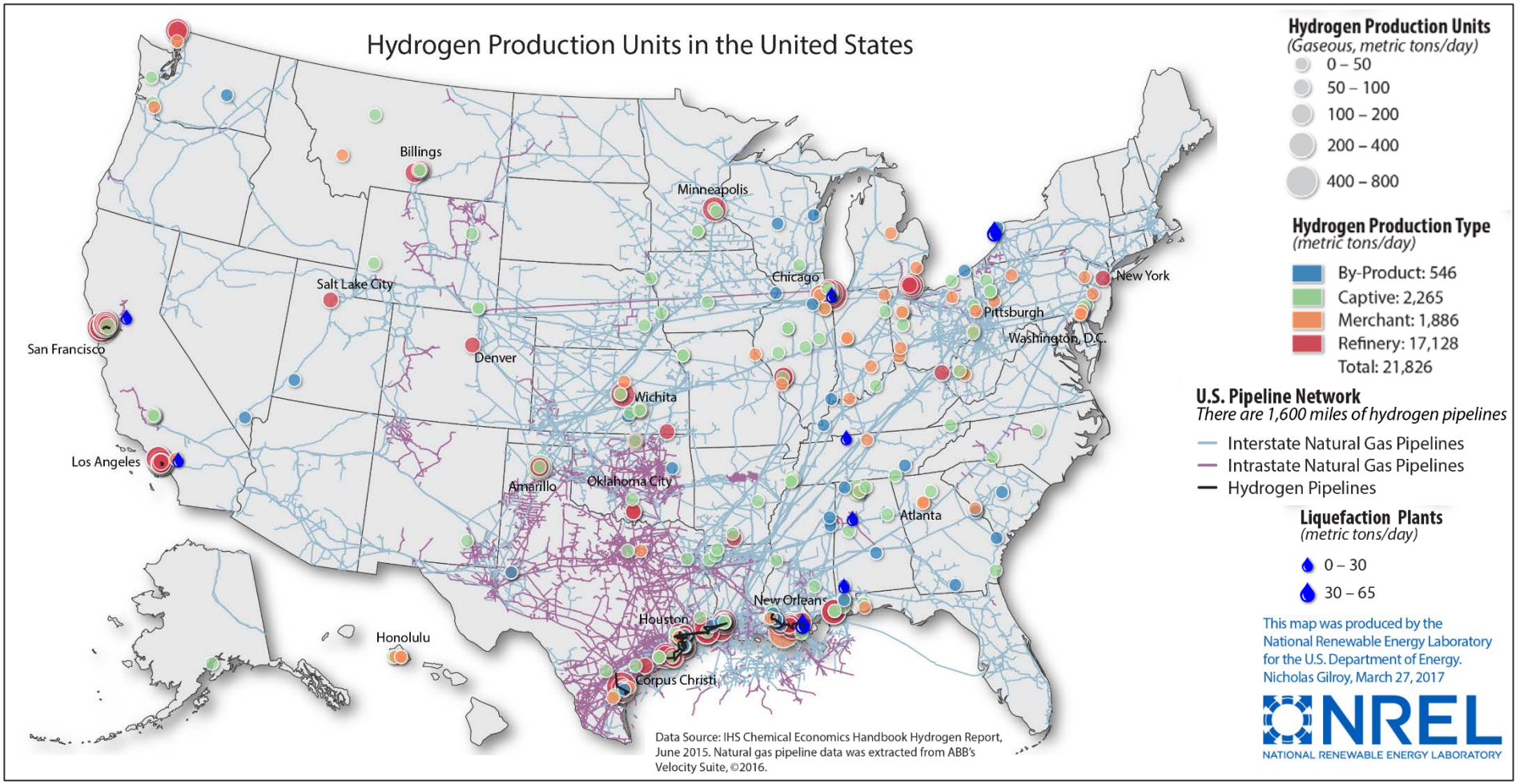

U.S. annual hydrogen production

10 million metric tons

Largest Users in the U.S.

Petroleum Processing	68%	Fertilizer Production	21%

Fuel Cell Car Sales and H_2 Stations on the Rise

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U.S. Fuel Cell Car Sales Growing Exponentially

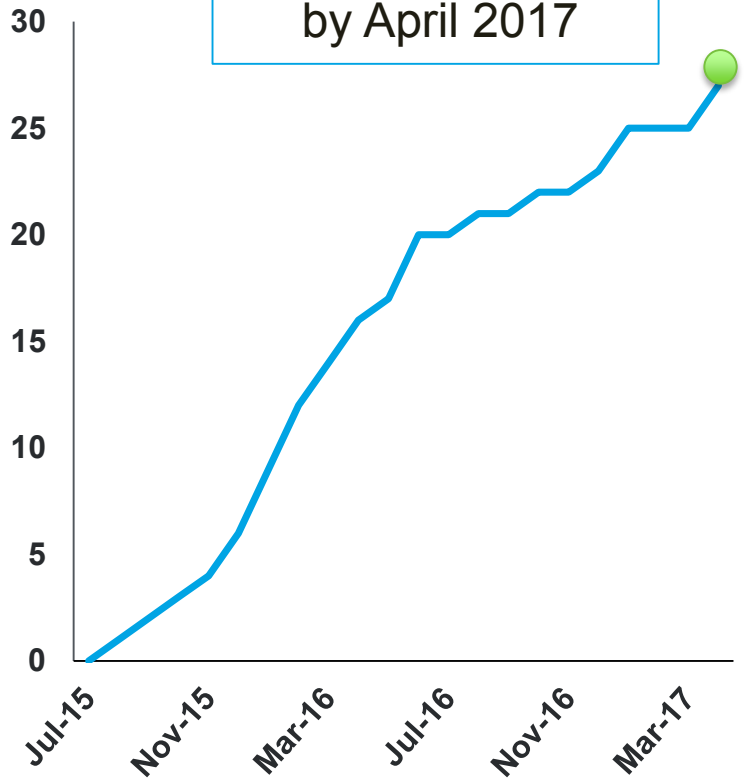
Fuel Cell Cars Sold/Leased in the U.S.

~1,800 fuel cell cars
by April 2017

Note: Cumulative number of vehicles sold/leased. Source: hybrid.com

Number of California Retail H_2 Stations Increasing

27 Retail H_2 stations
by April 2017



Sources: California Office of the Governor

Energy Security Benefits resulting from Hydrogen and Fuel Cell Technologies

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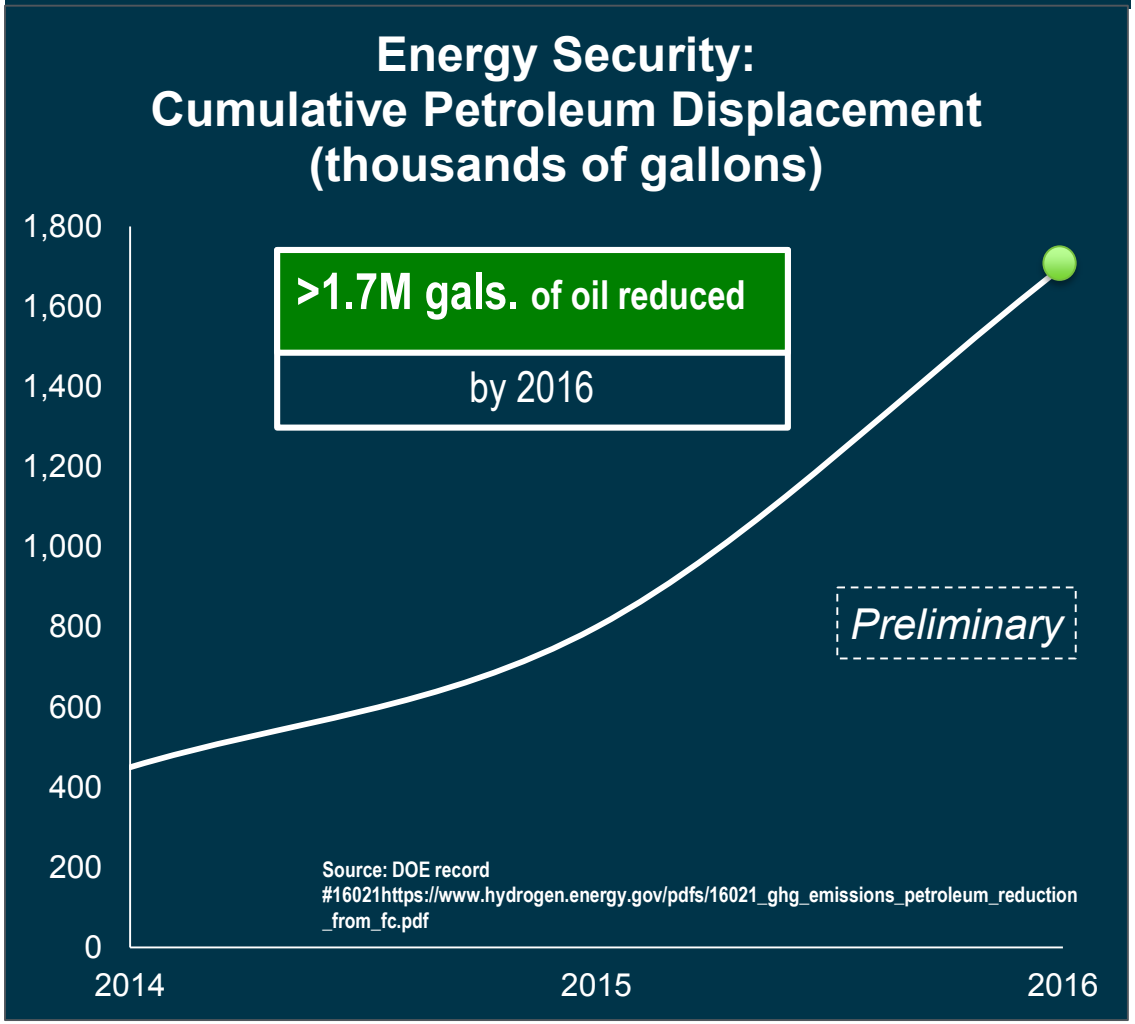
Petroleum Displacement Increasing Exponentially



DOE Hydrogen and Fuel Cells Impact

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Innovation

650 H_2 and fuel cells patents enabled by DOE funds

Job Potential from H_2 Refueling Infrastructure Buildout

A single H_2 fueling station creates ~52 jobs

Station development accounts for 73% of jobs; station operation for 27% of jobs

Source: ANL JOBS model and California report

Job Potential

Today

Approximately **16,000** jobs in the fuel cell car sector

Source: DOE, U.S. Energy and Employment Report (2017)

Future

More than **200,000** jobs from future fuel cell car sales

Under an approximately 20% market penetration scenario.
Source: Preliminary results from employment study update (ANL)

Systems Analysis – FY16-17 Highlights Accomplishments

Techno-Economic Analysis Guides R&D Portfolio

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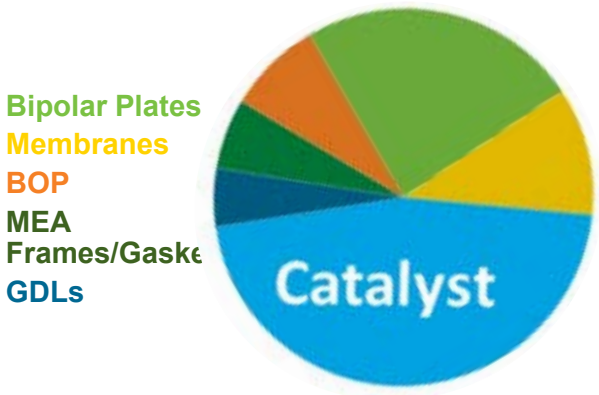
Fuel Cells

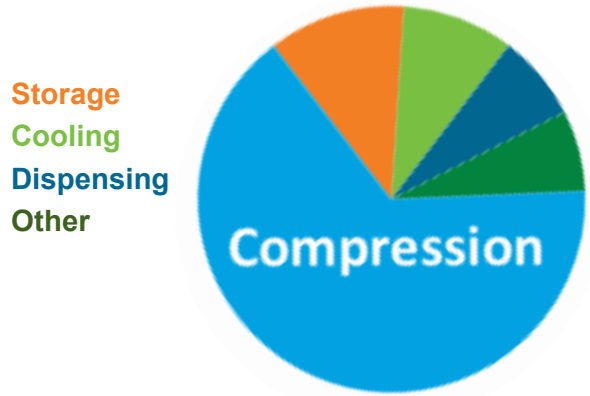


Focusing on…

Low and Non PGM Catalysts,

Alkaline Membranes

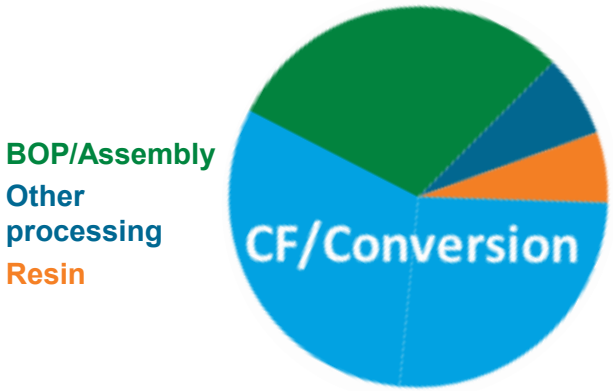
H_2 Station



Advanced Compression

Alternate Approaches

H_2 Storage



Low Cost Carbon Fiber (CF)

Long term Materials Approaches

Cost Analysis and Performance Requirements Drive R&D Strategy

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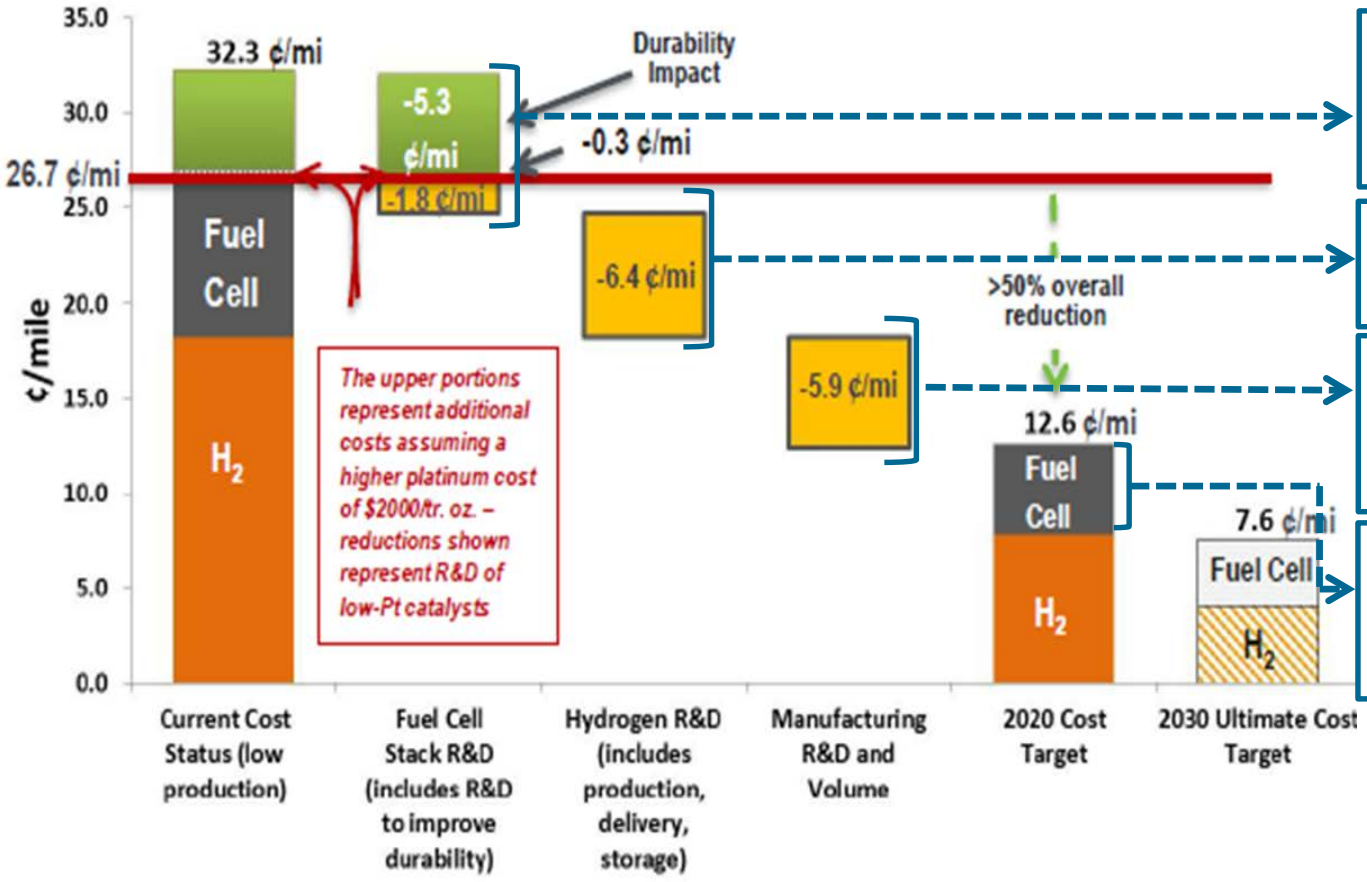
FCEV Cost Reduction Pathways

@ 100,000 units



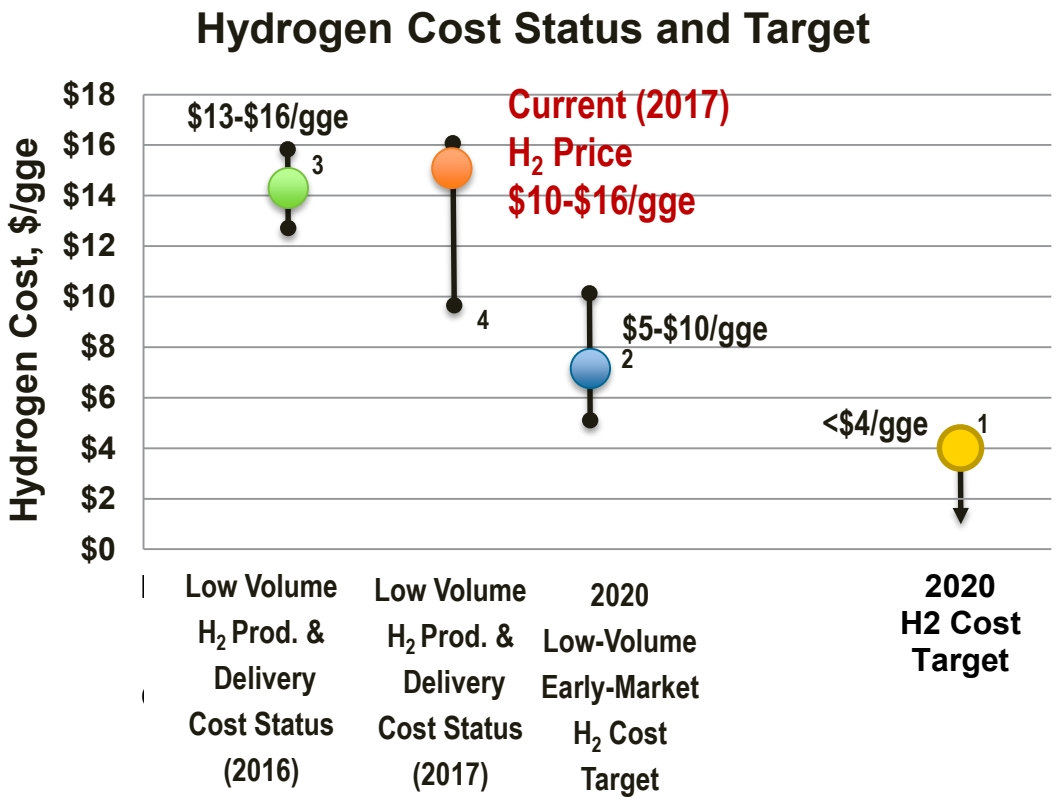
R&D Needs

- Catalysts, membranes, electrodes, BOP and increase in durability
- H_2 Production, delivery and storage
- Manufacturing R&D and processes, QC and high volume fabrication
- Additional progress needed for ultimate targets

Total cost of ownership analysis identifies key R&D needs to be competitive with incumbent and other advanced technologies

Hydrogen Cost Targets and Status

Current cost of low volume dispensed H_2 (includes production and delivery) ranges from $10 – $16/gge in California.



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*
4 – Air Products and Chemicals press release 2017

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.
- Current selling price range of H_2 at public retail stations in California is $9.99-$16.00/gge (5/2017).

FCTO Target Analysis

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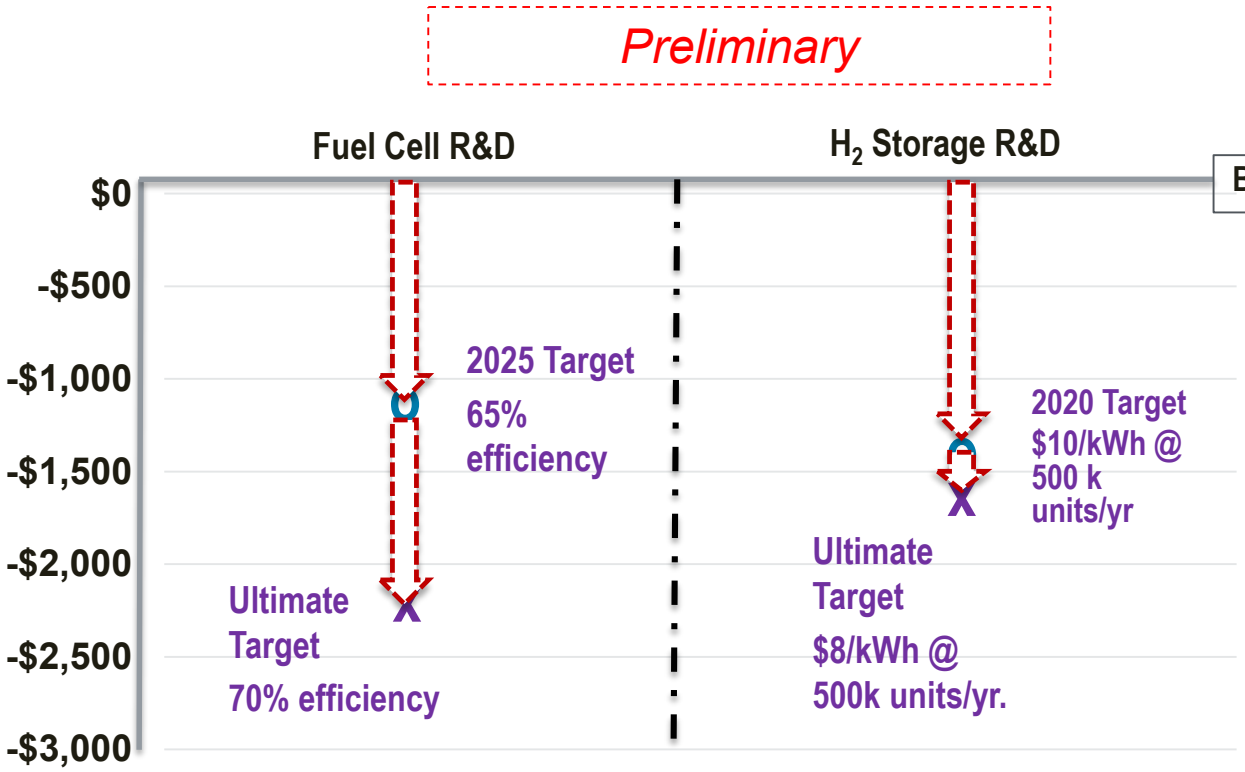
Achieving FCTO program R&D targets can reduce FCEV fuel and component manufacturing costs by $2,600 - $4,000

Impact of FCTO Targets on Fuel Savings and Vehicle Cost Reduction



Source: ANL Autonomie analysis

Baseline Assumptions

Storage: $17/kWh @ 100k units/yr.

Fuel cell efficiency: 59%

Hydrogen Cost: $4/gge

Next steps to evaluate the fuel cell and storage targets versus their marginal benefits.

Energy Security Analysis: Petroleum Reduction from FCTO R&D

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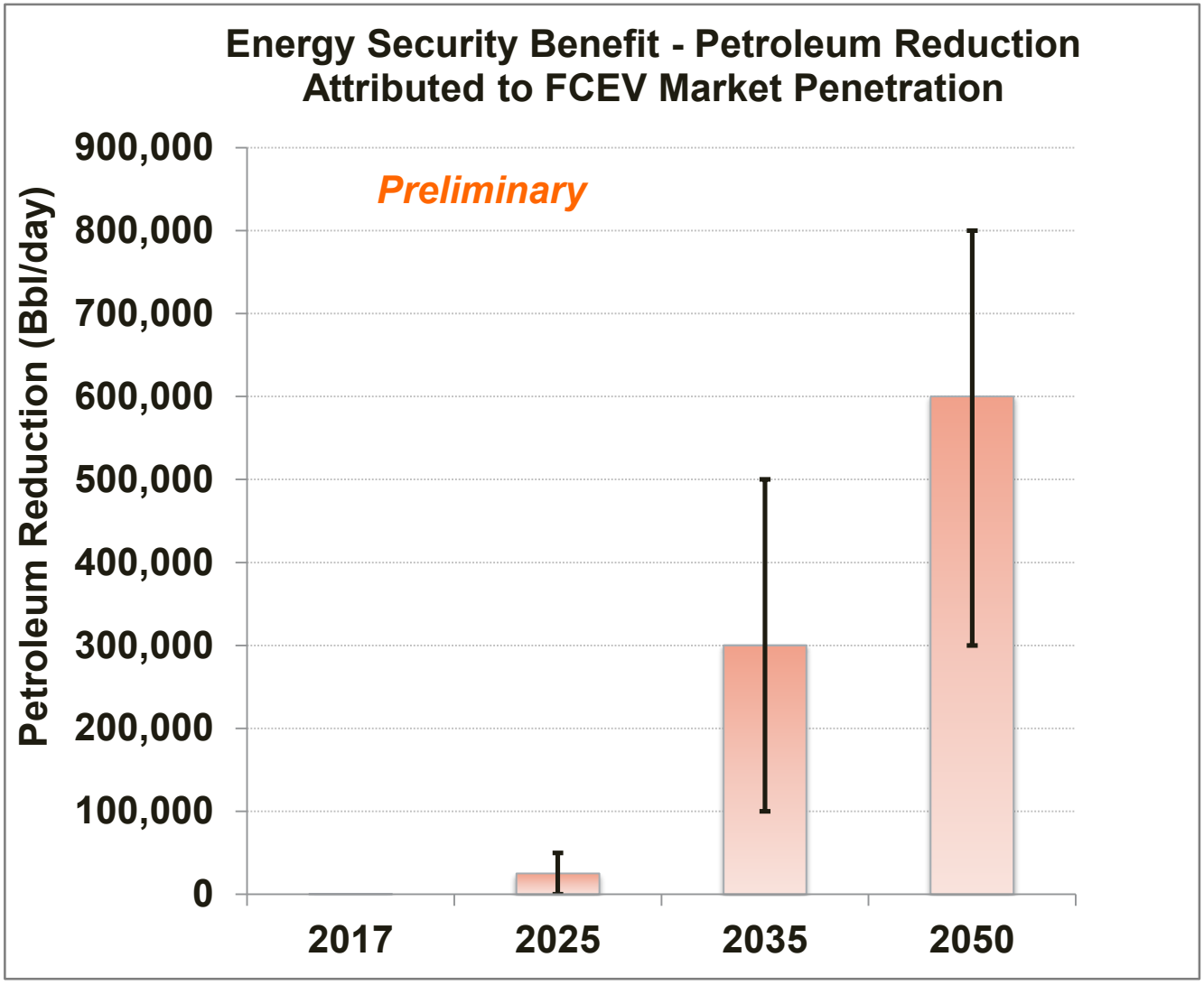
In a portfolio of conventional and alternative technology vehicles, FCEVs can achieve market penetration and reduce petroleum use by 300,000 – 800,000 bbls/d



Source: ANL GPRA Analysis

Analysis basis

- Based on combined analysis of VTO and FCTO
- FCEVs included in a portfolio of vehicles including ICEVs, HEVs, PHEVs and BEVs.

FCEV Assumptions		
	Base	Program targets
Fuel cells, $/kW	48	30
Storage, $/kWh	17	8
H_2 Cost, $/gge	8	3
Infrastruct.	Follows Veh. penetration	

Market Segmentation Analysis

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Various FCEV models show superior cost benefits for driving ranges >150 miles

Total Cost of Ownership (TCO) Difference between FCEVs and BEVs

Preliminary

Year: 2040

(*FCEV minus BEV-X Cost*)

	50 Miles	100 Miles	150 Miles	200 Miles	250 Miles	300 Miles	350 Miles
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				0.12	-$0.15
Midsize Cars	$0.05	$0.01				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

FCEVs Favored

Green shading cells are favorable TCO for FCEVs. TCO expressed in $/mi.

Source: *Market Segmentation of Light-Duty Battery Electric and Fuel Cell Electric Vehicles*

<u>Assumptions</u>

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.

Resource Analysis

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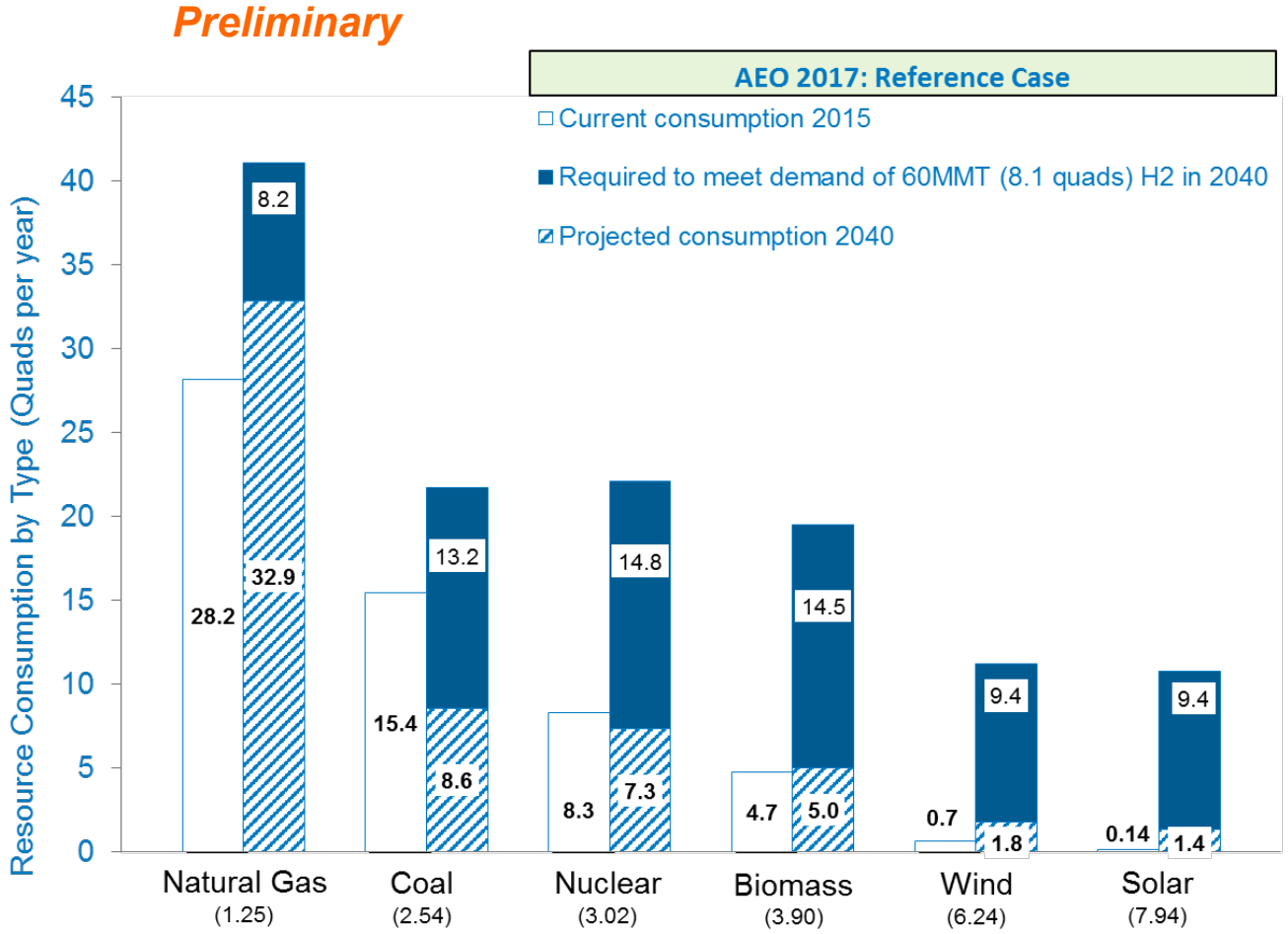
U.S. has an abundance of regionally distributed domestic resources to produce fossil fuel-based and renewable hydrogen



- Hydrogen can be produced from a variety of domestic resources including natural gas, nuclear, solar, wind and biomass.
- Resources are regionally distributed to meet hydrogen demand of FCEVs.
- Ratio of projected 2040 consumption and additional resource needed to supply 60 MMT H_2/yr is shown as a factor in parenthesis below each resource label at left.

Source: NREL

Employment Analysis

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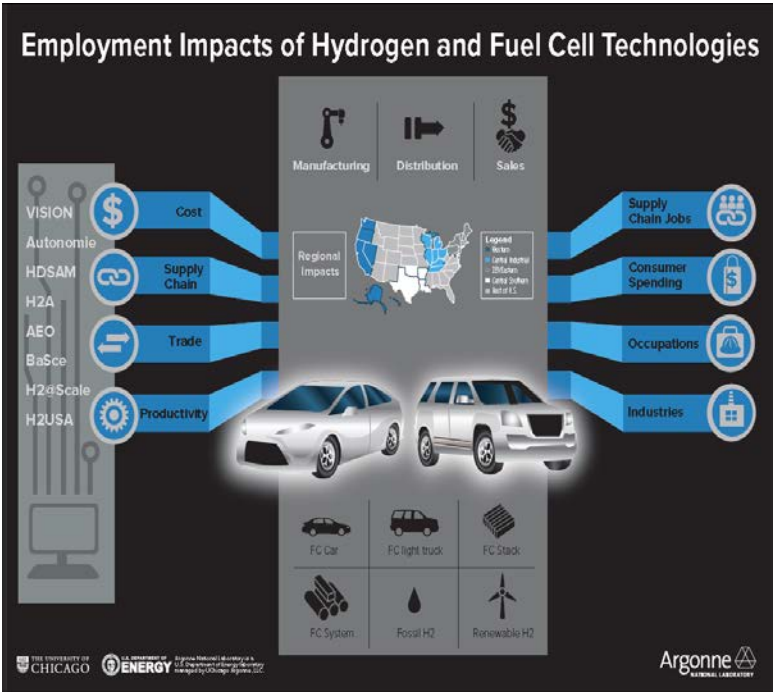
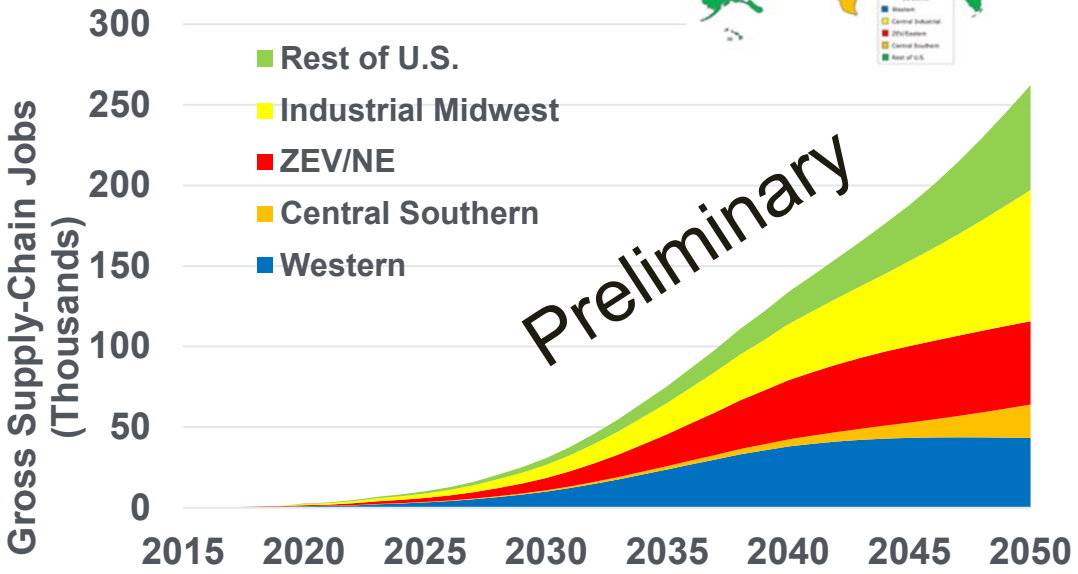
By 2050, ~260,000 Jobs Associated with FCEV Manufacturing, Distribution & Sale (MDS)

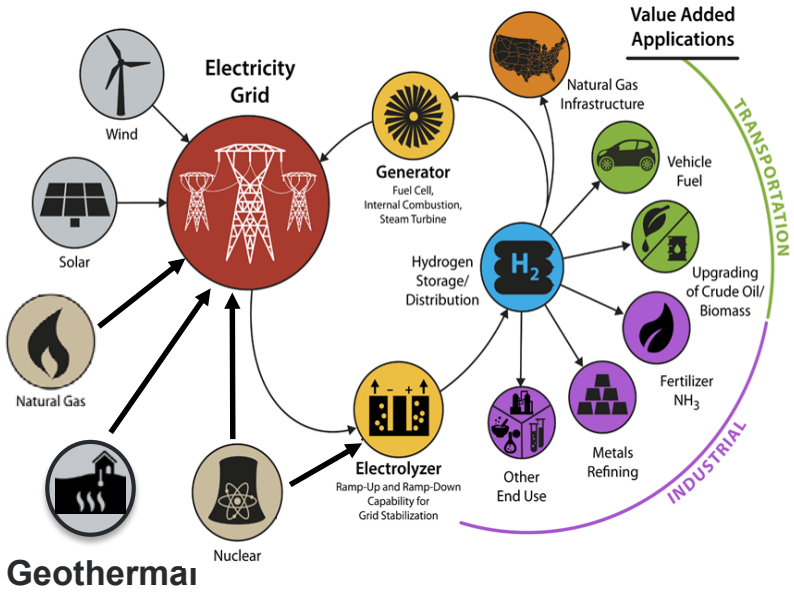
Multi Market Scenario, Supply-Chain Employment (Direct + Indirect)

- ~100,000 gross supply-chain jobs associated with FCEV manufacturing
- ~160,000 gross supply-chain jobs associated with FCEV distribution & sales, independent of where FCEV is assembled





H2@Scale Analysis



Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

INL Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

Lawrence Livermore National Laboratory

LBNL

Phase I - Analysis

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

In-depth Analysis (FY17)

- Vette initial results with stakeholders in Texas workshop
- Evaluate H_2 price requirements
- Identify supply options and costs
- Examine 3 scenarios
- Identify impact potential
- Perform stage-gate review

Additional analysis (FY18)

- Identify future scenarios
- Examine economic inertia and externalities
- Perform spatial analysis

H2@Scale: Where Resources are Sufficient

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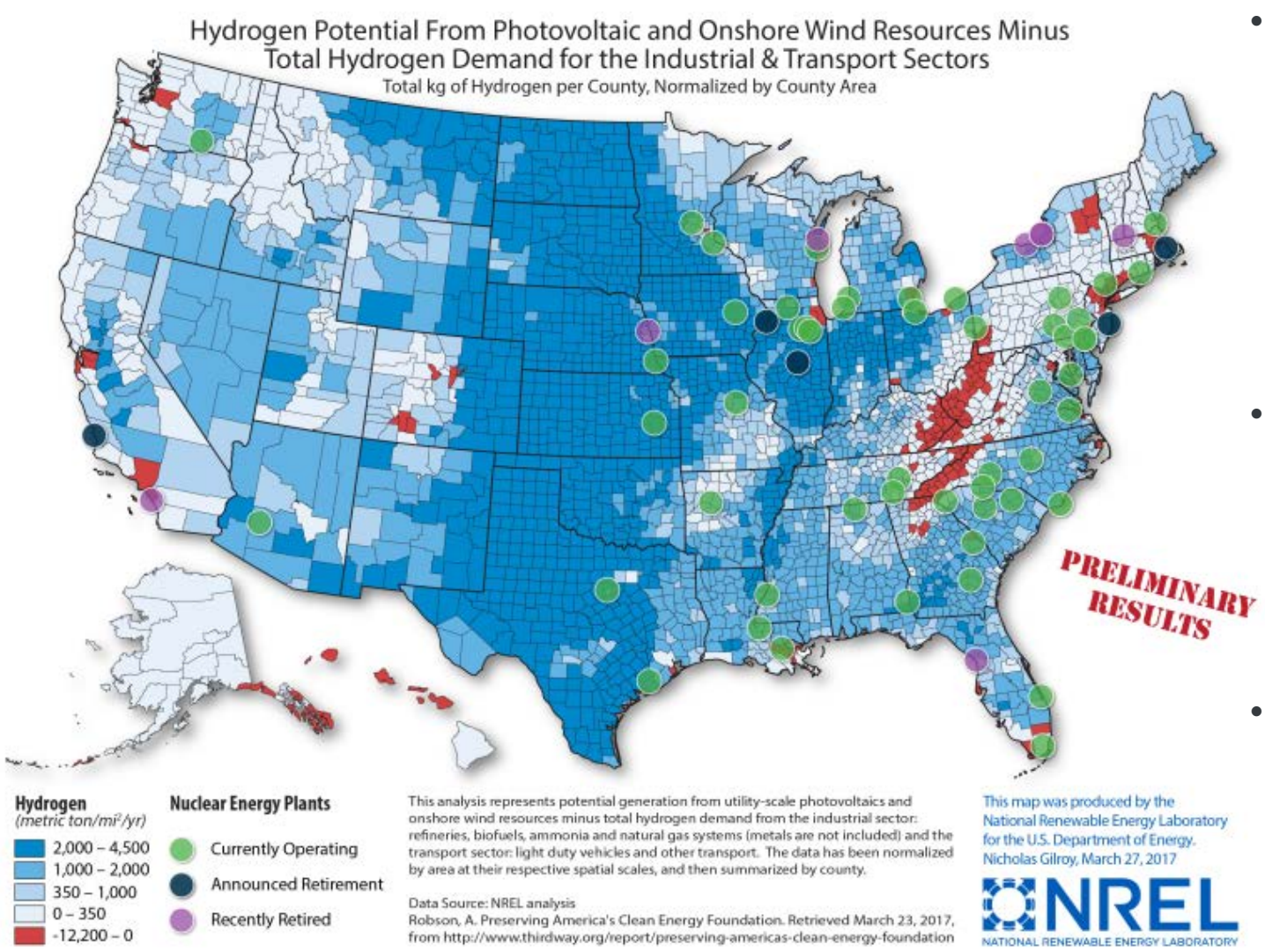

- PV and wind resources exceed industrial + transportation demand (not including metals) in **counties colored blue**
- Industrial + transportation demand is greater than resources **only in counties colored red**
- Nuclear production could provide the necessary additional generation

Most counties have sufficient renewable resources. Those that do not have renewable or nuclear resources nearby.

Sustainability Analysis

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

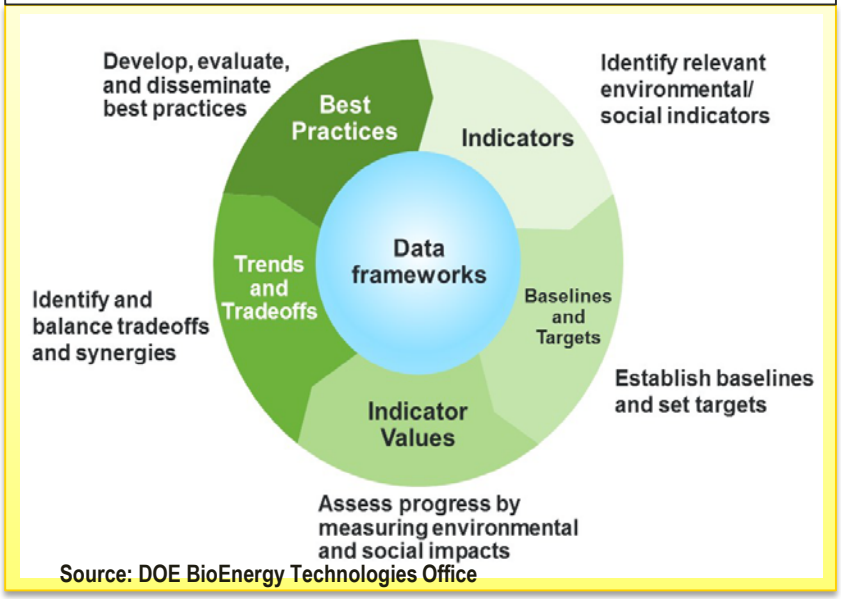
Potential H_2 and Fuel Cell Technologies Sustainability Framework

Energy Security	Employment Impacts	Land Use	Water Use and Resources
			
Lifecycle analysis of petroleum use	Employ. demand, skillset gaps and education	Land use for H_2 Production	Water use for H_2 Production

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

Approach: Establish process and metrics to guide FCTO R&D goals and priorities

Sustainability Process



Source: DOE BioEnergy Technologies Office

Technology Analysis: Total Cost of Ownership for Buses

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

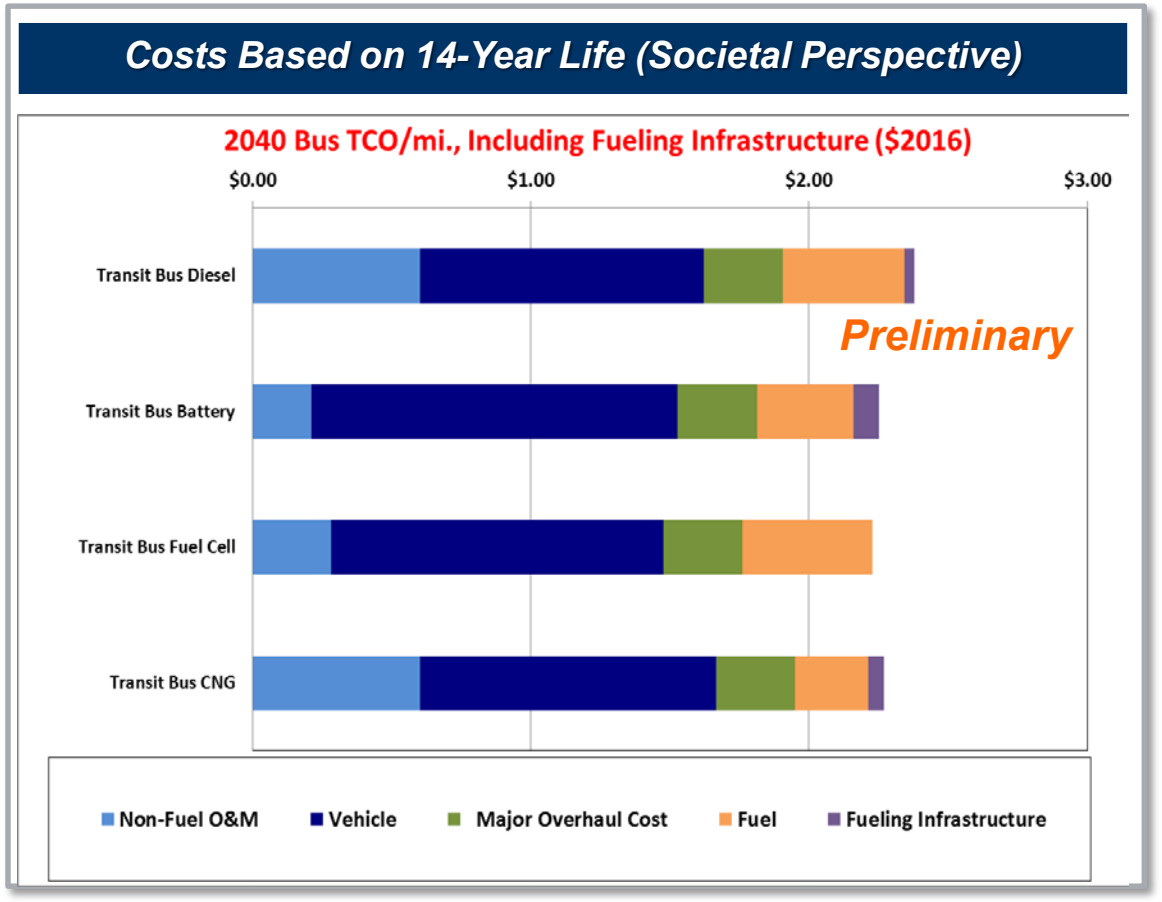
- **Joint analysis project with feedback from the Vehicle Technologies**
- **Vehicle life cycle costs being updated based on peer reviewer input**

Assumptions

- 14-year ownership
- 35,000 miles per year
- 5% discount for annual fuel costs

Vehicle Types

Ref. SI: Diesel Transit bus
Advanced battery: Transit Bus Battery
Advanced fuel cell: Transit Bus Fuel Cell
CNG: Transit Bus CN



2040 Costs	FC Buses	BEV Buses
Battery Cost, $/kWh		$250
Fuel Cell Cost, $/kW	$300	NA
Fuel Cost in ¢/kWh	$4.00	18¢

Well-to-wheel analysis of GHG emissions: Medium- and heavy-duty freight trucks

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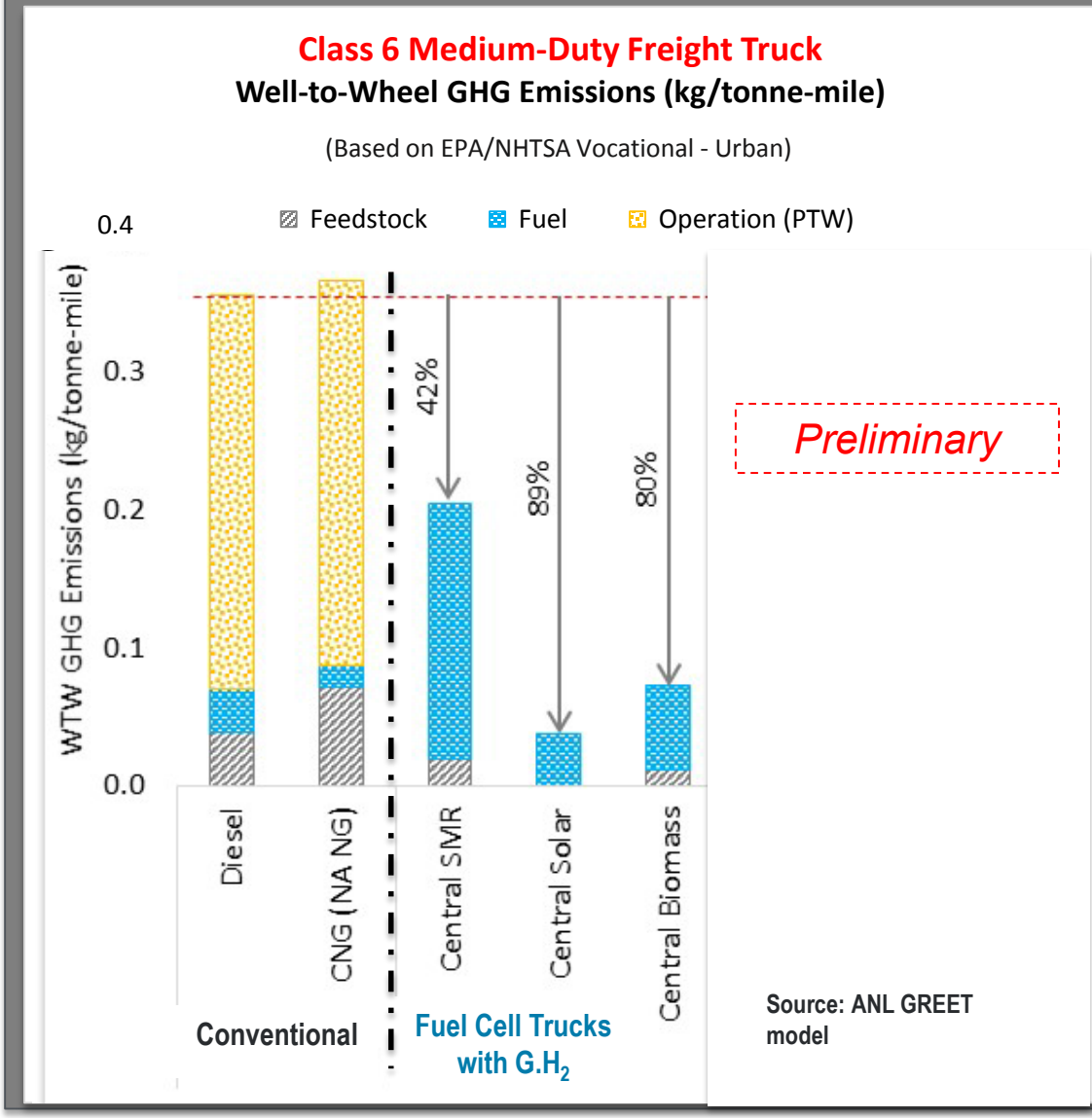
Gaseous hydrogen fuel cell trucks can achieve ~40-90% GHG emissions reduction compared to diesel.



- On a tonne-mile basis, gaseous (G.H2), hydrogen fuel cell hybrid-electric trucks (Class 6 and 8) emit less WTW GHGs in comparison with baseline diesel.
- GREET model for truck analysis has been upgraded to include fuel cells for multiple classes.

Criteria Emissions

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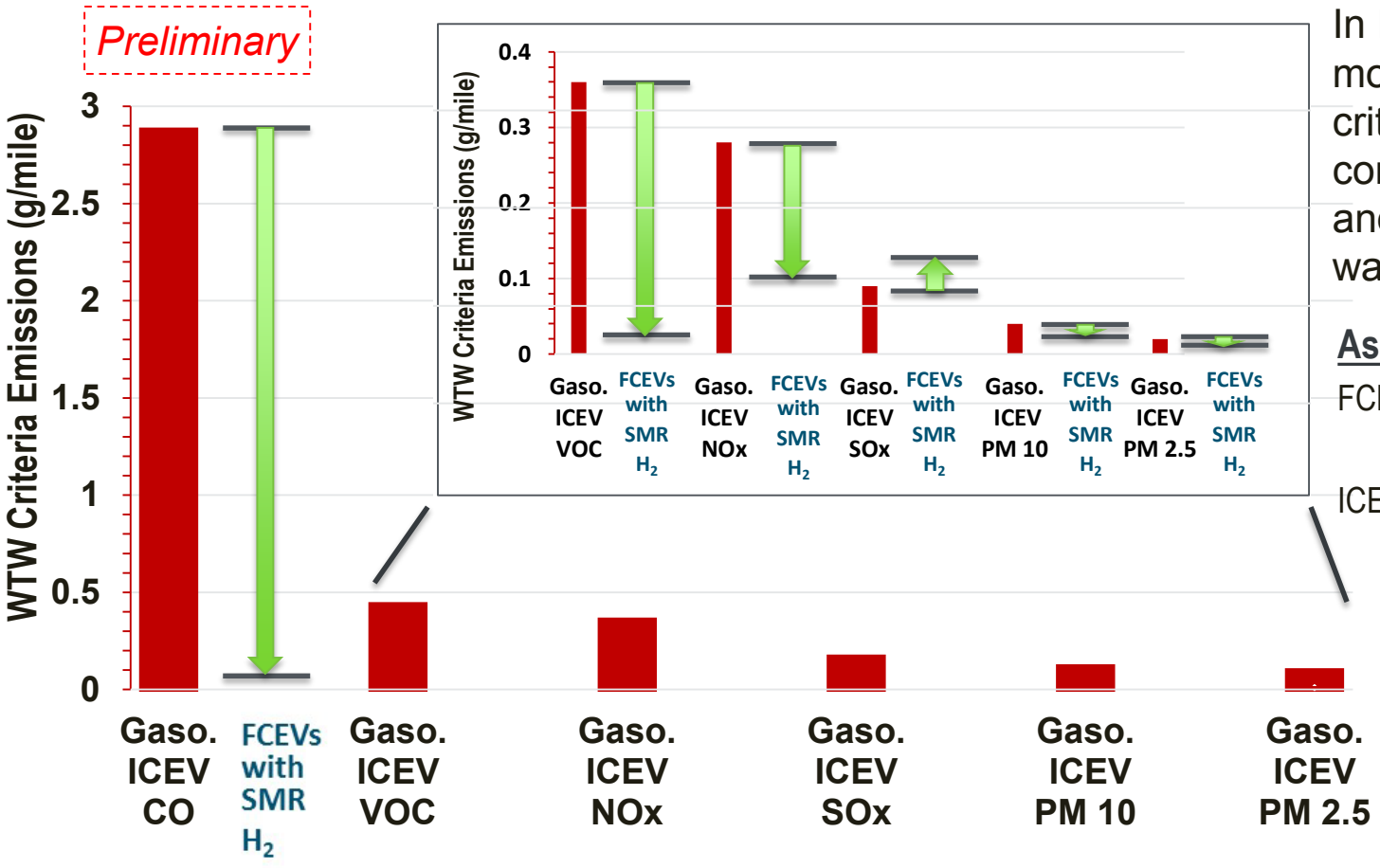
Criteria emissions attributed to FCEVs are significantly less than gasoline ICEVs. and achieve zero emissions during idling



Source: ANL GREET model

In FY2017, ANL GREET model representation for criteria emissions for conventional fuel/vehicle and hydrogen/FCEVs was updated.

Assumptions

FCEV fuel economy: 55 mpgge

ICEV fuel economy: 26 mpgge

Significant FCEV attribute: Criteria emissions from FCEVs during idling will be ZERO.

Recent and Upcoming Activities

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Emphasis in FY17

- Early market and infrastructure analysis
- Life-cycle analyses of cost, petroleum use, and water use.
- Assess programmatic impacts on market penetration, job creation, and return on investment.
- Evaluate sustainability framework and metrics for FCTO

FY 2017	FY 2018
• **Gaps and drivers for early market infrastructure cost** • **Employment study - national employment impacts** • **Sustainability metrics for FCTO** • **GHGs for medium & heavy duty trucks** • **Integrate consumer choice in vehicle market penetration**	• **Gaps and drivers for program R&D** • **Program R&D target impact assessment and integrated analysis** • **Energy security impact of FCTO targets and programs** • **Sustainability metrics for FCTO** • **Target and metric assessment for medium & heavy duty trucks** • **H2@Scale analysis**

Collaborations

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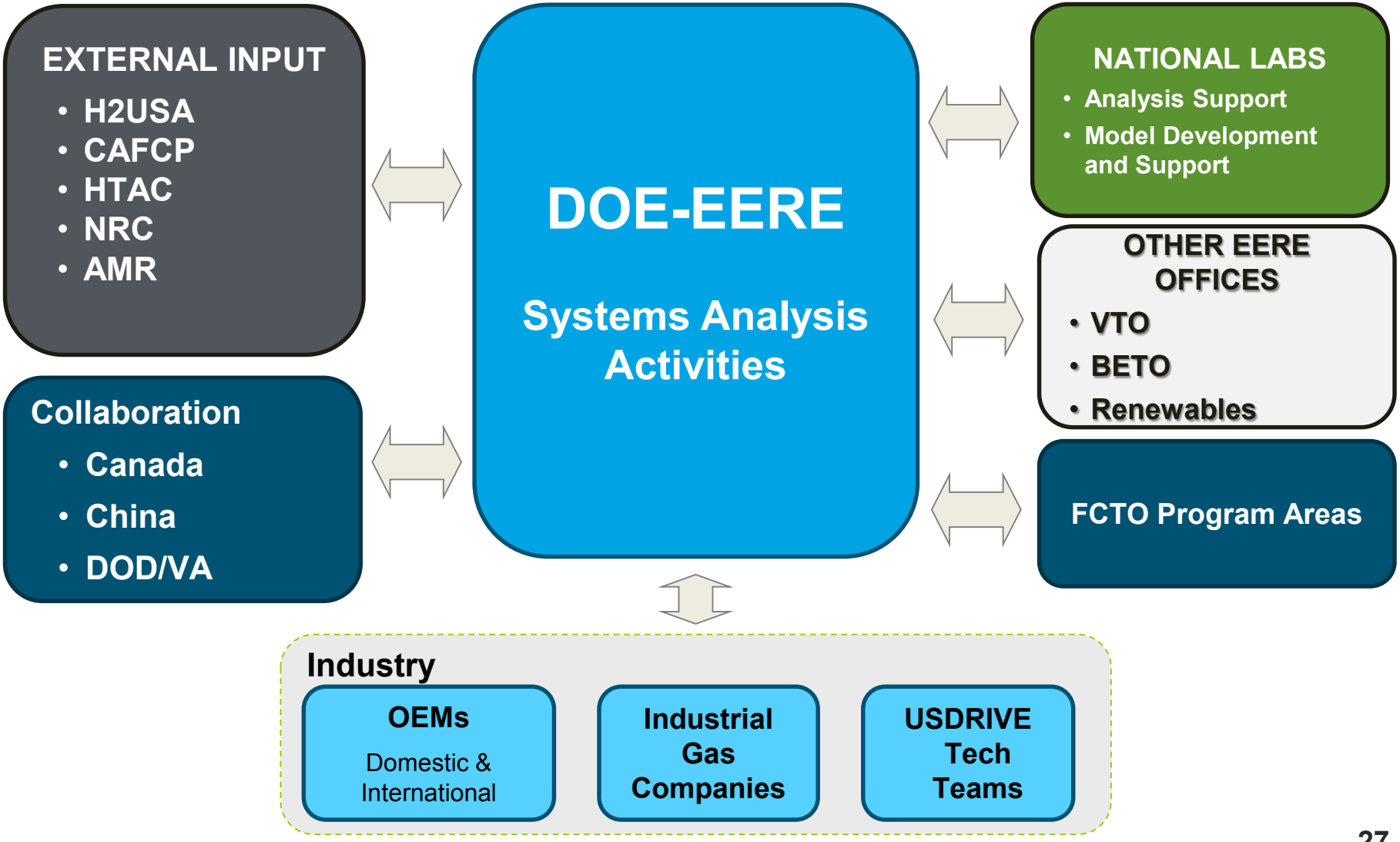
Analysis and peer review input coordinated among national and international organizations.



Contacts

U.S. DEPARTMENT OF ENERGY

For more information contact:

Fred Joseck - Team Lead 202-586-7932 fred.joseck@ee.doe.gov	
Tien Nguyen !RETIRED!	John Stevens !NEW! 202-586-7925 john.stevens@ee.doe.gov
Shawna McQueen !NEW! 202-586-0833 shawna.mcqueen@ee.doe.gov	Vanessa Trejos Support Contractor 202-586-5153 vanessa.trejos@ee.doe.gov

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