U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Fuel Cell Buses in the U.S.
Status, Progress and Opportunities

Sunita Satyapal – Director, Fuel Cell Technologies Office, U.S. DOE

North American Fuel Cell Bus Conference

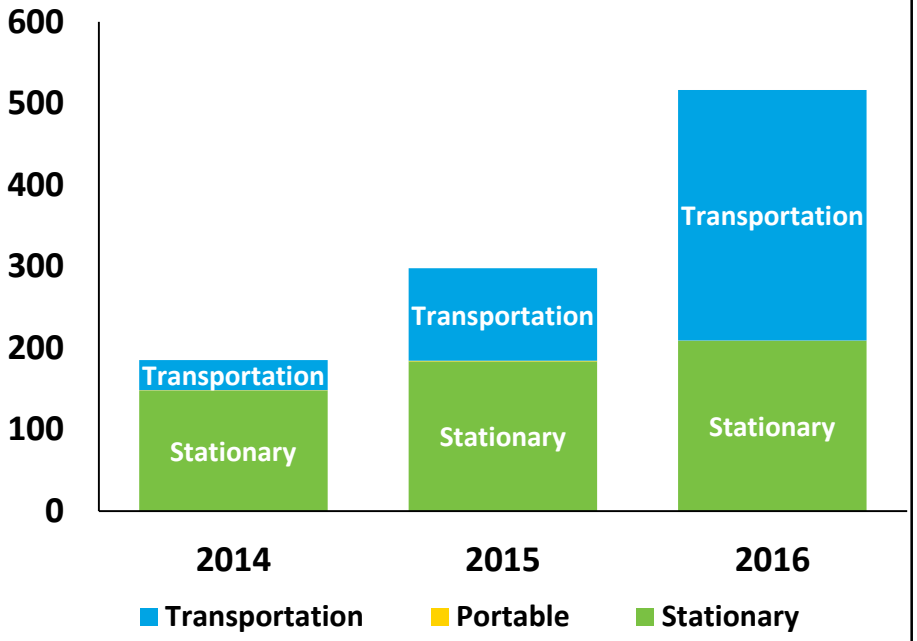
Canton, OH–November 2 – 3, 2017

Market Growth

2016 Global Shipments – Trends

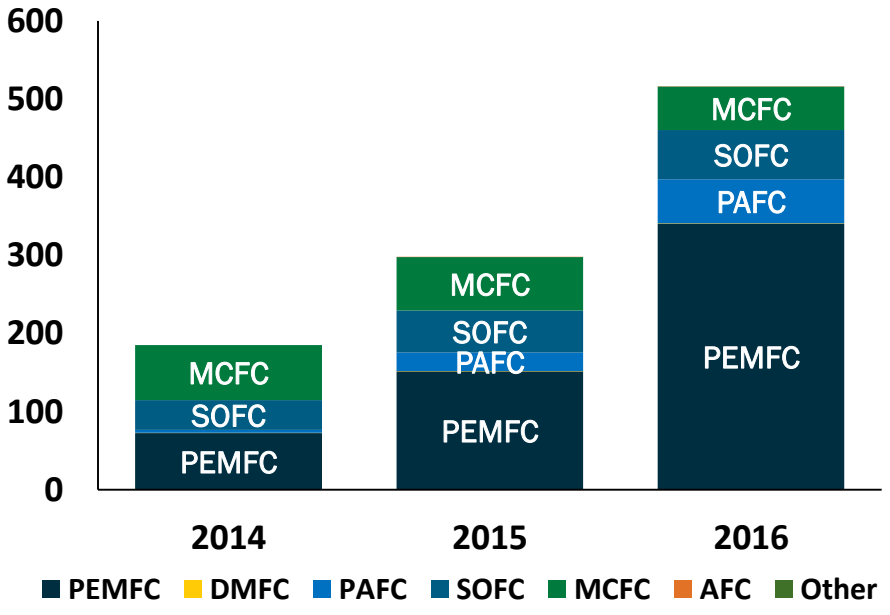
Total power (in MW) shipped by application

Growth in Transportation



Total power (in MW) shipped by fuel cell chemistry

Growth in PEMFC



500 MW fuel cell power shipped worldwide

62,000 fuel cell units shipped worldwide

Approximately **$1.6 Billion** fuel cell revenue

Source: DOE Fuel Cell Technologies Market Report. Available at: https://energy.gov/eere/fuelcells/market-analysis-reports

Other Heavy Duty Vehicle Applications Emerging

Fuel cell delivery and parcel trucks starting deliveries in CA and NY

Industry demonstrates first heavy duty fuel cell truck in CA

ZH2: U.S. Army and GM collaboration First of its kind

Market Segmentation Analysis- DOE Study Underway

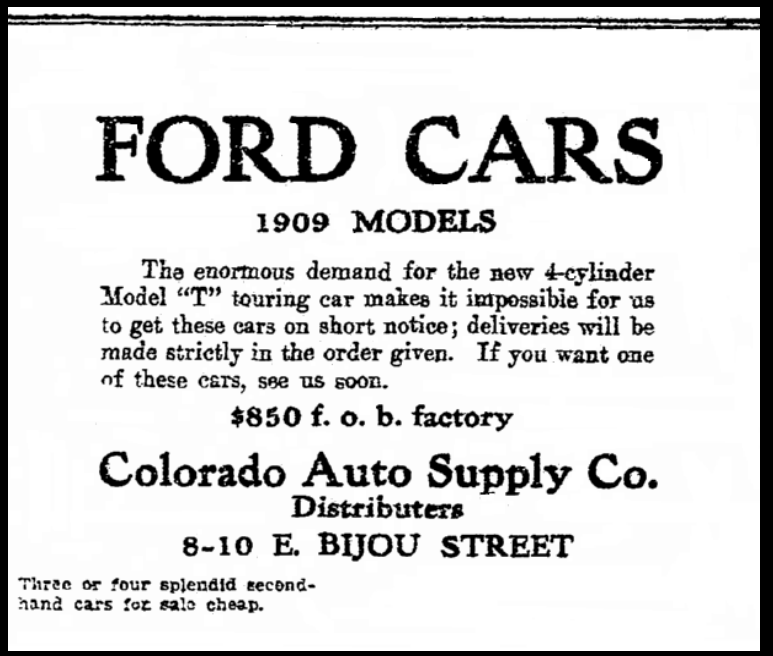
FCEV costs: favorable in larger size classes and higher driving range

Year 2040: FCEV minus PEV-X Cost

	50 mi.	100 mi.	150 mi.	200 mi.	250 mi.	300 mi.	350 mi.
Two-seaters	$0.04	$0.00	-$0.04	-$0.07	-$0.11	-$0.15	-$0.19
Minicompacts	$0.05	$0.02	-$0.01	-$0.04	-$0.07	-$0.10	-$0.13
Subcompacts	$0.04	$0.01	-$0.02	-$0.04	-$0.08	-$0.11	-$0.14
Compacts	$0.03	$0.00	-$0.03	-$0.06	-$0.09	-$0.12	-$0.15
Midsize Cars	$0.03	$0.00	-$0.04	-$0.06	-$0.10	-$0.13	-$0.17
Large Cars	$0.03	$0.00	-$0.03	-$0.06	-$0.09	-$0.12	-$0.16
Small Station Wagons	-$0.01	$0.00	-$0.04	-$0.06	-$0.11	-$0.15	-$0.19
Pass Van	$0.03	-$0.01	-$0.06	-$0.11	-$0.15	-$0.20	-$0.24
SUV	$0.02	-$0.03	-$0.09	-$0.14	-$0.19	-$0.25	-$0.30
Std Pickup	$0.14	$0.10	$0.07	$0.04	$0.01	-$0.03	-$0.06
Small Pickup	$0.06	$0.01	-$0.03	-$0.07	-$0.11	-$0.15	-$0.19

What can we learn from history?

Henry Ford's Quadricycle in 1896 to Model T in 1908



FORD CARS

1909 MODELS

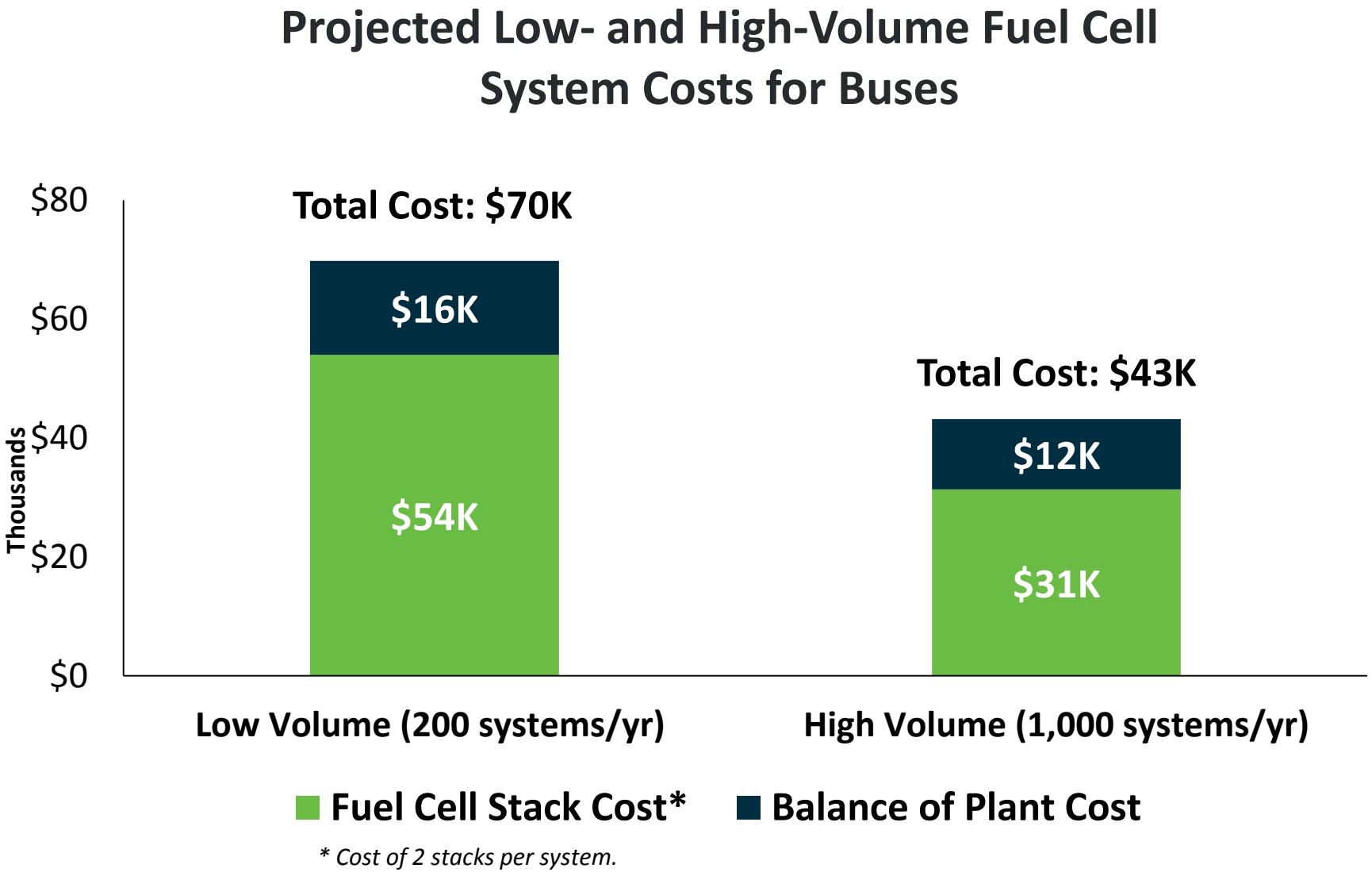
The enormous demand for the new 4-cylinder Model "T" touring car makes it impossible for us to get these cars on short notice; deliveries will be made strictly in the order given. If you want one of these cars, see us soon.

$850 f. o. b. factory

Colorado Auto Supply Co.
Distributers
8-10 E. BIJOU STREET

Three or four splendid second-hand cars for sale cheap.

Cost Projections for Bus Fuel Cell Systems

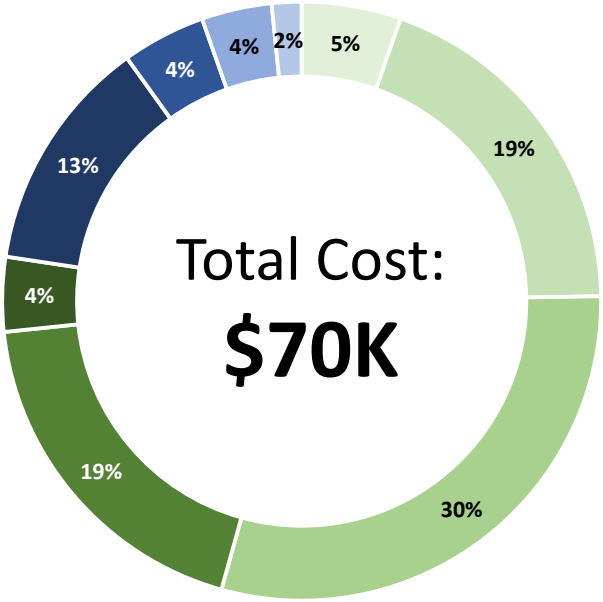


** Cost of 2 stacks per system.*

Source: DOE FCTO project: SA

Fuel Cell Costs for Buses

Low-Volume Fuel Cell System Total Cost
(200 systems/yr.)



Fuel Cell Stack Cost: $54K
BOP Cost: $16K

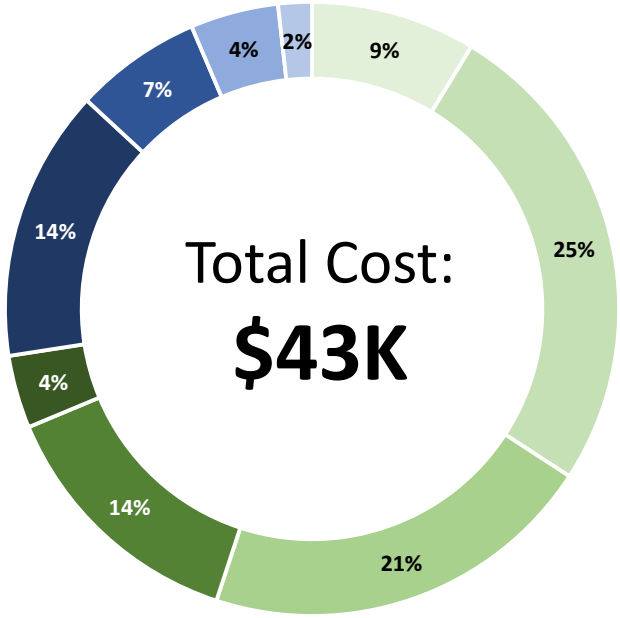
- Bipolar Plates
- Catalyst & Application Total
- MEAs (incl. frame and gaskets)
- GDLs Total
- Balance of Stack Total

Stack costs

- Air Loop
- High temp, Low temp and fuel loops
- Humidifier, system controller and sensors
- Miscellaneous

Balance of Plant (BOP) costs

High-Volume Fuel Cell System Total Cost
(1000 systems/yr.)



Fuel Cell Stack Cost: $31K
BOP Cost: $12K

Source: DOE FCTO project: SA Cost Analysis- 2016 Update

Analysis for H_2 Storage System for Buses

Cryo-Compressed Potential: Same Driving Range at Lower Cost, Weight & Volume

	Cryo-compressed* (future)	Ambient* (current)
Storage pressure	500 bar	350 bar
System Cost @ 5K systems/yr.	~$12/kWh (~$16K total)**	~$14/KWh (~$19K total)
Amount of H_2	4 tanks x 10 kg H_2 (40 kg total)	8 tanks x 5 kg H_2 (40 kg total)
Liner	2-mm SS	7.1-mm Al
Storage Temperature	72 K	288 K
H_2 Storage Density (H_2)	75 g/L	24 g/L
Usable Hydrogen	95%	96%
Gravimetric Capacity	8.4% (~500 kg total)	4.4% (~900 kg total)
Volumetric Capacity	50.8 g/L (~800 L total)	18.5 g/L (~2200 L total)
Amount of CF Composite	4 tanks x 54 kg CF (~215 kg total)	8 tanks x 50 kg CF (~400 kg total)
Dormancy (95% Full)	3.6 days	NA
Dormancy (75% Full)	15 days	NA
Dormancy (60% Full)	24 days	NA

*Source: DOE, ANL, Strategic Analysis (SA)

**Based on preliminary results from SA

Fuel Cell Bus 2017 Status vs. DOE-DOT Targets

	Fleet Avg.	Fleet Max.	2016 Target	Ultimate Target	Target Met
Bus lifetime (years)	4.9	7	12	12	
Bus lifetime (miles)	131,963	189,168	500,000	500,000	
Powerplant lifetime[a] (hours*)	14,309	25,395	18,000	25,000	✓
Bus availability (%)	75	93	85	90	
Roadcall frequency[b] (bus)	4,649	--	3,500	4,000	✓
Roadcall frequency (fuel cell system)	21,741	--	15,000	20,000	✓
Maintenance cost ($/mi)	1.20	2.42	0.75	0.40	
Fuel economy (mpdge)[c]	7.01	7.82	8	8	
Range (miles)[d]	300	357	300	300	✓

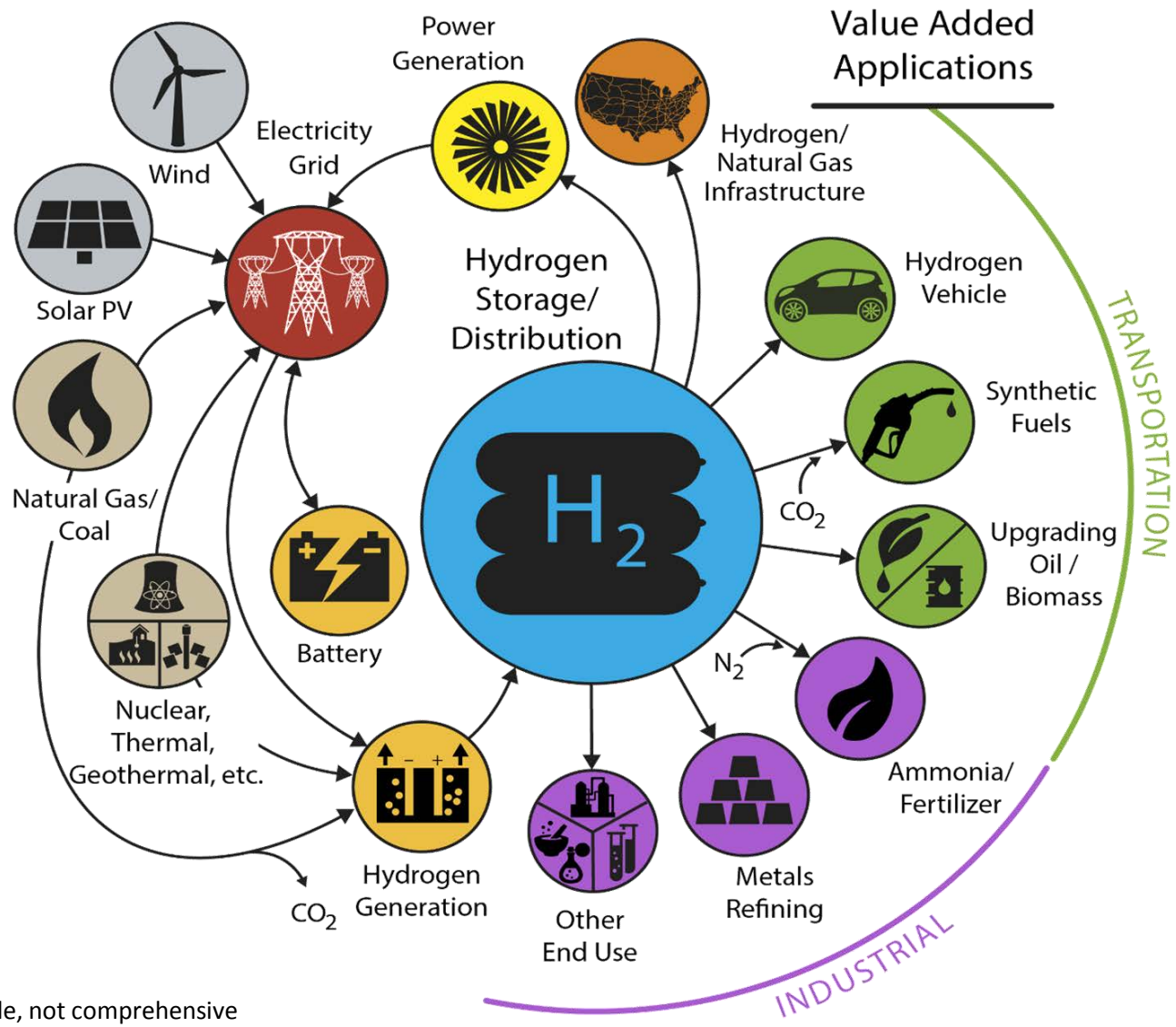
[a] Fuel cell hours accumulated to date from newest FCPP to oldest FCPP. Does not indicate end of life.
[b] MBRC: average for current designs.
[c] Miles per diesel gallon equivalent
[d] Estimated range based on fuel economy and 95% tank capacity.

Source: 2017 NREL Bus Report

*Hours not met by all buses

H2@Scale Energy System

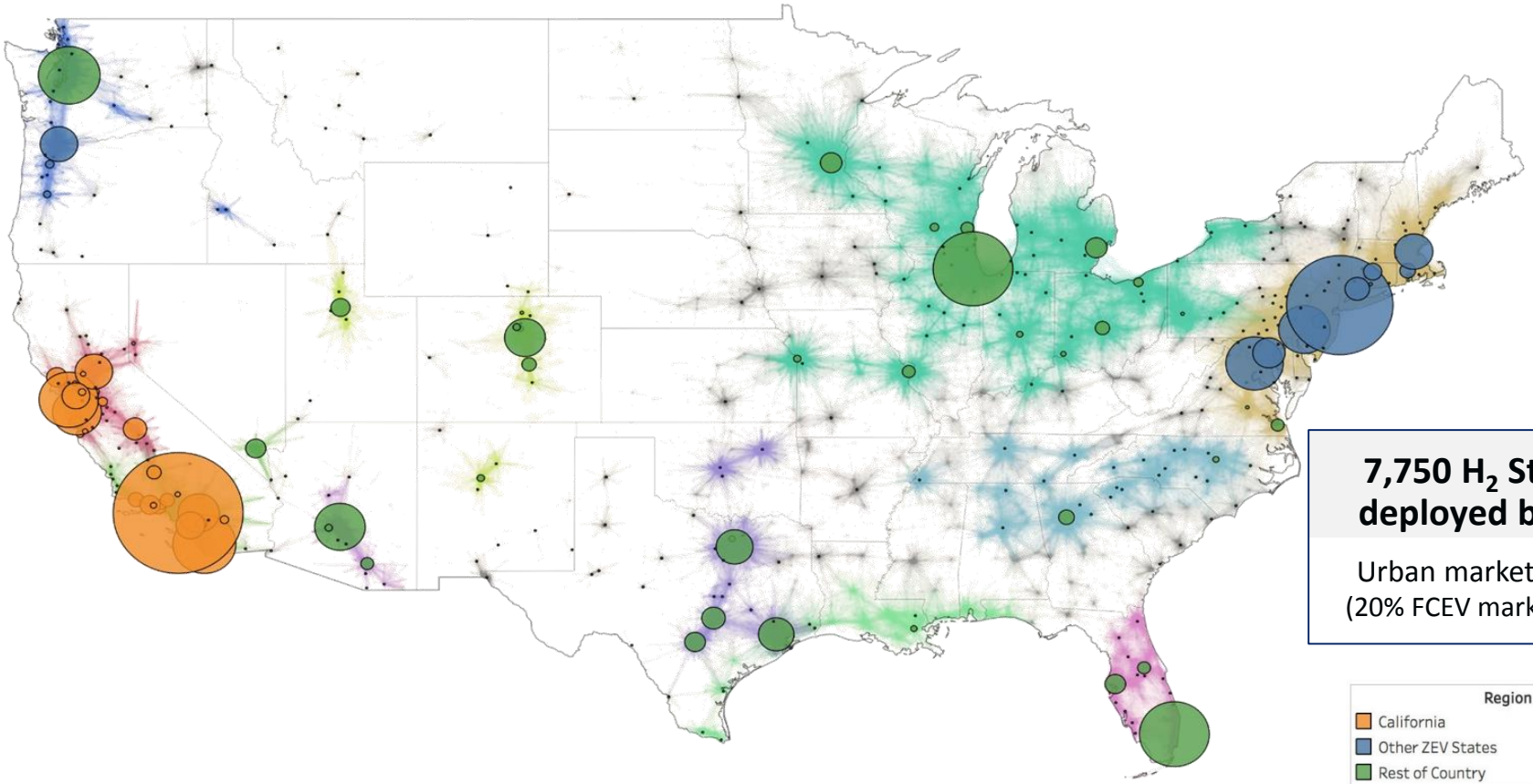
H_2 at Scale Energy System



*Illustrative example, not comprehensive
Source: NREL

Hydrogen Station Rollout Modeling - Example

NREL's Station Rollout Scenario Analysis in support of H_2USA



7,750 H_2 Stations deployed by 2050

Urban markets scenario
(20% FCEV market share*)

*Nationwide

Region
- California
- Other ZEV States
- Rest of Country

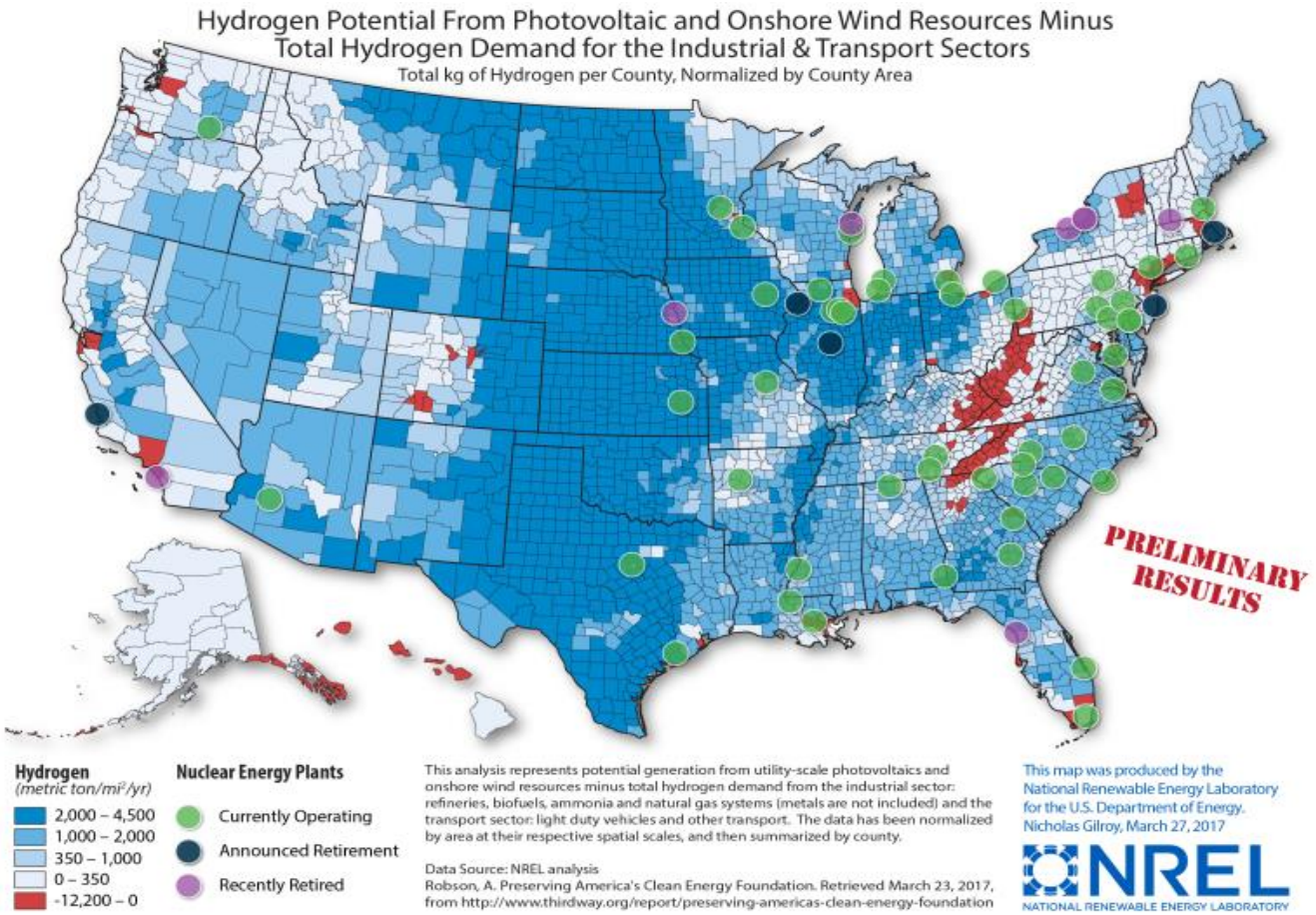
Total Capacity (kg/day)
- 180
- 1,000,000
- 2,000,000
- 3,000,000
- 4,000,000

Examples of variables considered in scenarios:

- ✓ Consumer adoption
- ✓ Station Expansion Network

Source: Marc Melaina, et al, NREL

H2@Scale: Nationwide Resource Assessment



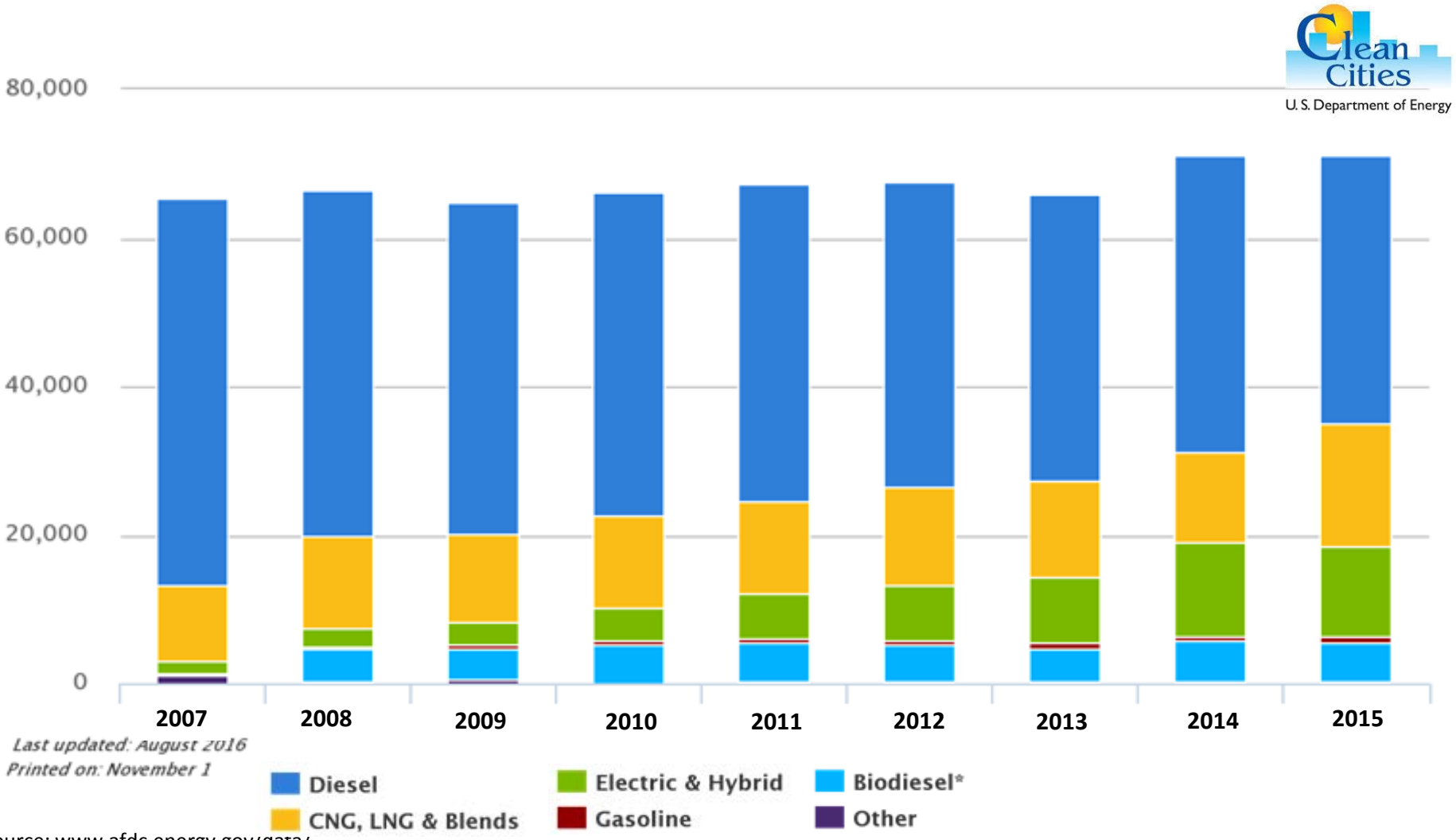
Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

Labs assess resource availability. Most regions have sufficient resources.

Red: Only regions where projected industrial & transportation demand exceeds supply.

U.S. Transit Buses by Fuel Type

Electric and Hybrid: Fastest Growing



Source: www.afdc.energy.gov/data/

Fuel Cell Buses in the U.S. - Examples

California

Current: 19 Buses

San Francisco Bay Area (13), Thousand Palms (4), Santa Ana (1), Irvine (1).

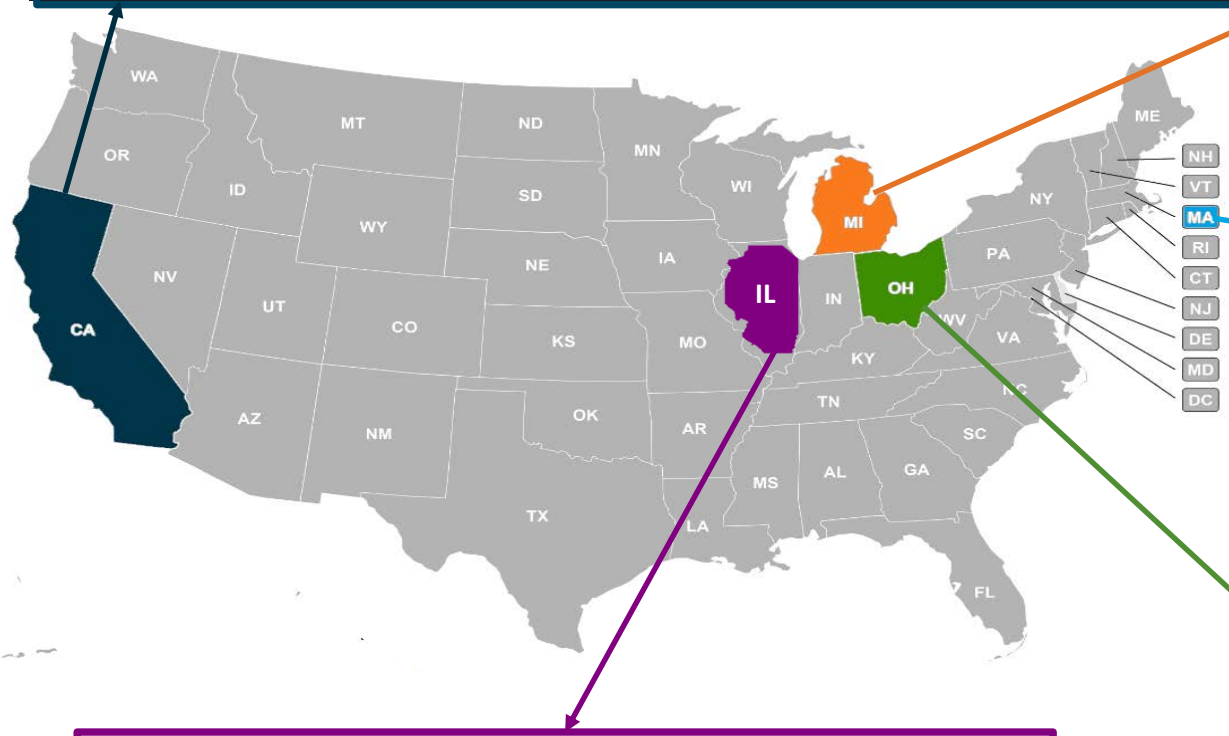
Planned: 33 Buses

Oakland and Santa Ana (21), Thousand Palms (12).

Michigan

Current: 1 Bus

Flint



Massachusetts

Current: 1 Bus

Boston

Ohio

Current: 5 Buses

Canton

Planned: 7 Buses

Canton , Columbus

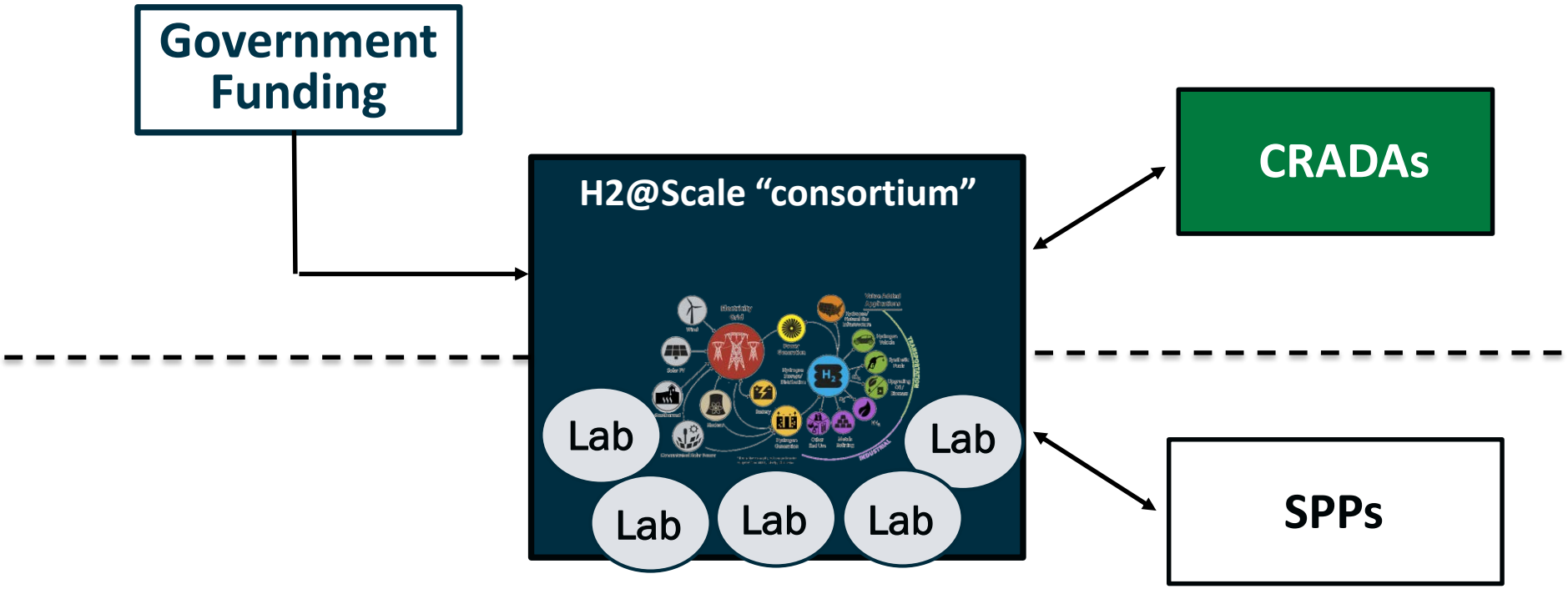
Illinois: Planned: 1 Bus (Champaign-Urbana)

Source:
2017 NREL Bus Report

Collaborations and Resources

H2@Scale partnerships with labs

- To leverage **lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.**
- **Round 1 closed Sept. 15 – stay tuned for winners and future rounds**



CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

Hydrogen Fueling Infrastructure Research & Station Technology (H2FIRST)

Addressing problems with hydrogen stations

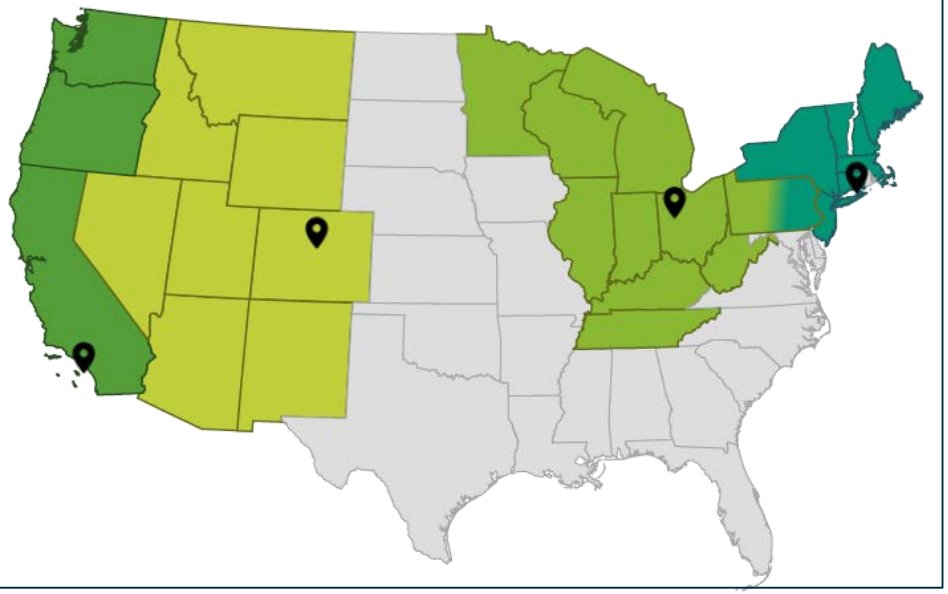
- HySTEP
- Reference Station Designs
- H_2 Meter Benchmarking
- Dispenser Reliability
- H_2 Contaminant Detector

H_2FIRST
(SNL & NREL)

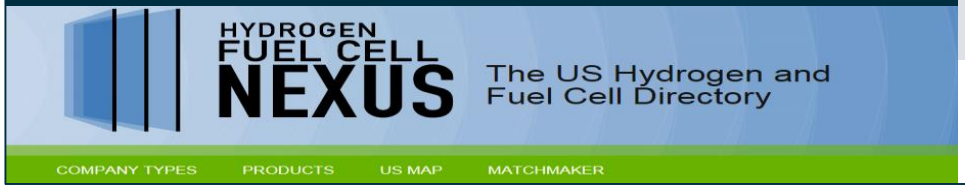
Enabling Supply Chain – Resources

Network of Four Regional Technical Exchange Centers

- **Mid-West** - Ohio Fuel Cell Coalition
- **Rocky Mountain** - National Renewable Energy Laboratory
- **East-Coast** - Connecticut Center for Advanced Technology
- **West Coast** - National Fuel Research Center (UC Irvine)



Online Database of U.S. suppliers and integrators

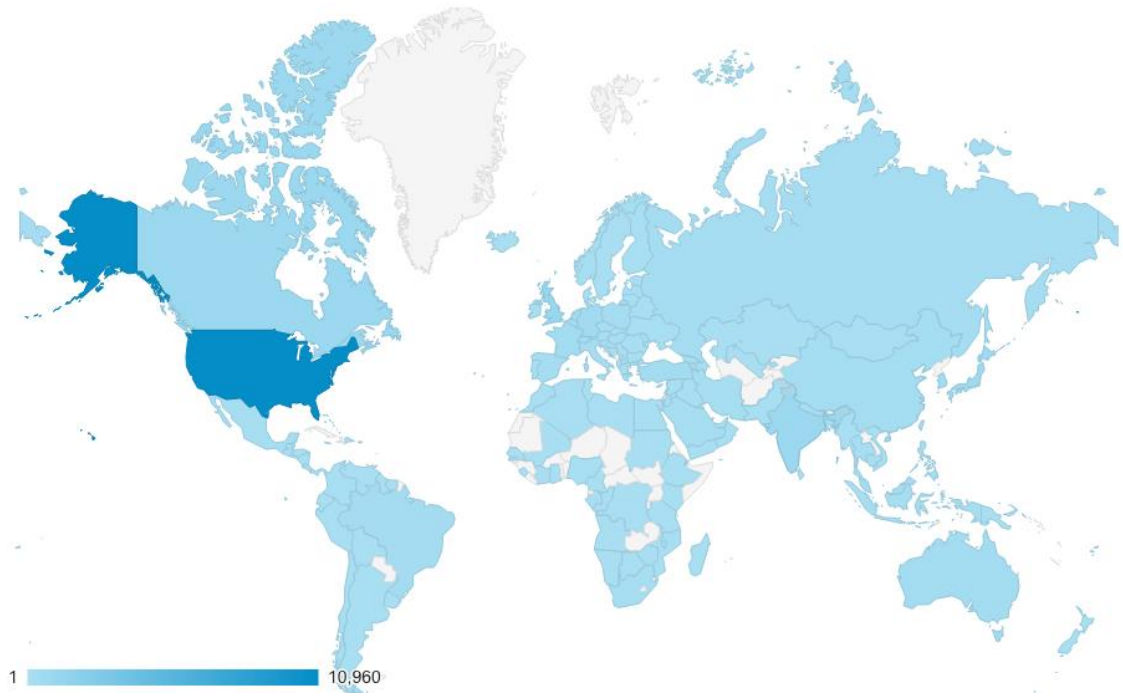


Connect at

HFCnexus.com

Over 300 companies included

H2Tools: One-stop for H2 safety knowledge



- Includes resources on **safety** best practices, **first responder training**, and **H_2 codes & standards**

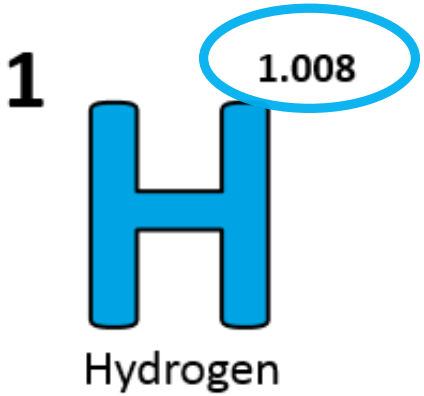
- Site visit tracking shows a **global reach: 50%** of visits are **international!**
- Nearing **150,000 visits since 2015**
- Training resource **translated into Japanese and other languages underway**

Ways to Spread the Word

Celebrate Hydrogen & Fuel Cell Day

October 8 or 10/8

(Held on its very own atomic- weight-day)



Learn more:

energy.gov/eere/fuelcells

Give an "*Increase your H2IQ*" presentation in your community!

INCREASE YOUR H2IQ

Download for free at:

energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource


FUEL CELL
Powered by
Hydrogen Fuel Cells

Summary

- **Enable early R&D innovation**
  - Hydrogen fuel
  - Fuel cells
  - H2@Scale
- **Leverage activities to maximize impact**
  - Enable infrastructure and cross-sector impacts
  - Partnerships--other agencies, industry, states, etc.
  - Collaboration on safety R&D and information sharing

Thank You

Dr. Sunita Satyapal
Director
Fuel Cell Technologies Office
Sunita.Satayapal@ee.doe.gov

energy.gov/eere/fuelcells