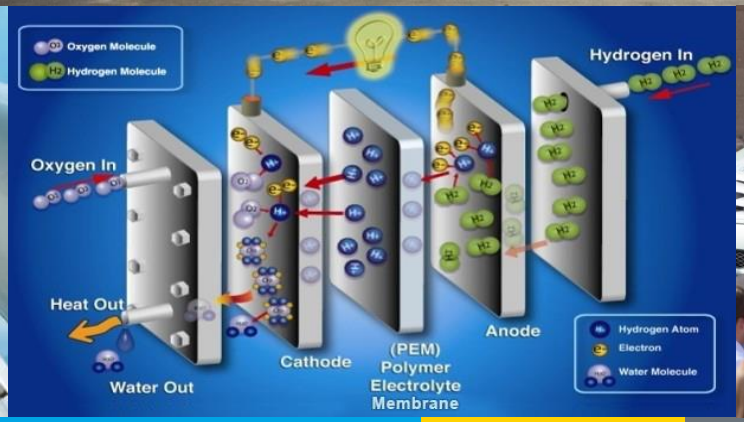
U.S. Department of Energy Hydrogen and Fuel Cells Program

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



2017 Annual Merit Review and Peer Evaluation Meeting

Washington, DC

June 5, 2016

Dr. Sunita Satyapal

Director

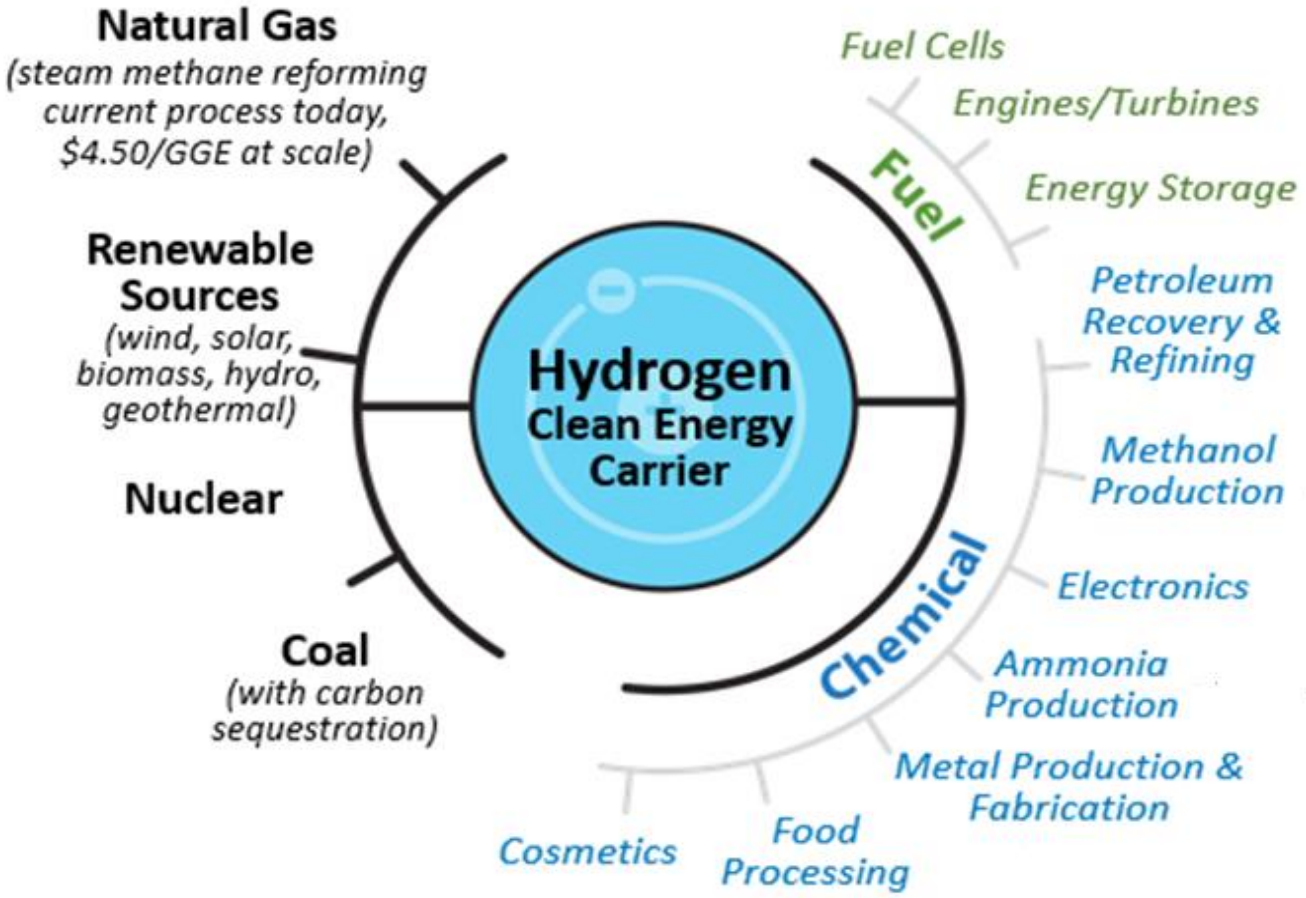
Fuel Cell Technologies Office

U.S. Department of Energy

Hydrogen- A Clean, Flexible Energy Carrier

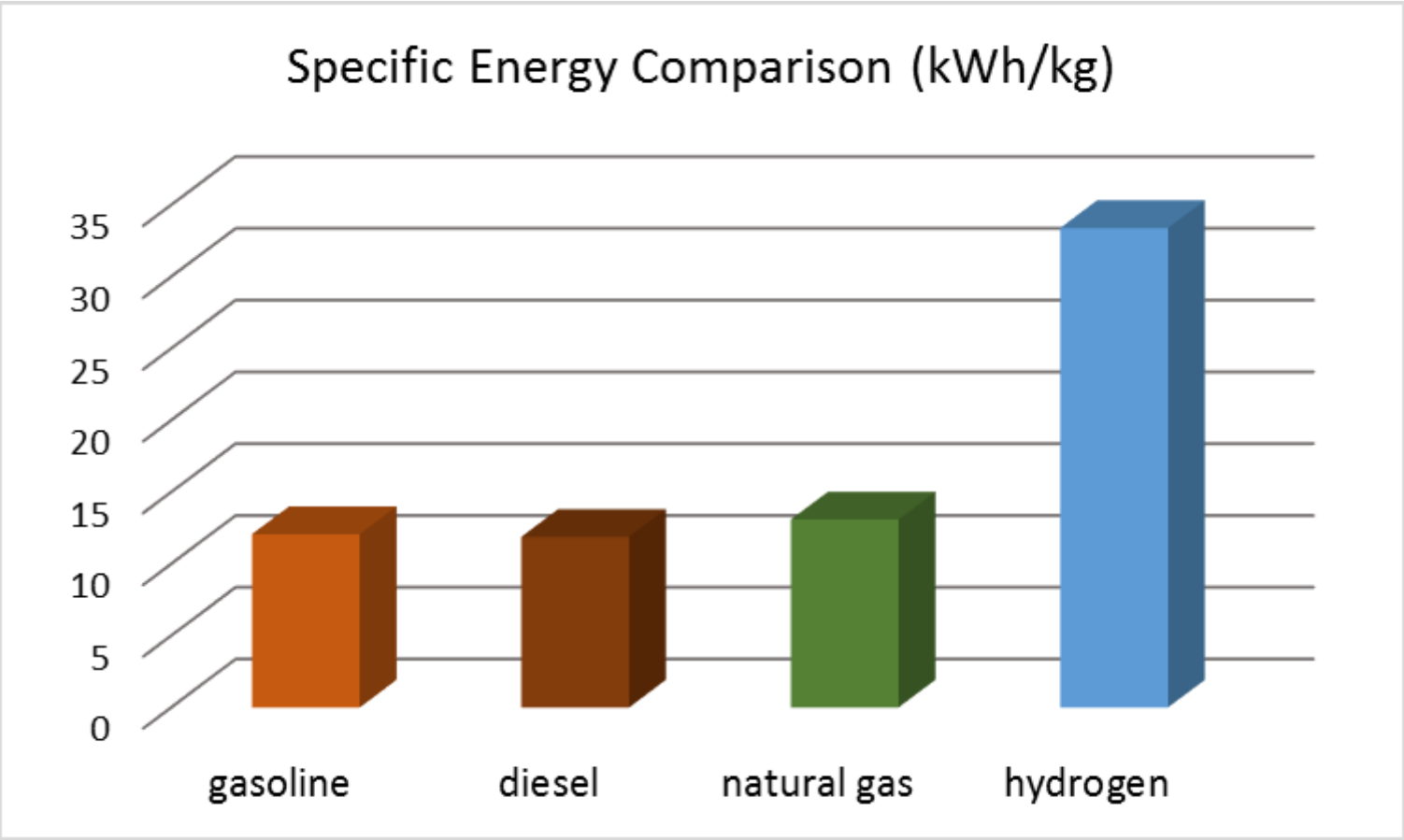
Diverse domestic sources can be used to produce H_2

Many applications rely on or can benefit from H_2



Hydrogen is a versatile, clean, and efficient energy carrier

Energy Content of Fuels 101



~ *Three times* more energy by mass than most other fuels but need higher volumes to store

The Beginning of the DOE Fuel Cell Program…

1970s | **A group from labs, government and industry met at Los Alamos to set the foundation for DOE fuel cell programs**

Lab researchers taught scientists around the world how to fabricate fuel cell electrodes. Group from GM relocated to Los Alamos.

Forty years later, for the first time in history….


Hyundai Tucson Fuel Cell SUV


Toyota Mirai


Honda Clarity

Commercial **fuel cell electric cars are here!**

Power, performance, petroleum-free, pollution-free

- **Refuels in minutes**
- **Up to 360 mi driving range**
- **Up to 66 mpgge**

2017 Preliminary Jobs Analysis Updates

Approx. **16,000** jobs today

in the **fuel cell car sector in the U.S.**

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

Over **200,000** potential jobs

in the future **with fuel cell cars** in the U.S.

Includes Direct and Indirect Jobs in

Manufacturing

Approx.
100,000 jobs

- **Multiple industries** (manufacturing; professional services; wholesale, retail, transportation; etc.)
- **60% in industrial central region**

Distribution and Sales

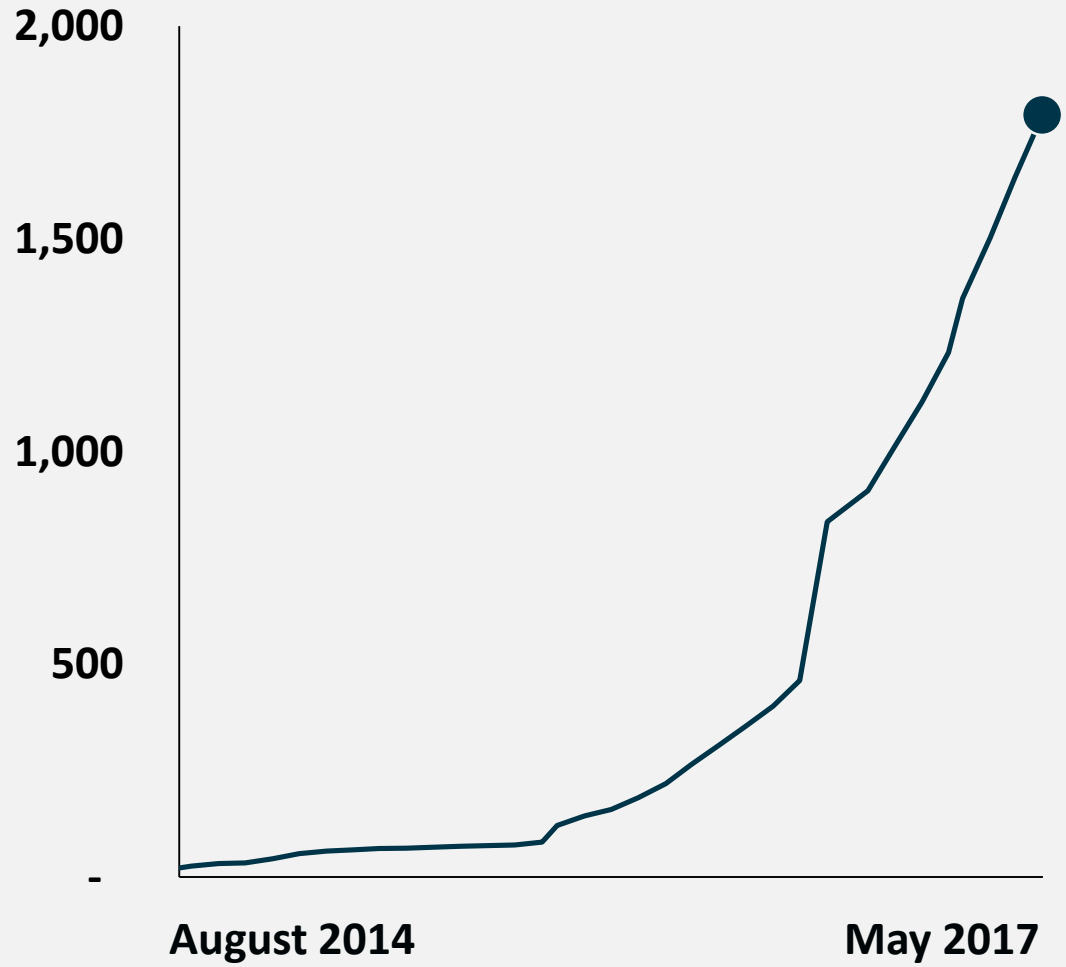
Approx.
150,000 jobs

- **50% in Western and Northeast** (highest fuel cell car sales regions)
- **Multiple occupations available** including retail sales**,** vehicle operators, supervisors of sales, mechanics, etc.

Source: Preliminary DOE ANL Employment Study, June 2017, updates underway

U.S. Fuel Cell Car Sales and Expert Outlook

Fuel Cell Car Sales Growing



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

1,800 fuel cell cars

sold or leased in the U.S.

78%
of executives

Absolutely or partly **agree that**

Fuel cell cars will be the real breakthrough for electric mobility

KPMG, Global Automotive Executive Survey 2017 (Jan. 2017)

Fuel Cell Buses: Recent Progress

Exceeded DOE-DOT 2016 Durability Target:

Nearly 25,000 hours (June 2017)

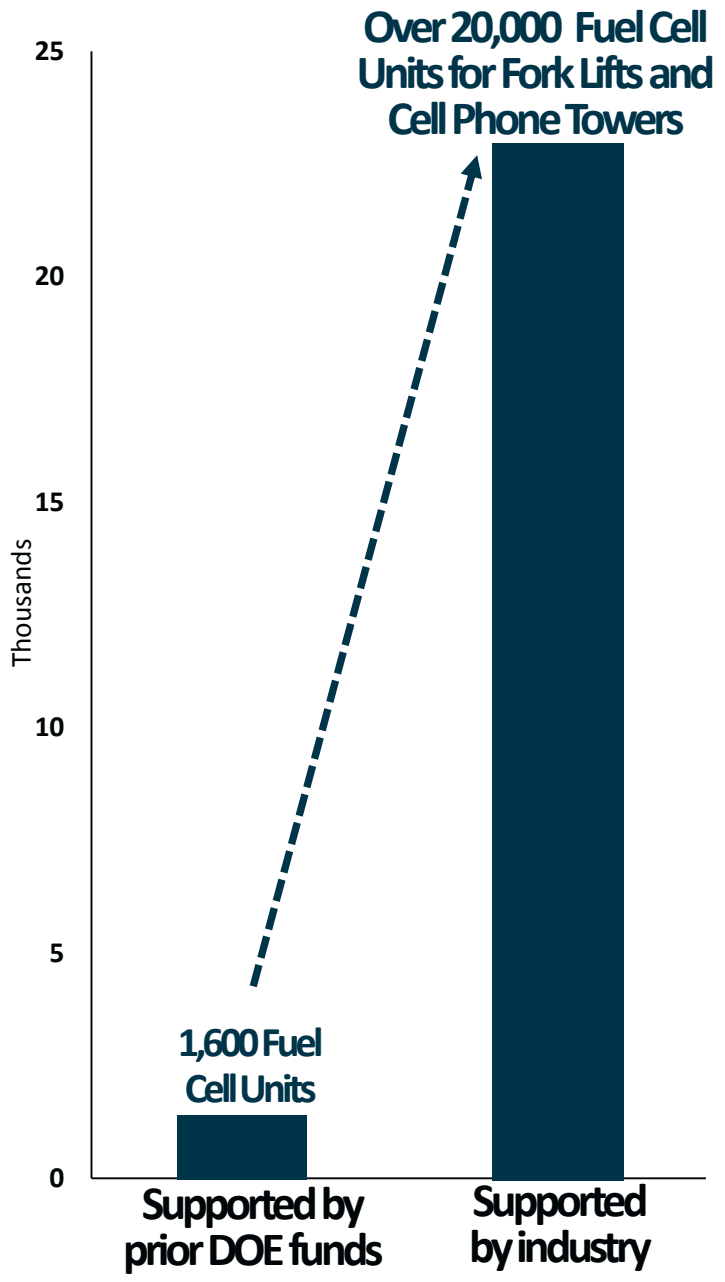
Source: AC Transit

By 2017: Served 17 million passengers

Industry Orders for Fuel Cells on the Rise

Over 15,000 fuel cell forklifts deployed or on order

Approx. 6 million hydrogen refuelings to date



Fuel Cells: New Applications Demonstrated

World's first hydrogen fuel cell train in Germany

World's first 4-seater fuel cell plane takes off at German Airport

New DOE-Industry Cost Shared Prototypes

1st fuel cell cargo tow trucks at U.S. airport

New DOE-Industry Cost Shared Prototypes

Fuel Cell Electric Delivery and Parcel Trucks

First of its kind demonstration starting deliveries in the summer!

Industry's first heavy duty fuel cell truck

New DOE-Industry Cost Shared Prototypes

World's first fuel cell for maritime ports

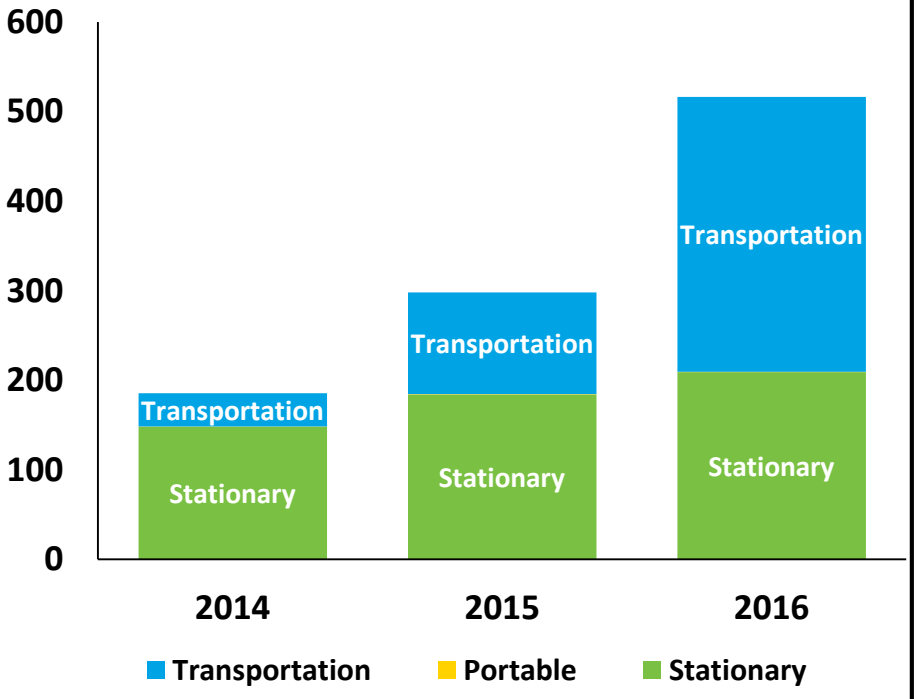
Fuel Cells: Recent Progress

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

2016 Global Shipments – Trends

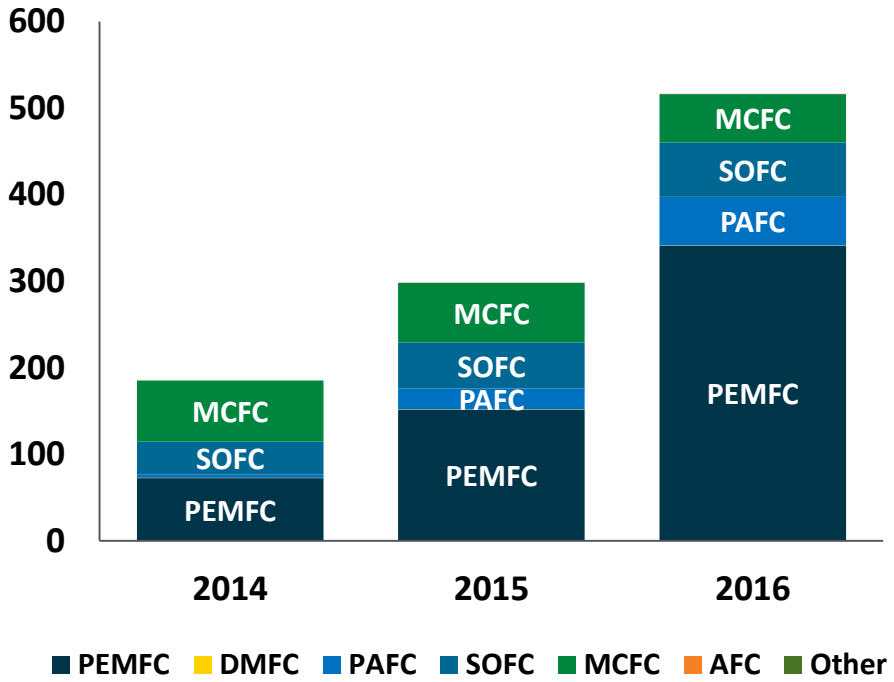
Total power (in MW) shipped by application

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: E4tech

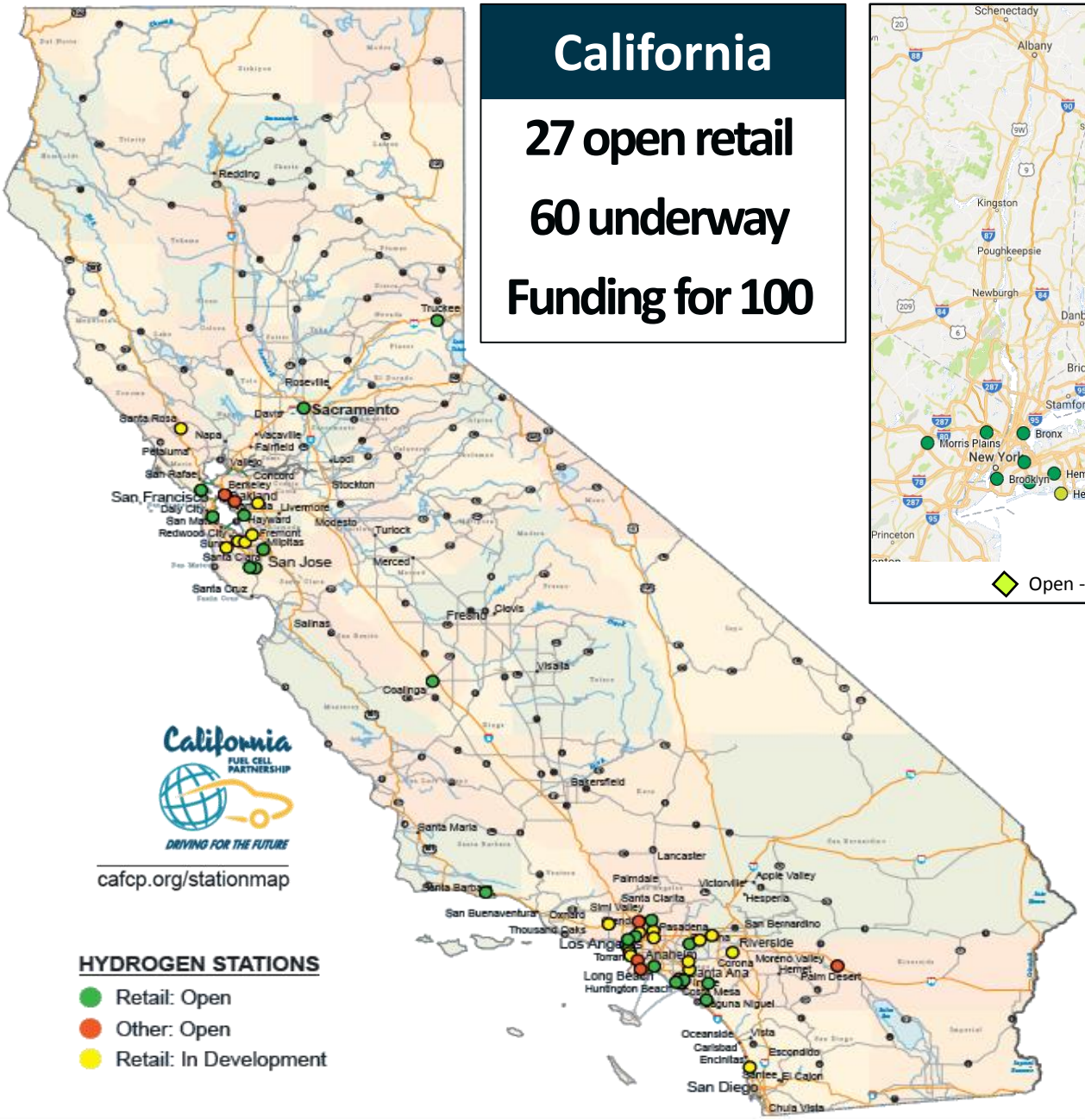
Hydrogen Stations – California and Northeast Area

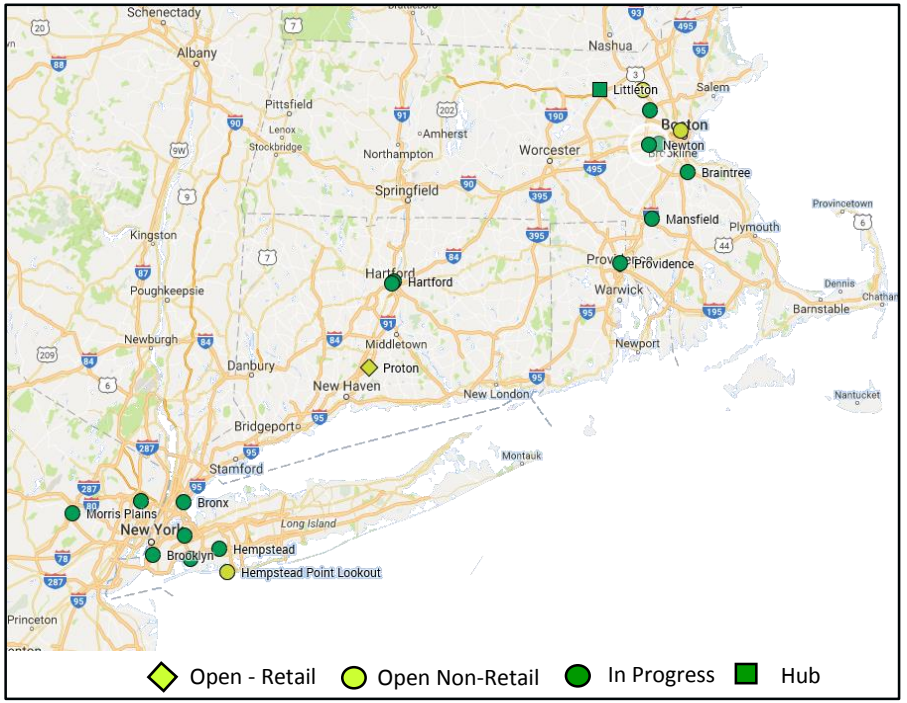
California

27 open retail

60 underway

Funding for 100





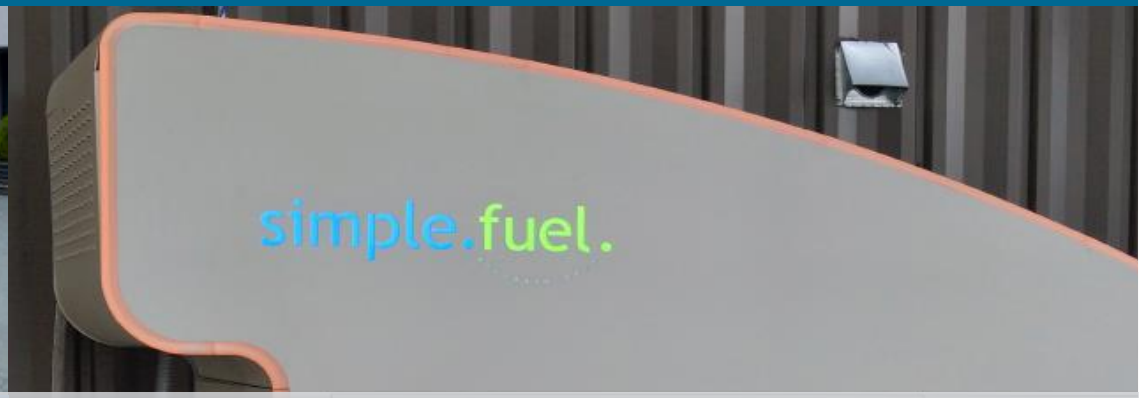
Northeast

Approx. 12 to 25 retail planned

Hydrogen R&D demonstration station opens in Washington D.C. Data collection guides future R&D

Proton OnSite FCTO Project

Enabling Infrastructure: H-Prize



DOE awards $1M H-Prize to Simple Fuel for winner small-scale H_2 fueling design

H2refuel U.S. Department of Energy
www. hydrogenprize.org

simple.fuel.™
Email: connect@ivysinc.com
More info: www.teamsimplefuel.com

Ivys Energy Solutions (MA)
McPhy Energy (MA)
PDC Machines (PA)

Enabling Infrastructure: Revised Metering Standard

NIST revised Metering Standard from
1.5% dispensing accuracy to 5%
Example of CA, DOE, NIST, and global collaboration

NIST HB 44 – Available at:
www.nist.gov/sites/default/files/documents/2016/11/10/hb44-2017-web_final.pdf

Target and Status

Target Updates

Examples: Medium/Heavy Duty Trucks

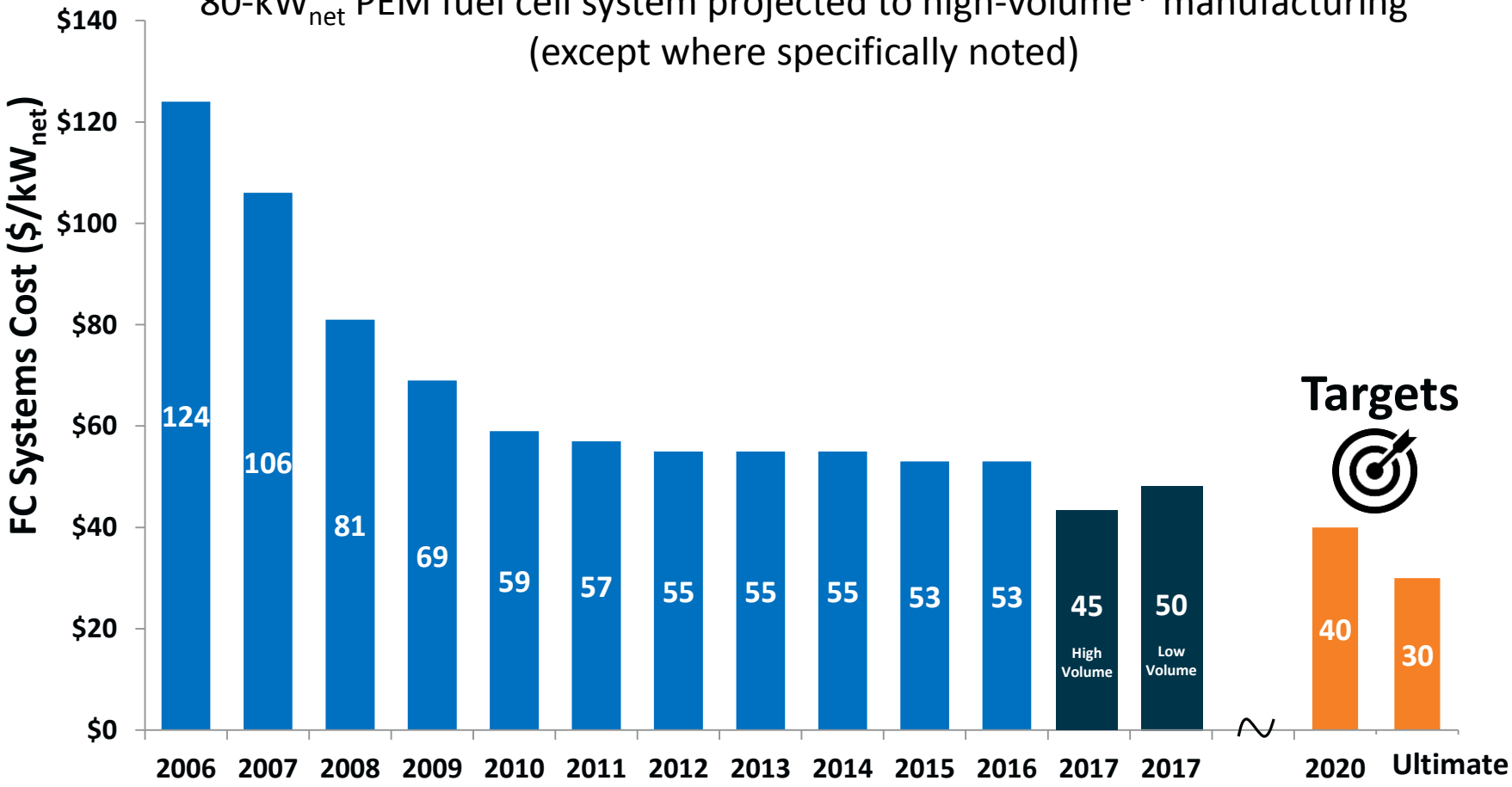
Hydrogen Storage

(see backup slides- final publication coming soon)

Projected Fuel Cell System Cost Reduction

Modeled Cost of Fuel Cell System Over Time

80-kW_{net} PEM fuel cell system projected to high-volume* manufacturing (except where specifically noted)



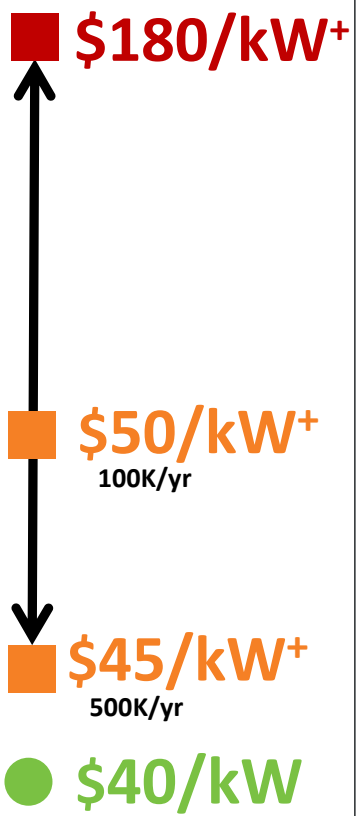
*Preliminary 2017 cost status

Advances in catalysts and MEAs enabled major cost reductions in 2017

DOE Cost Status and Targets

Fuel Cell R&D

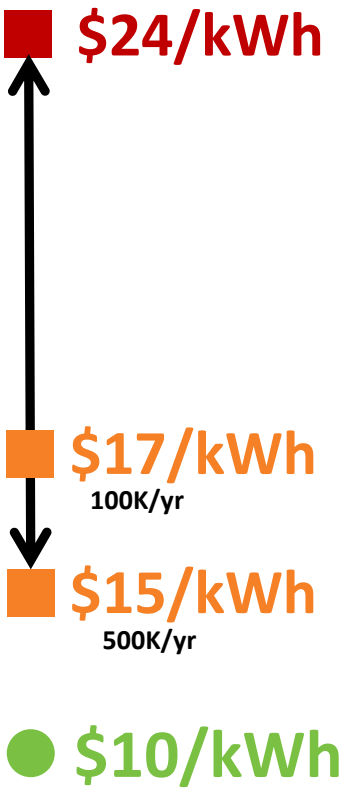
System



Hydrogen R&D

Production, Delivery & Dispensing

Onboard Storage
(*700-bar compressed system*)



2020 Targets | High-Volume Projection | Low-Volume Estimate

*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

Note: Graphs not drawn to scale and are for illustration purposes only.

U.S. Department of Energy – Impact

Innovation

650 H_2 and fuel cell **patents** enabled by FCTO funds

Approx. **40%** of H_2 and fuel cell patents come from National Labs

Market Impact

More than **30** **Technologies** commercialized by private industry

and over **75** **with potential** to be commercial in the next 3-5 years

can be traced back to FCTO R&D

Examples of Progress enabled by DOE FCTO in the last decade

Fuel Cell R&D

- Reduced cost 60%
- Quadrupled durability

H2 Production R&D

- Cut electrolyzer costs 80%

Hydrogen & Fuel Cells Budget (EERE FCTO)

Key Activity	FY 2016 ($ in thousands) Approp.	FY 2017 ($ in thousands) Enacted	FY 2018 ($ in thousands) Request
Fuel Cell R&D	**35,000**	**32,000**	**15,000**
Hydrogen Fuel R&D[1]	**41,050**	**41,000**	**29,000**
Systems Analysis	**3,000**	**3,000**	**1,000**
Technology Acceleration	-	**18,000**	-
Technology Validation	**7,000**		
Manufacturing R&D	**3,000**		
Market Transformation	**3,000**		
Safety, Codes and Standards	**7,000**	**7,000**	-
NREL Site-wide Facilities Support	**1,900**	-	-
Total	**100,950**	**101,000**	**45,000**

White House Budget Proposal Language FY 2018

- Increased reliance on the **private sector to fund later-stage research, development, and commercialization**
- Focuses resources toward **early-stage research and development**

DOE Basic Energy Sciences FY16 funding relevant to H_2 and fuel cells: $24.7 M

[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

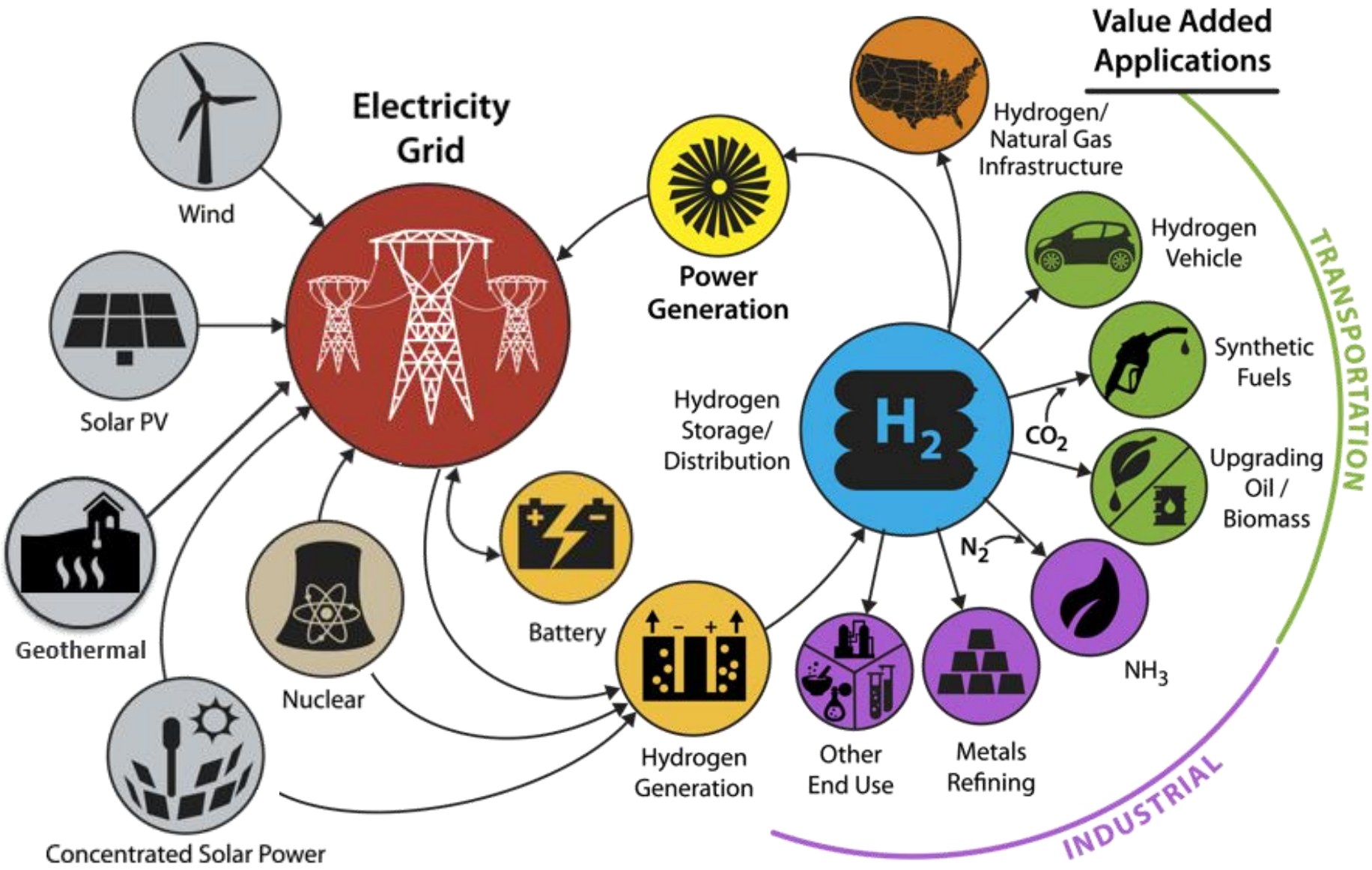
Stronger emphasis on early R&D and relying on industry for later stage R&D

Strategy

Early stage R&D to enable innovation

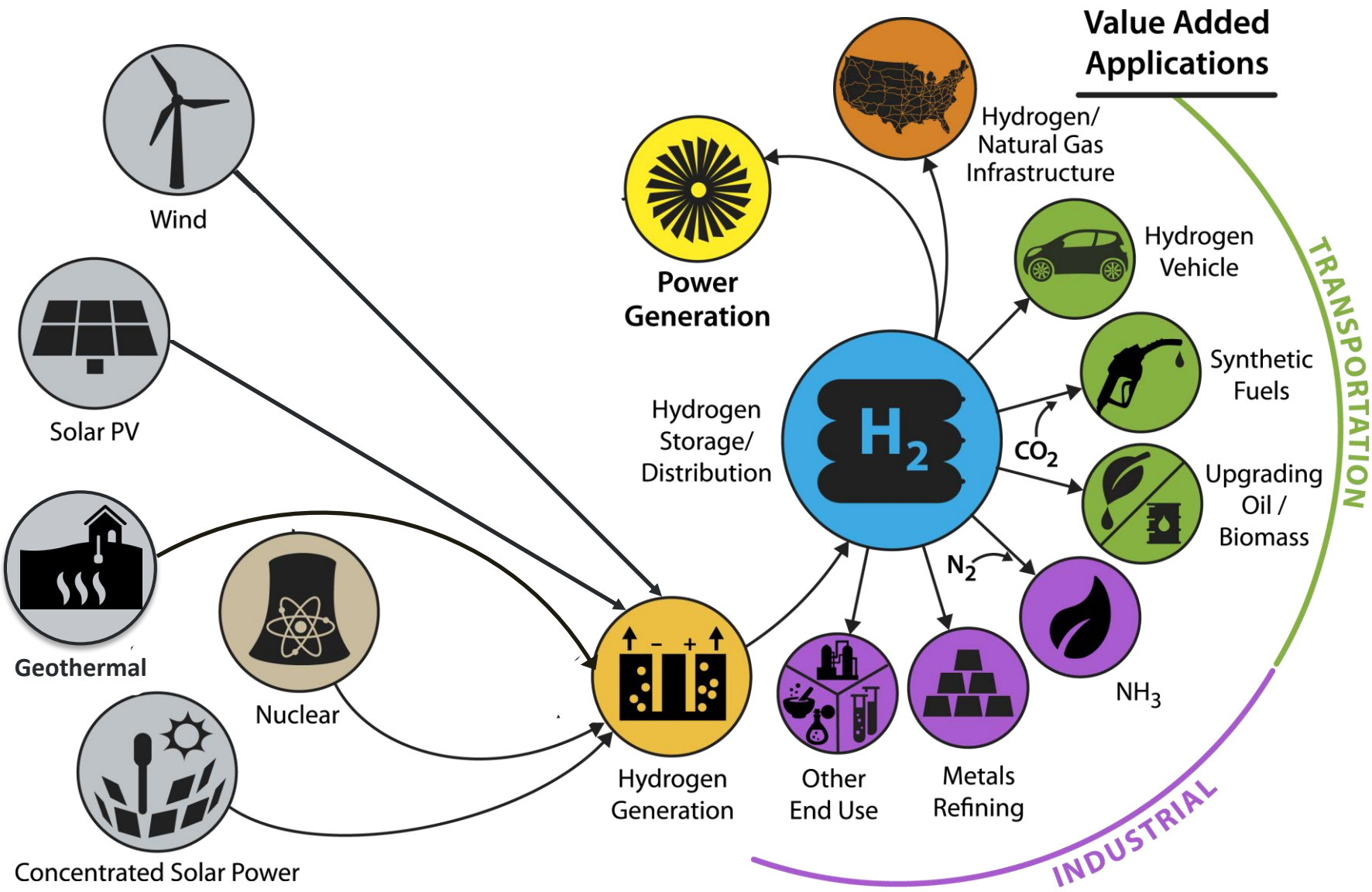
- **Fuel Cells ($15M): Focus on PGM-free catalysts, electrodes, membranes**
- **Hydrogen ($29M): Focus on materials R&D, advanced water-splitting, enablers for H2@Scale** (materials, delivery and storage related technologies, liquefaction, etc.)

H2@Scale Energy System



*Illustrative example, not comprehensive
Adapted from NREL, Lab Big Idea Team

H2@Scale Energy System



Collaboration
is
Critical

The Hydrogen Council formed Jan 2017

Investment

$10.7B

towards

hydrogen and fuel cells

Members

13 companies

representing

$1T in revenues and 1.7M jobs

More information: hydrogeneurope.eu

DOE National Lab System: A Reservoir of Talent for Science and Technology

Founded by DOE nearly 80 years ago

War effort motivated scientific breakthroughs: Manhattan project, radar development

A few $M in **DOE investment** in the ‘40s

Labs at ~ $10B today

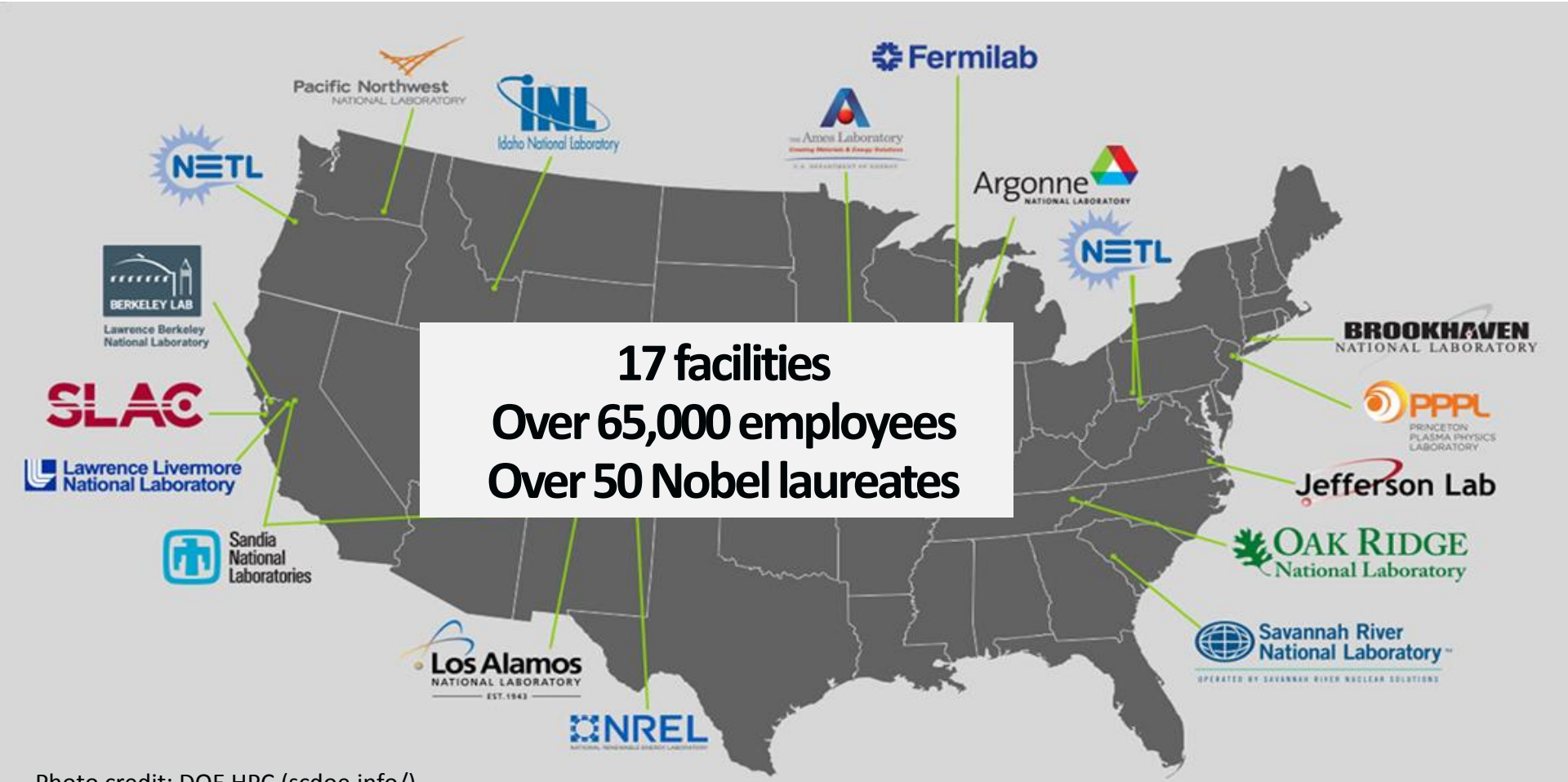
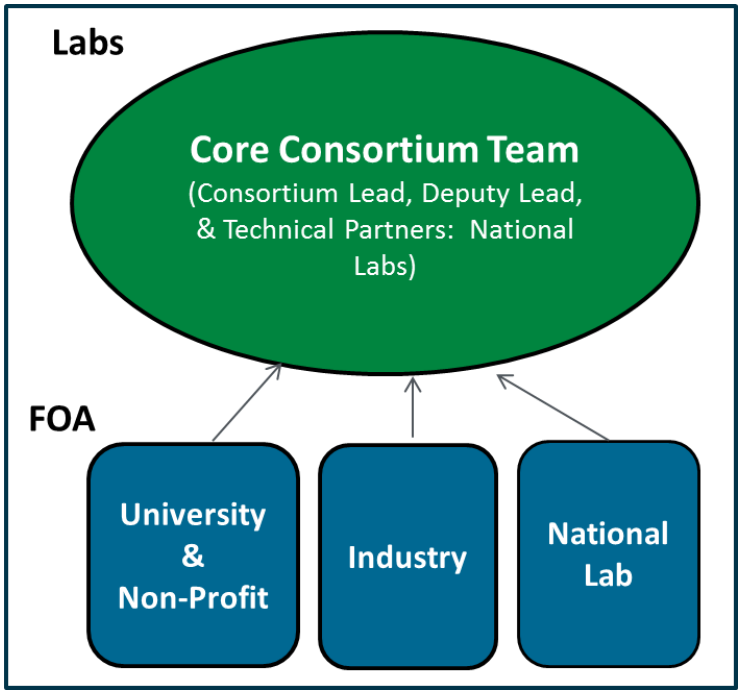


Photo credit: DOE HPC (scdoe.info/)

Leveraging National Labs to Enable Early R&D

Consortium Approach

Multi-lab core capabilities with steady influx of new partners



Energy Materials Network
U.S. Department of Energy

Consortia Launched

Improved PEM fuel cells

FCPAD
FUEL CELL PERFORMANCE AND DURABILITY

PGM-free catalysts

ElectroCat
Electrocatalysis Consortium

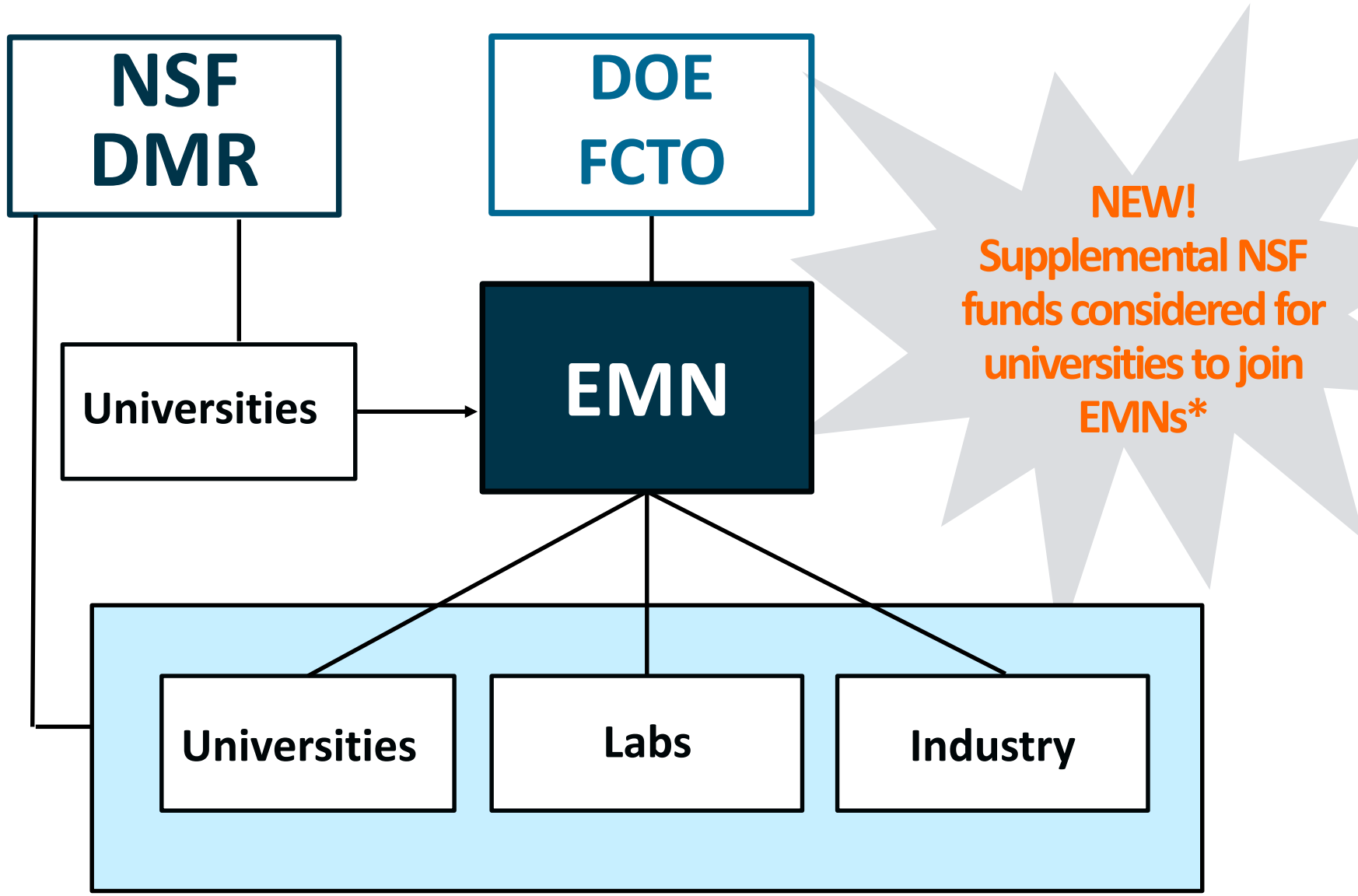
Advanced H_2 materials storage

HyMARC
Hydrogen Materials Advanced Research Consortium

Materials for renewable H_2 production

HydroGEN
Advanced Water Splitting Materials

Leveraging Funding- Example Pilot



DMR- Division of Materials Research, NSF

FCTO- Fuel Cell Technologies Office, EERE, DOE

* Guidance to be provided by NSF DMR in upcoming 'Dear Colleague' communications

Four-Lab Consortium – Roll-to-Roll Processes

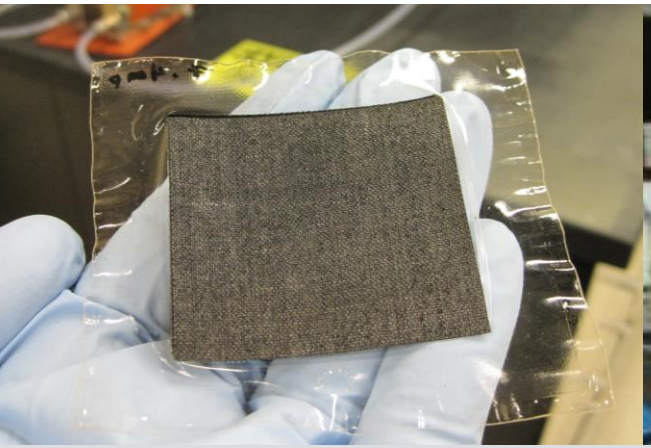
DOE Offices: AMO, FCTO and VTO

Funding: Over $2M ($1M from FCTO and $1.3 from AMO)

FCTO will cost share AMO funding on electrolyzer and fuel cell topics

Labs: Oak Ridge, Argonne, Lawrence Berkeley and National Renewable Energy Labs

AMO: Advanced Manufacturing Office; VTO: Vehicle Technologies Office; FCTO: Fuel Cell Technologies Office



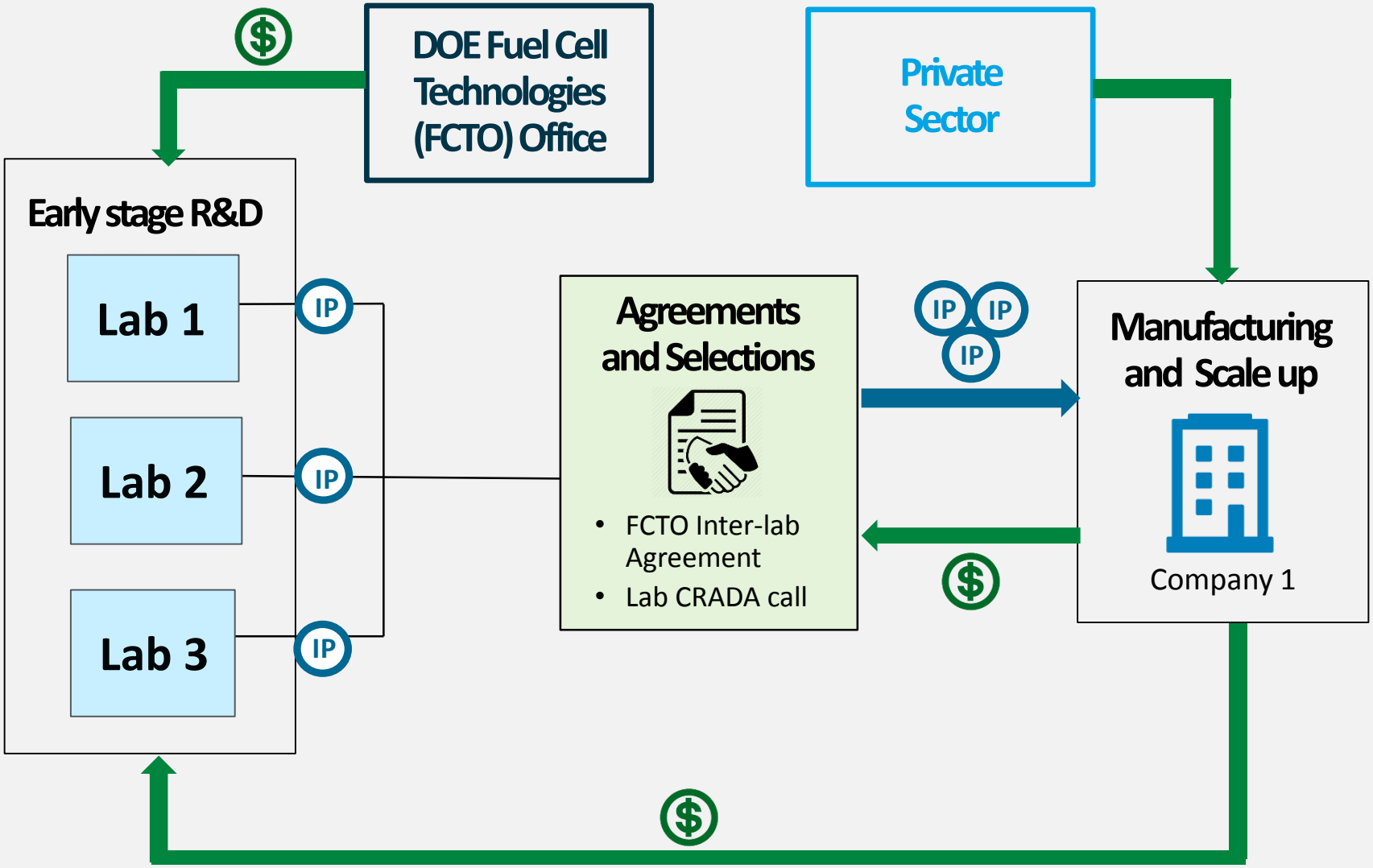
CRADA Now Open to Proposals!

More info: www. fbo.gov

Solicitation Number: ORNL-R2RAMM-2017-02-02

Questions? Email R2RAMM@ornl.gov

L'Innovator= "Lab Innovator" FCTO Pilot



H2@Scale CRADA Call Planned

(Cooperative Research & Development Agreement)

to work with National Labs

Up to $3M in FY17 Funds

Other Lab Capabilities (Examples- Draft)

Modeling and Analysis

Examples

- Value proposition
- Demand/market projection
- Cost/benefit, financial and application evaluation
- Scenario analysis
- Resource assessment

Labs

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

H_2 – Materials Compatibility R&D

Examples

- H_2 materials exposure effects testing
- Materials selection and innovation

Labs

OAK RIDGE National Laboratory

Sandia National Laboratories

SRNL SAVANNAH RIVER NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Simulation and Testing

Examples

- Grid simulation
- Electrolyzer performance testing
- Model Validation

Labs

INL Idaho National Laboratory

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Pacific Northwest NATIONAL LABORATORY

Safety R&D

Examples

- Hydrogen behavior assessment
- Safety training and outreach
- Certification/permitting
- Quantitative risk assessment
- Safety testing and model validation
- Project/Facility safety review

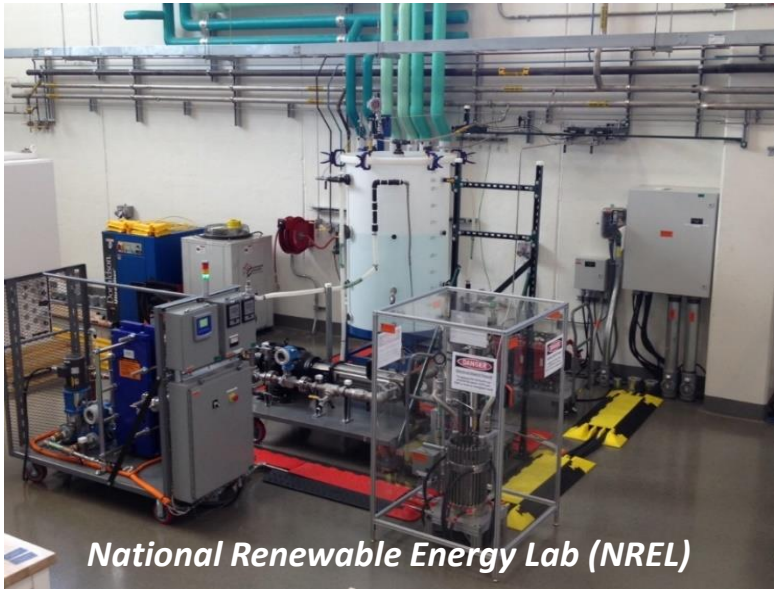
Labs

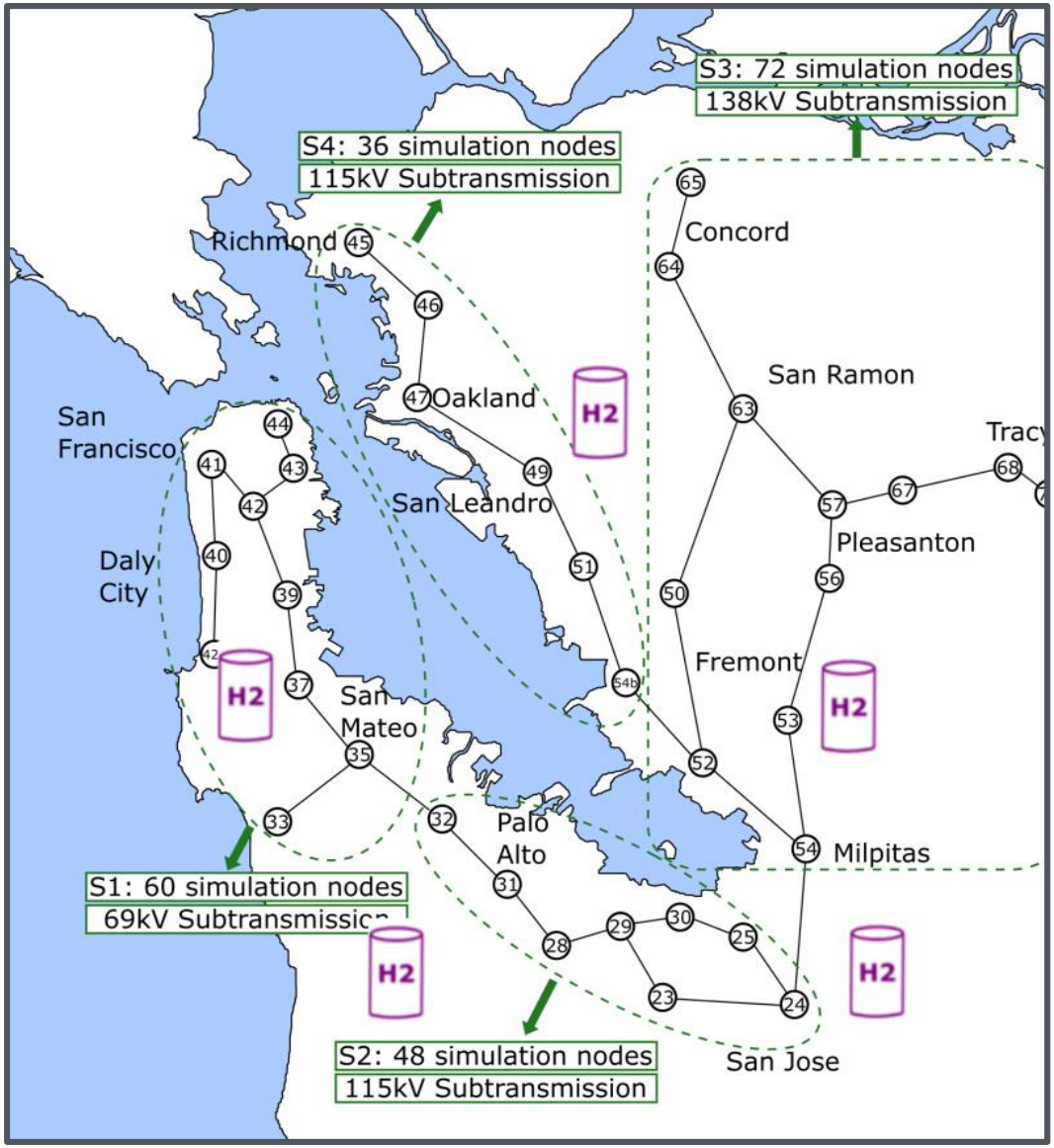
Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

H_2 safety panel

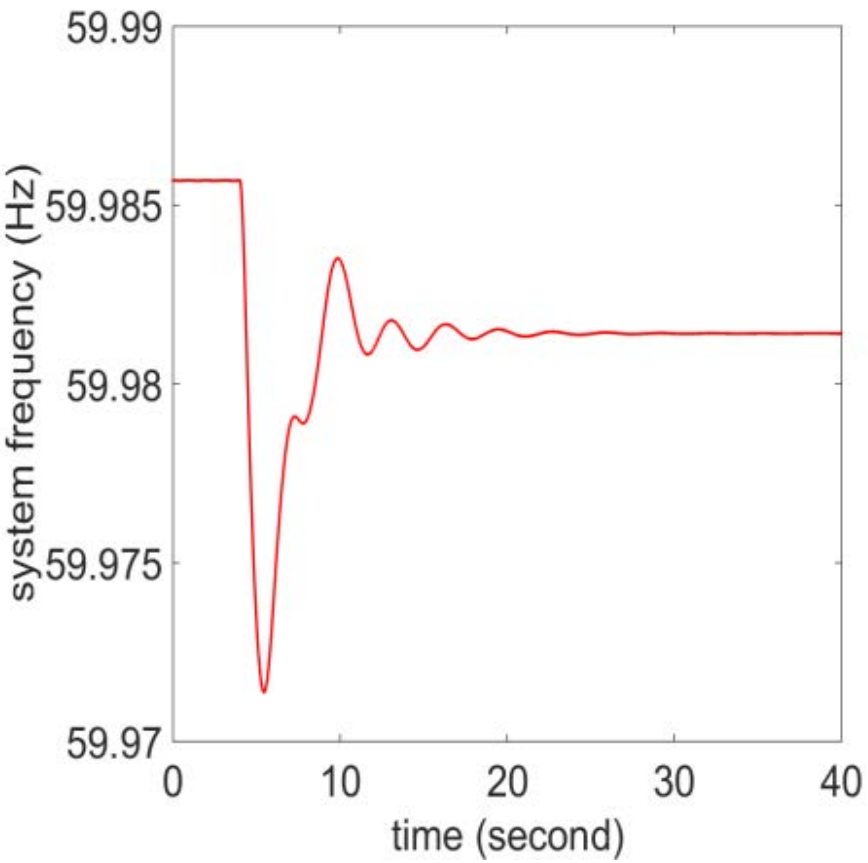
Lab Testing: Electrolyzer Grid Integration

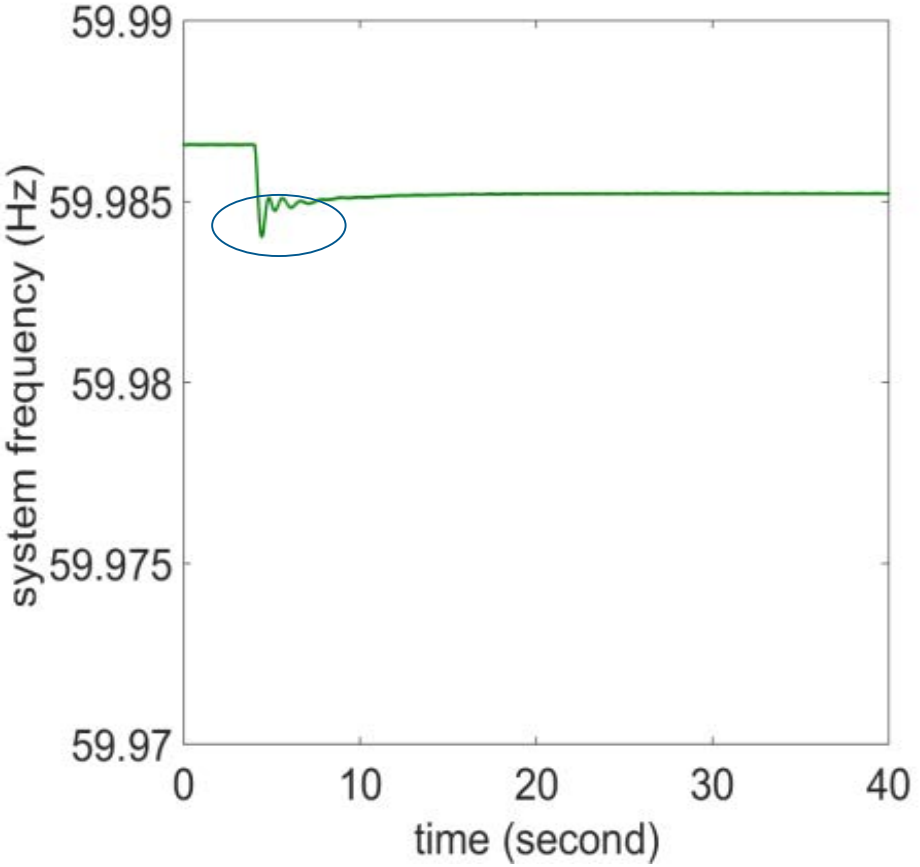




First ever validation of real time grid simulation with electrolyzers

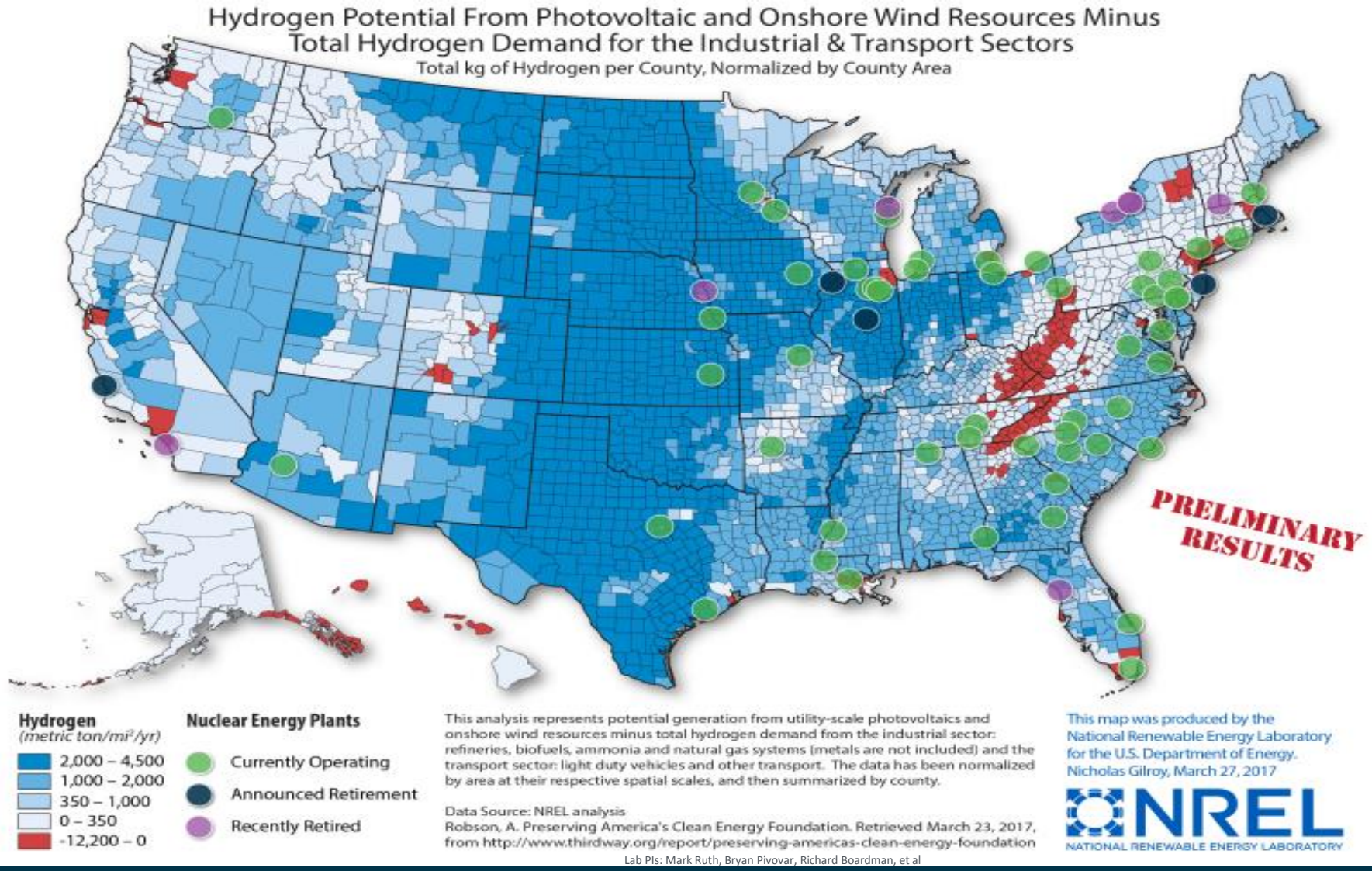
First Demonstration of Frequency Regulation





First independent validation of frequency regulation with electrolyzers and sub-second response times (INL, NREL)

H2@Scale: Nationwide Resource Assessment

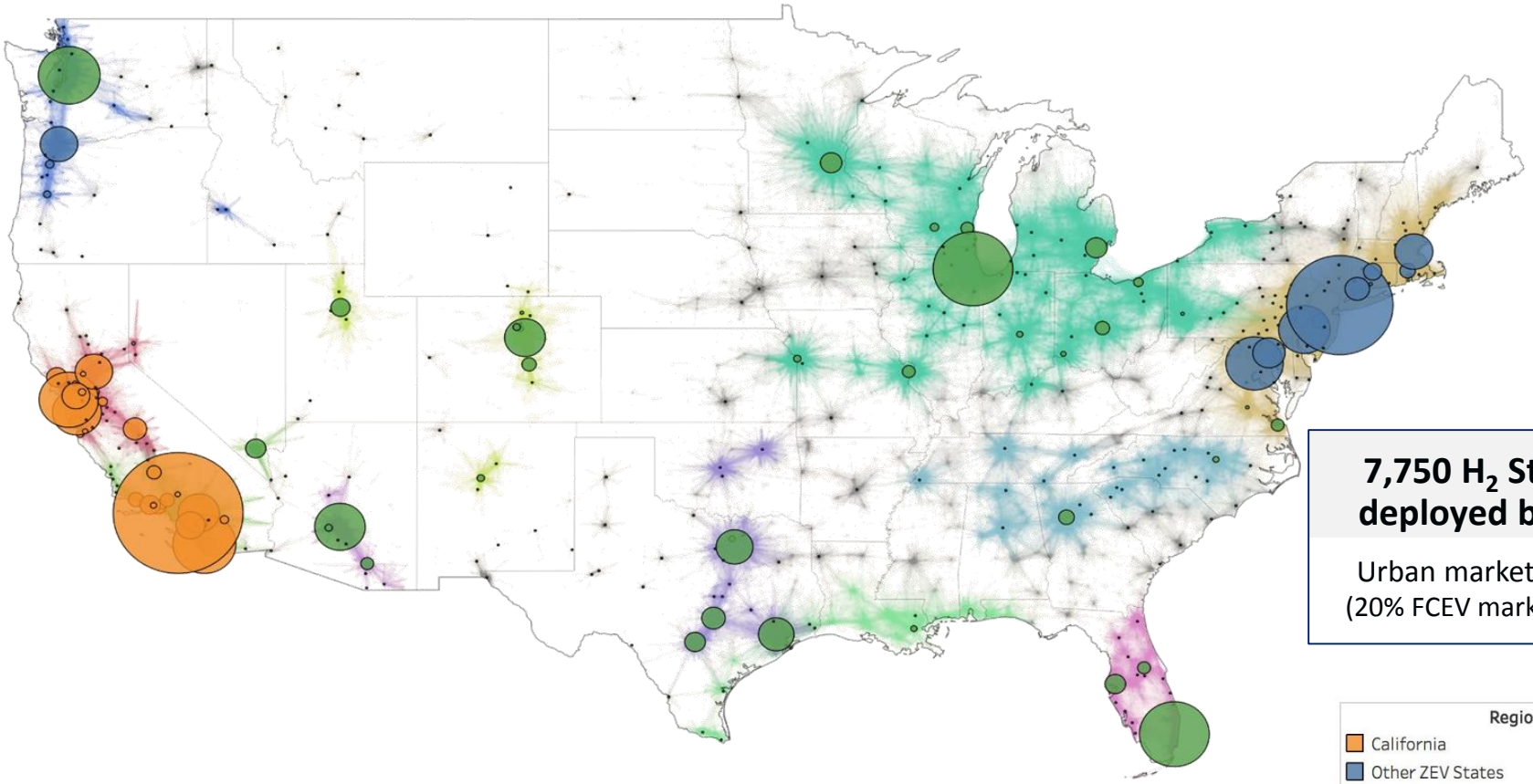


Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

Labs assess resource availability. Most regions have sufficient resources.

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

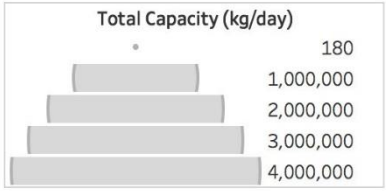
NREL's Station Rollout Scenario Analysis in support of H_2USA



7,750 H_2 Stations deployed by 2050

Urban markets scenario
(20% FCEV market share*)

*Nationwide



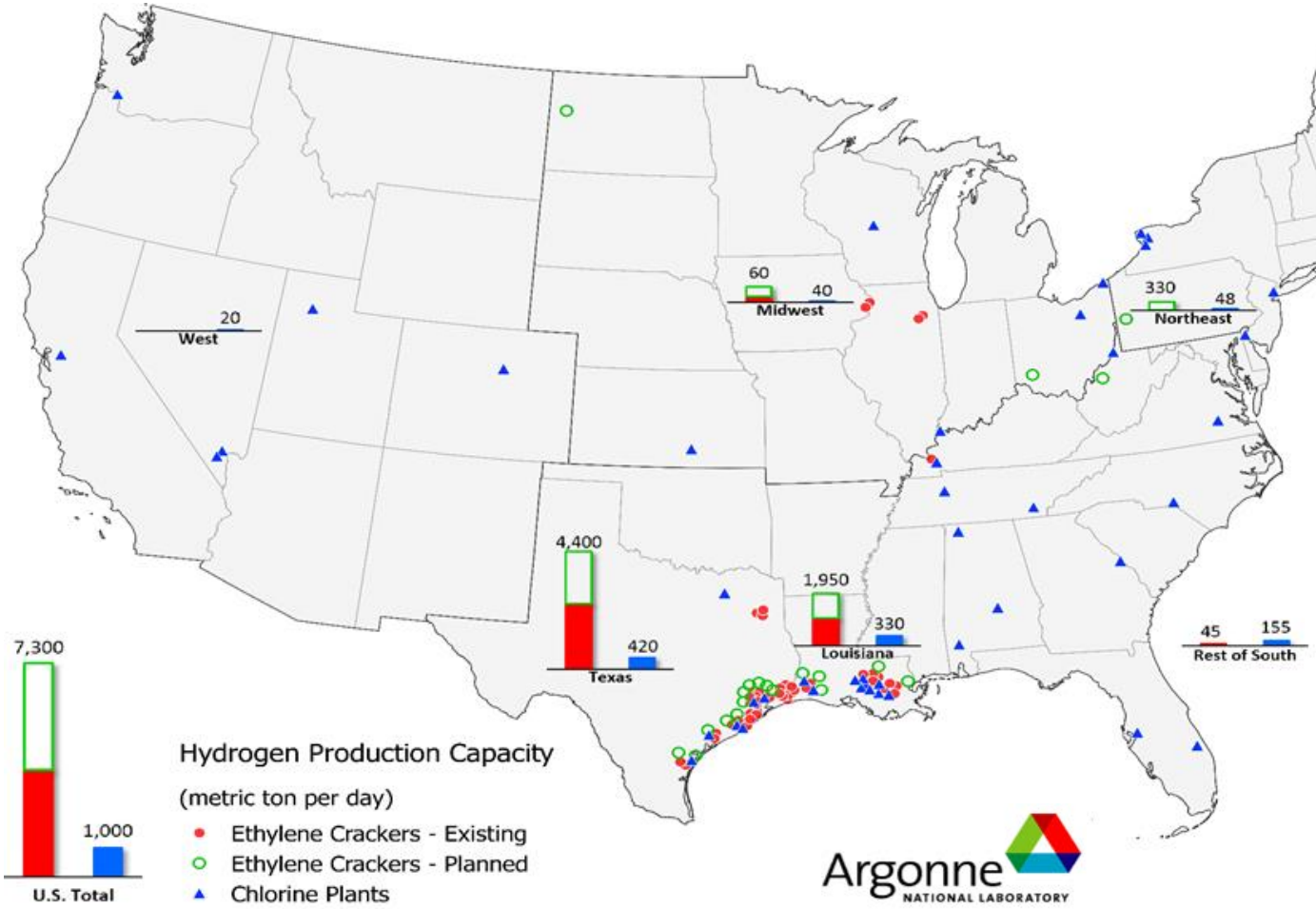
Examples of variables considered in scenarios:

- ✓ Consumer adoption
- ✓ Station Expansion Network

Source: Marc Melaina, et al, NREL

Example Lab Analyses: Byproduct Hydrogen

More than 4,000 metric tons per day of H_2 byproduct
from chlorine and ethylene cracker plants



Source: Amgad Elgowainy, et al

Existing hydrogen byproduct production capacity can serve

8 Million
hydrogen fuel cell cars

=1M fuel cell cars

*average FCEV needs approx. 0.5 kg of hydrogen per day

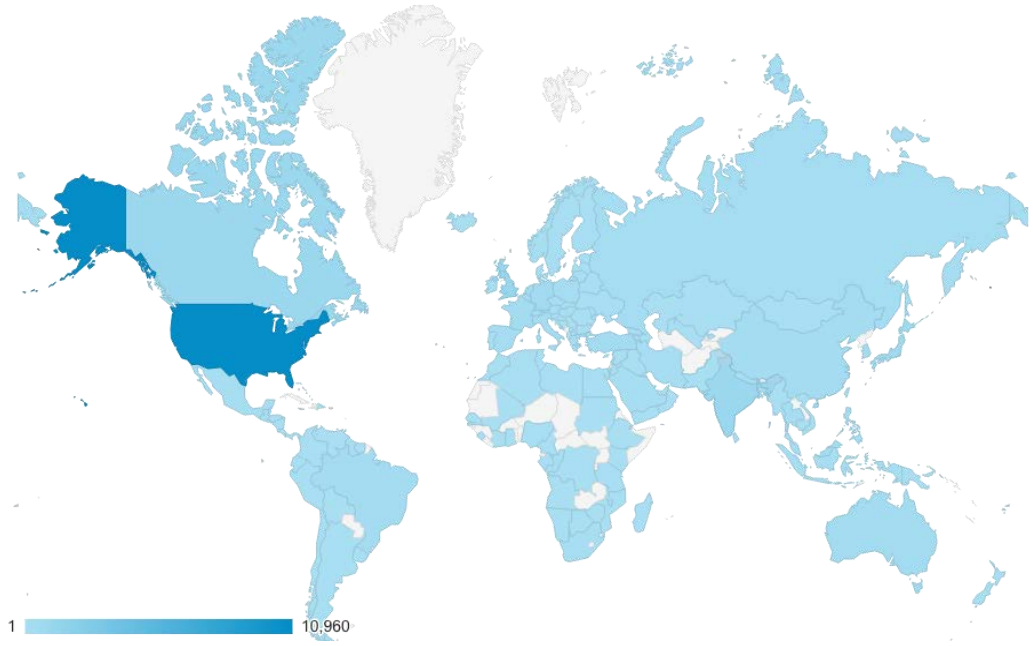
Safety Resources Available

H2Tools.org disseminates information on hydrogen safety

A Global Resource

nearing 150,000 visits since 2015 - 50% are international

Portions translated to Japanese, other languages underway



Hydrogen Risk Assessment Models (HyRAM) for risk analysis under various scenarios

Hydrogen Safety Panel with 400 years of collective safety expertise, collaborating worldwide to advance safety, codes & standards

Nominations for experts now being accepted
Contact: hsp@h2tools.org

30 new FCTO awards totaling approx. $16M in FY 2017 funding
to be announced very soon

Stay Tuned

Active in Social Media?

Share your hydrogen and fuel cell thoughts this week

#H2AMR

#H2IQ

Innovation at the National Labs

https://energy.gov/eere/technology-to-market/videos/eeres-national-lab-summit-inspiring-innovation

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

Sunita.Satyapal@ee.doe.gov

hydrogenandfuelcells.energy.gov

Upcoming Events

Save the Dates!

National Hydrogen & Fuel Cell Day | 10·08

Participate in social media using
#HydrogenNow #FuelCellsNow

H2@Scale Session at the Fuel Cell Seminar
November
Long Beach, LA

AMR and Industry Expo
June 2018 (to be confirmed soon)
Washington, DC