U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

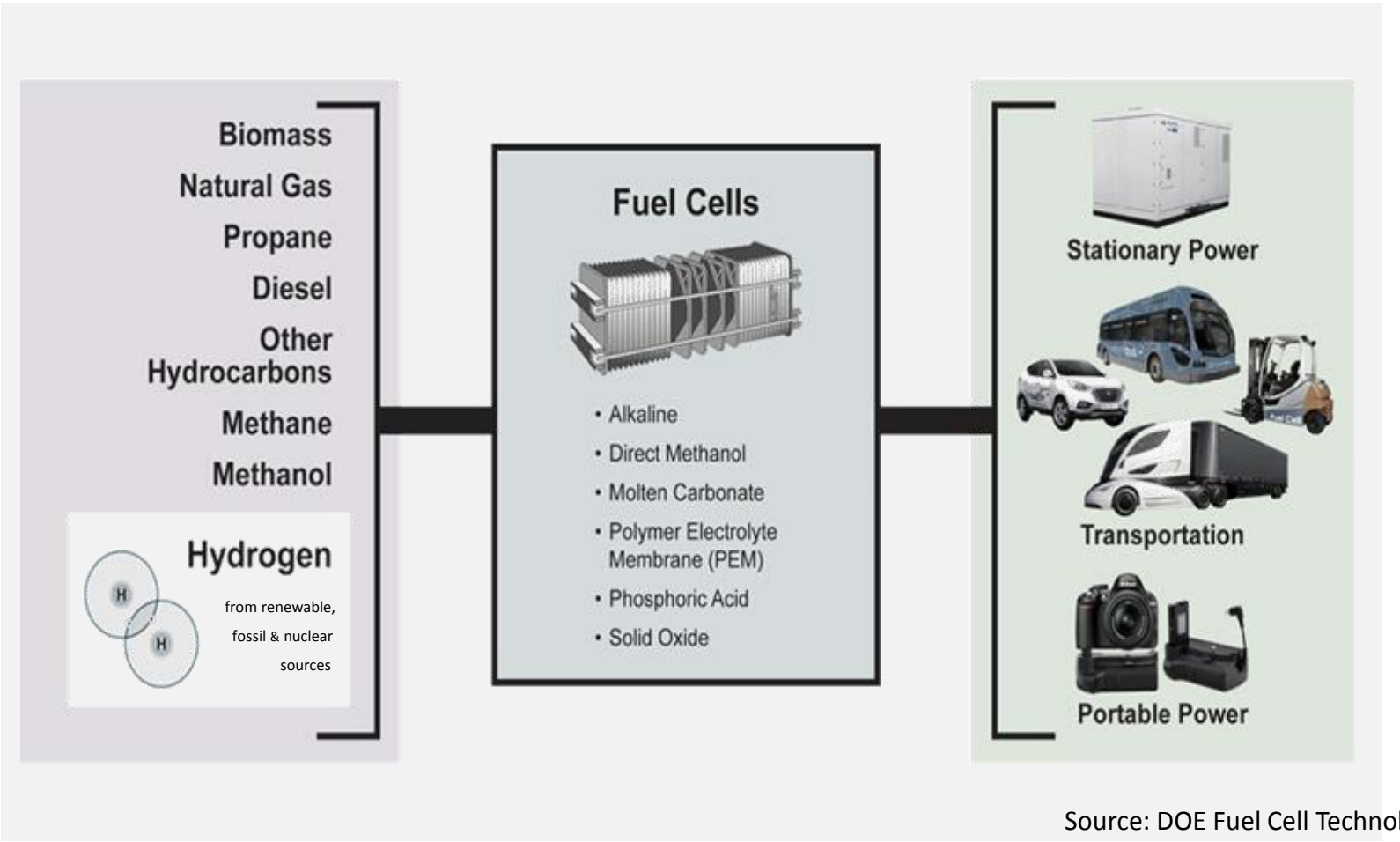
H2@Scale: Progress, Opportunities and Needs

Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office

State Energy Advisory Board

Washington, DC – July 12, 2018

Fuel Cell Technologies Office Introduction



Source: DOE Fuel Cell Technologies Office

Domestic Energy Sources

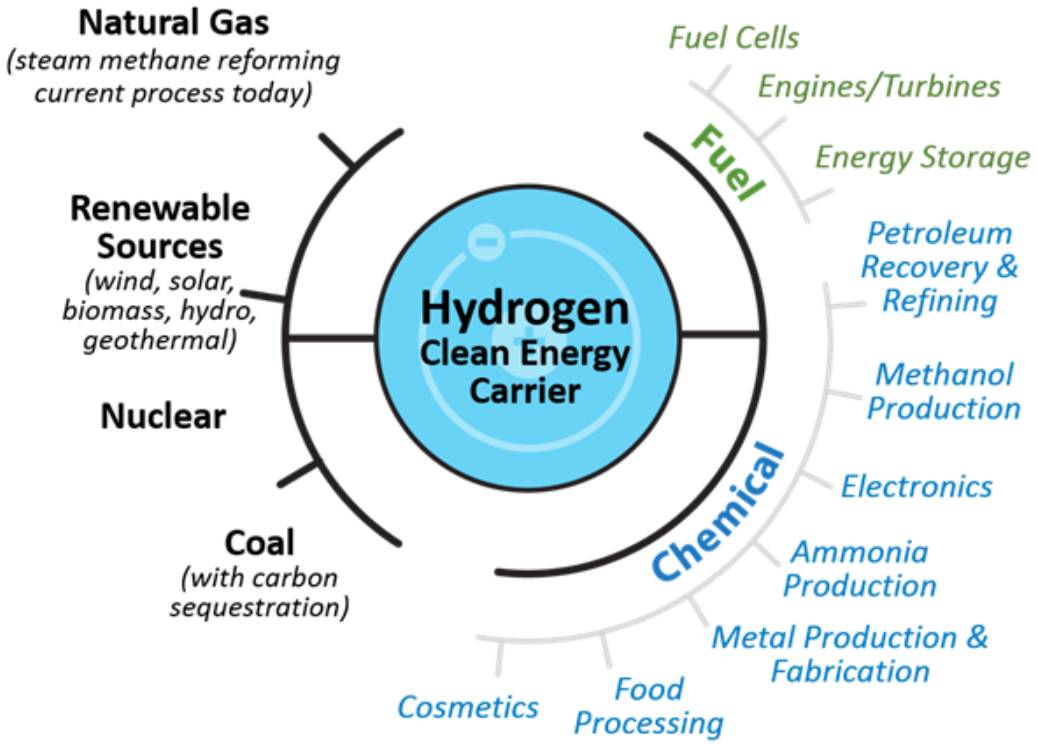
Clean, Efficient Energy Conversion

Multiple, Diverse and Versatile Uses

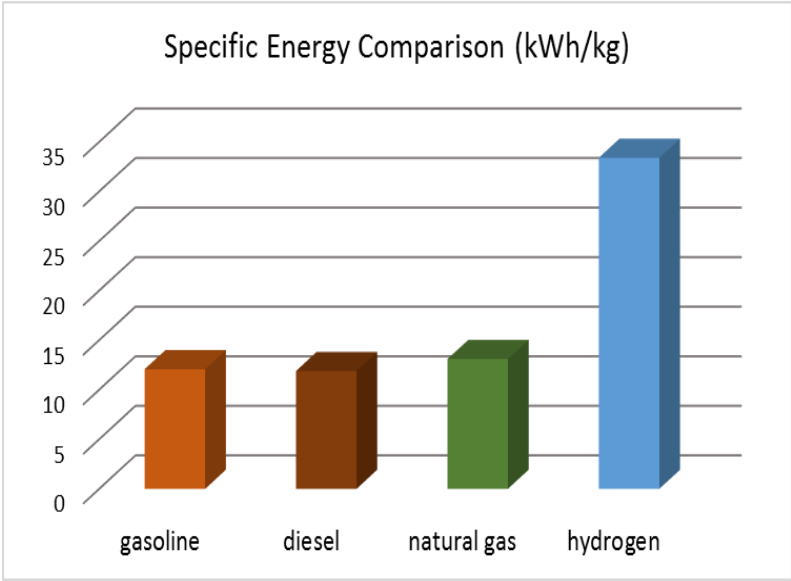
Hydrogen is Part of an All of the Above Portfolio

H_2 can be produced from diverse domestic sources

Many applications rely on or could benefit from H_2



Very High Specific Energy



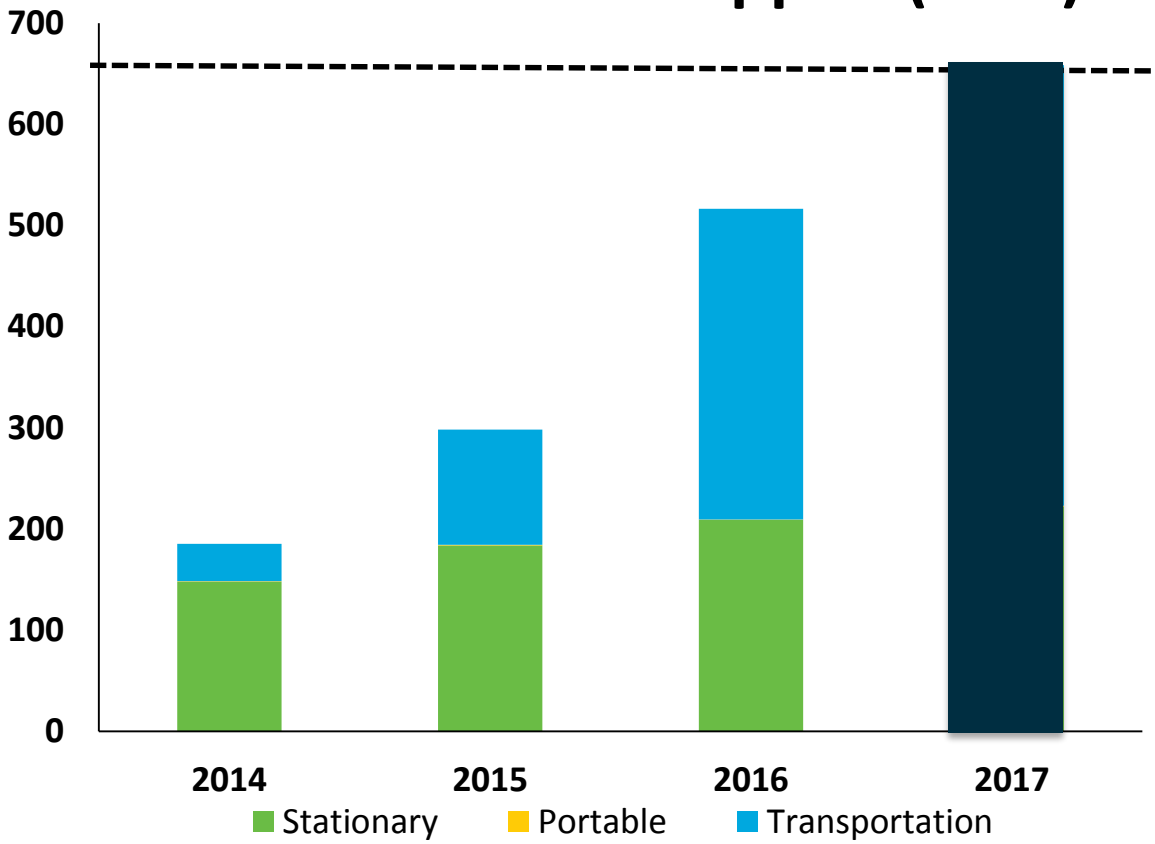
About *three times* more energy by mass than gasoline. But worse in terms of volume.

Clean , sustainable, versatile, and efficient energy carrier

4 Key Messages

1. Progress

Upward trend with global fuel cell shipments



650 MW
fuel cell power
shipped worldwide

70,000
fuel cell units
shipped worldwide

Approximately
$2 Billion
fuel cell revenue

Source: DOE and E4Tech

Electrolyzers: Over 100MW/year estimated global sales

*Courtesy of NOW, E4tech and partners: A collaborative effort to assess electrolyzer market potential

An exciting time for the transportation sector

Honda Clarity

Nearly **5,000** | **sold or leased** in the United States

As of Dec 2017


Hyundai Tucson Fuel Cell SUV

Commercial **fuel cell electric cars are here**


Toyota Mirai

- No petroleum, no pollution
- Refuels in minutes
- More than 360 mi driving range
- Over 60 mpgge

Secretary Perry Drives Fuel Cell Car

Interest in material handling equipment applications

More than **20,000 forklifts**

Over **12 million refuelings**

Long-Range, Heavy Duty Applications Emerging

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

Fuel cell buses in CA surpass 19M passengers

Industry demonstrates first heavy duty fuel cell truck in CA

Stationary Power Applications Emerging

Fuel cells provided backup power during Hurricane Sandy in the U.S. Northeast

Fuel cells used to power new World Trade Center in NYC

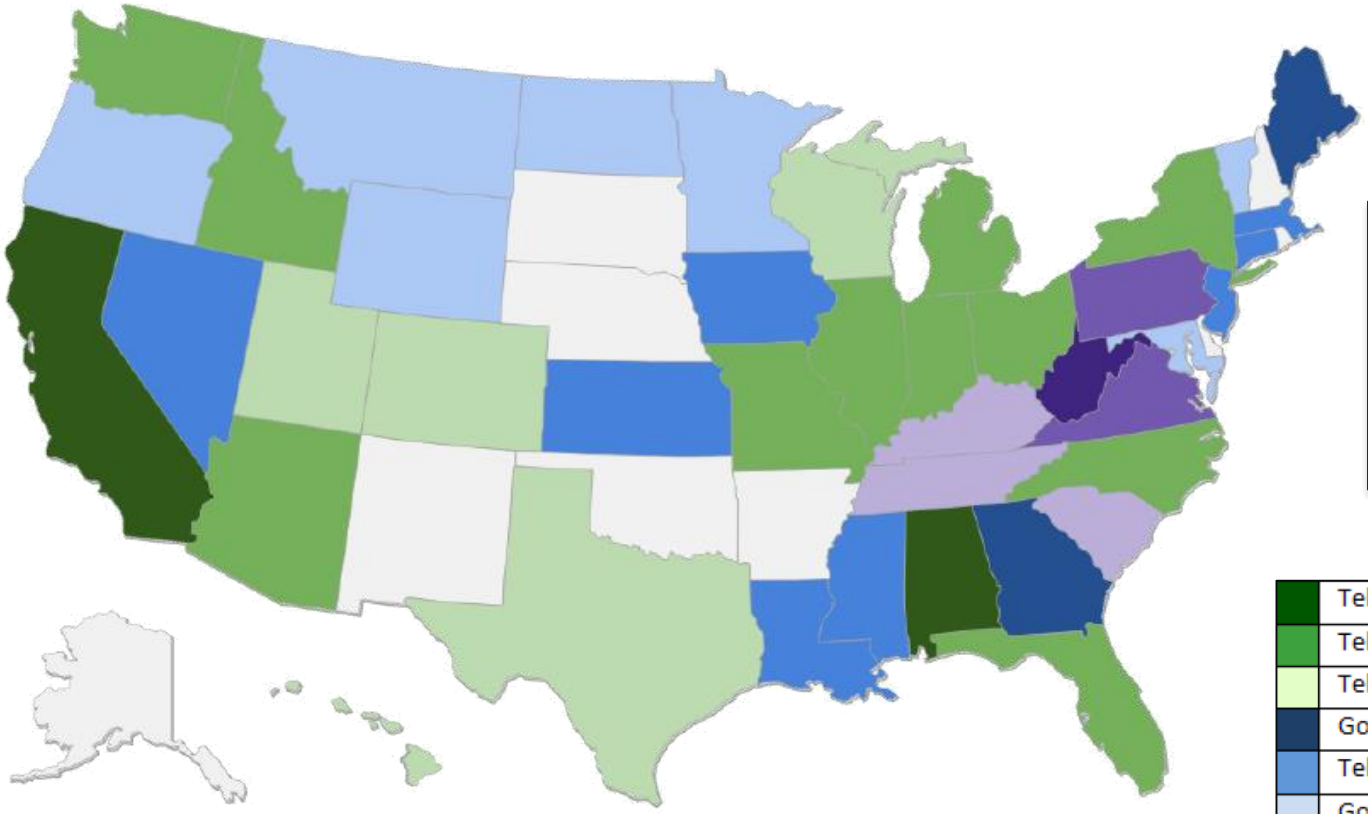
Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii

Over 240 MW of fuel cell stationary power installed across more than 40 US states

Photo credit: Fukuoka Pref.

Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states



Over 240MW

in stationary fuel cell power installed

Telecom, Government, Railroad, Utility sites
Telecom, Government, Railroad sites
Telecom and Government sites
Government, Railroad, Utility sites
Telecom sites
Government sites
Railroad sites
Utility sites
Government and Railroad sites
Telecom and Railroad sites

Over 8,000 backup power units

deployed or on order

Source: DOE State of the States: Fuel Cells in 2016 Report

Multiple H_2 and Fuel Cell Applications in the U.S.

U.S. Snapshot

>240MW
Backup Power

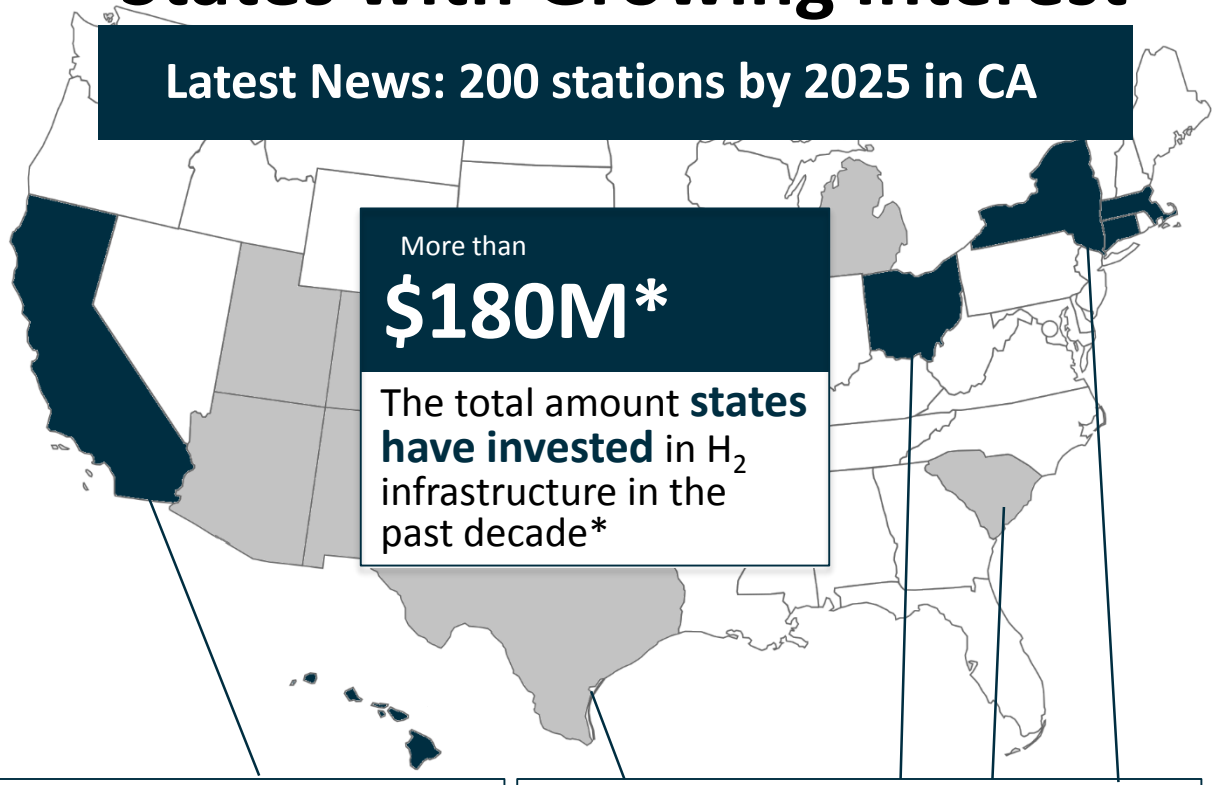
>20,000
Forklifts

>30
Fuel Cell Buses

35
H_2 retail stations

Nearly
5,000
fuel cell cars

States with Growing Interest

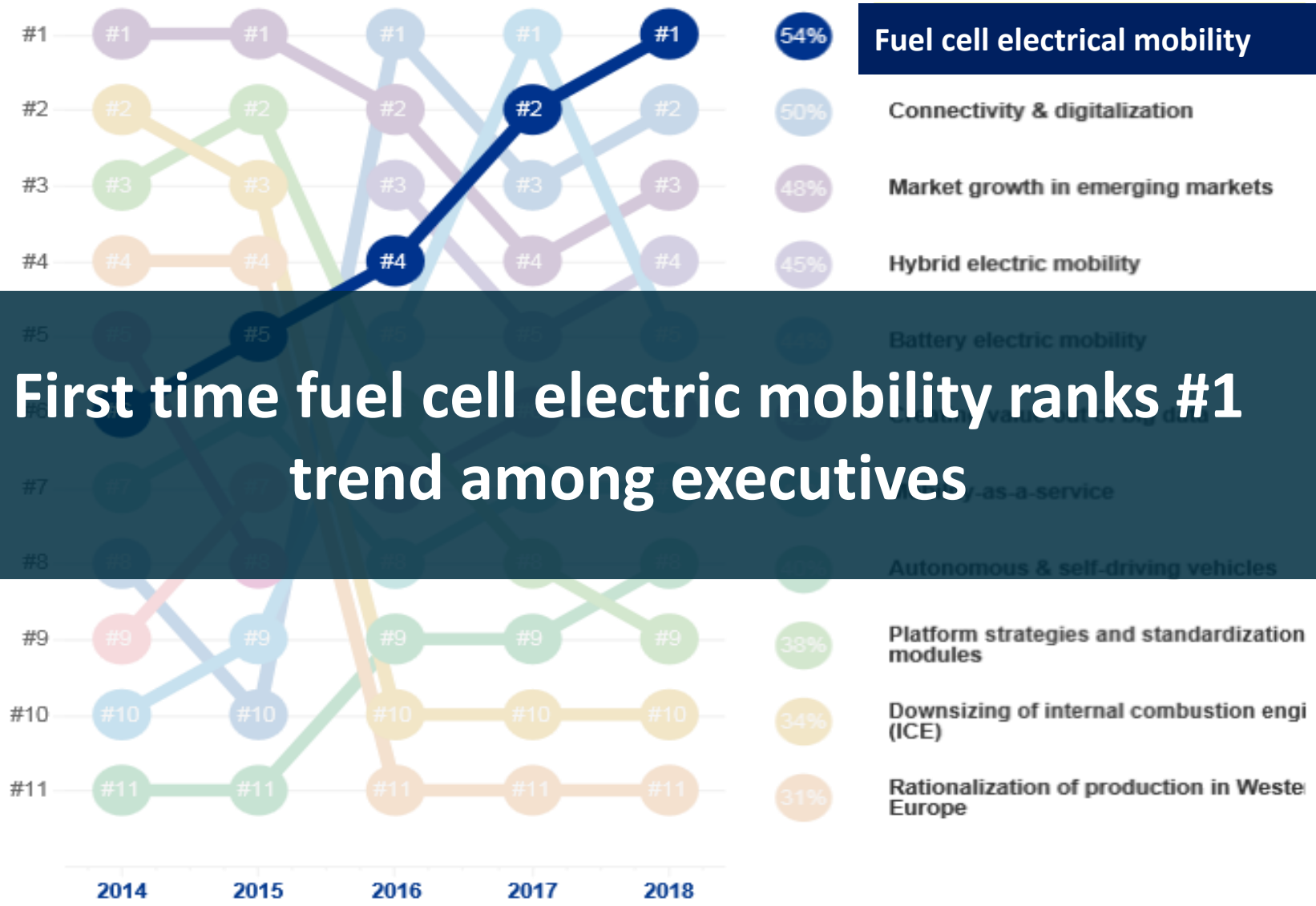


CA
- 200 stations planned
- Over 30 public stations open
- $150M invested
- $235M announced in 2018

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others with interest
- Over $27M invested
- 12-25 stations planned in the NE

*Excludes recent announcement from CA to invest $235M in electric vehicles

Automotive Executives Survey Results



First time fuel cell electric mobility ranks #1 trend among executives

Source: KPMG Global Automotive Executive Survey 2018

2. Challenges

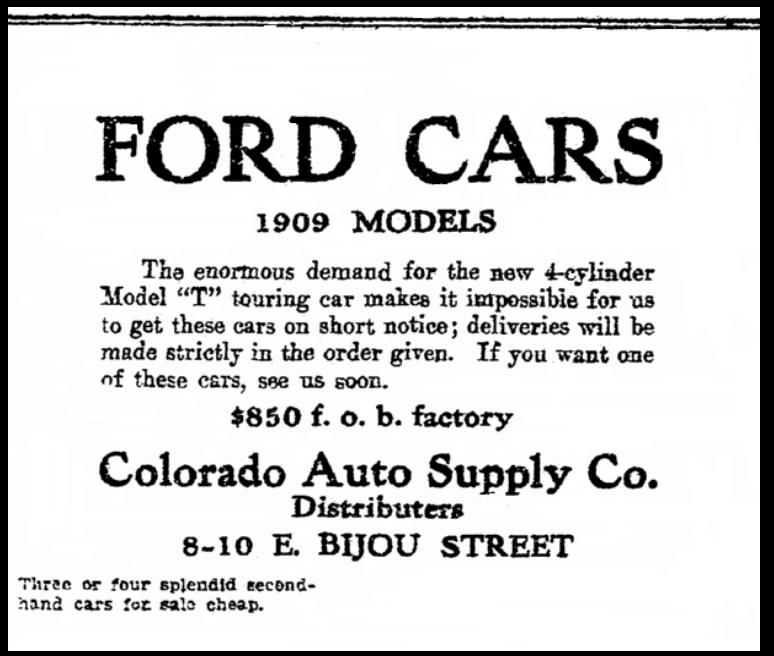
Remaining challenges being addressed

Cost and durability

Infrastructure cost, availability, reliability

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

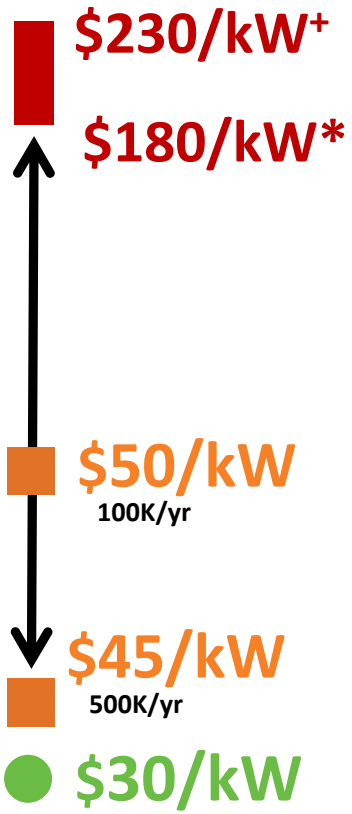
Colorado Auto Supply Co.
Distributers
8-10 E. BIJOU STREET

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

DOE Cost Status and Targets for R&D

Fuel Cell R&D

System



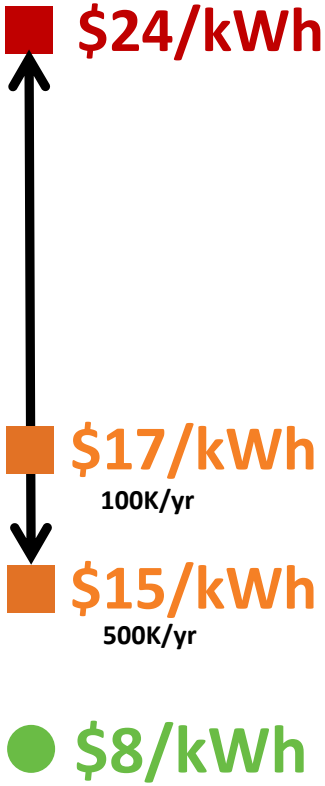
†Based on commercially available FCEVs

*Based on state of the art technology

Hydrogen R&D

Production, Delivery & Dispensing

Onboard Storage
(*700-bar compressed system*)



†Range assumes current production from NG and delivery and dispensing.

*Highest possible cost at high vol., assumes H2 from electrolysis at $5/gge and delivery via pipelines and liquid tankers at $5/gge

** Lowest possible cost at high vol., assumes H2 from SMR at $2/gge and delivery via tube trailer at $3/gge

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

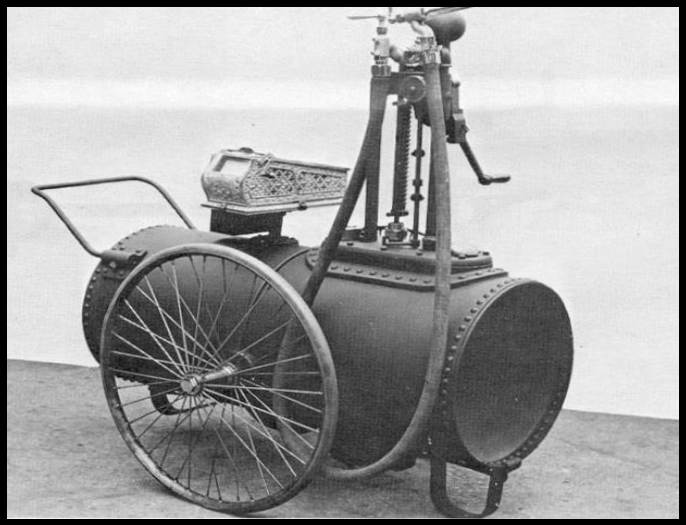
Notes: Graphs not drawn to scale and are for illustration purposes only. gge: gallon of gasoline equivalent

Gasoline History: Many diverse options

Cans, barrels, home models, mobile refuelers

Source: M. Melaina 2008.

Source: Vieyra, 1979



Source: Milkues, 1978

Complementing Retail Stations: H_2Refuel H-Prize

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)

U.S. Dept. Of Energy H_2 and Fuel Cells R&D Focus

Early R&D Focus

Applied research, development and innovation in hydrogen and fuel cell technologies leading to:

- Energy security
- Energy resiliency
- Strong domestic economy

Early R&D Areas

Fuel Cells

- PGM- free catalysts
- Durable MEAs
- Electrode performance

Hydrogen Fuel

- Production Pathways
- Advanced materials for storage

Infrastructure R&D

- Safety
- Manufacturing
- Delivery components
- Others

PGM = Platinum group metals
MEA = Membrane Electrode Assembly

Enabling

H2@Scale
U.S. Department of Energy

3. H_2@Scale concept

Vision

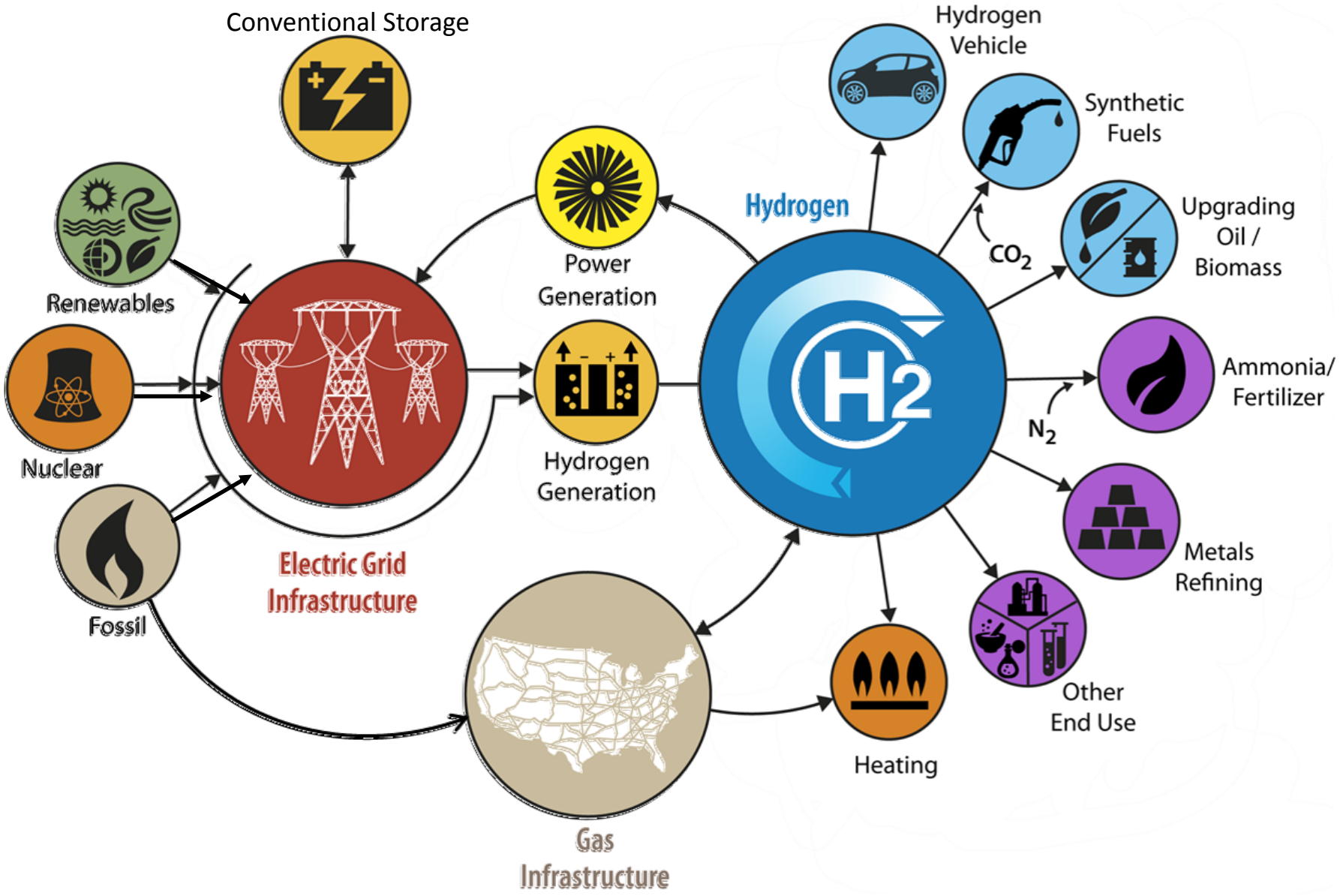
H2@Scale: Enable affordable, reliable, clean and secure energy across sectors

Versatility

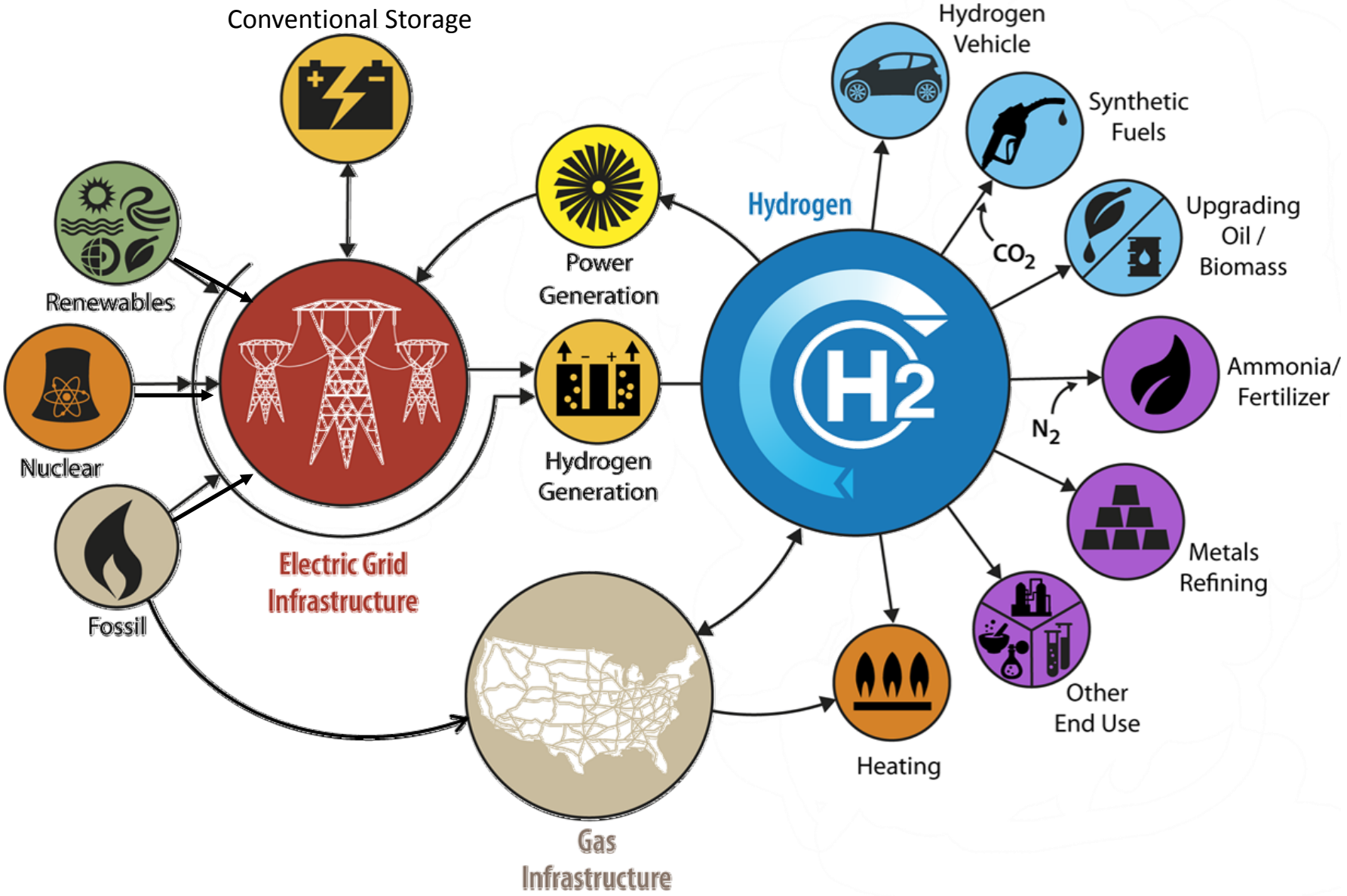
Volume

Value Proposition

H_2@scale: Enabling affordable, reliable, clean, and secure energy across sectors

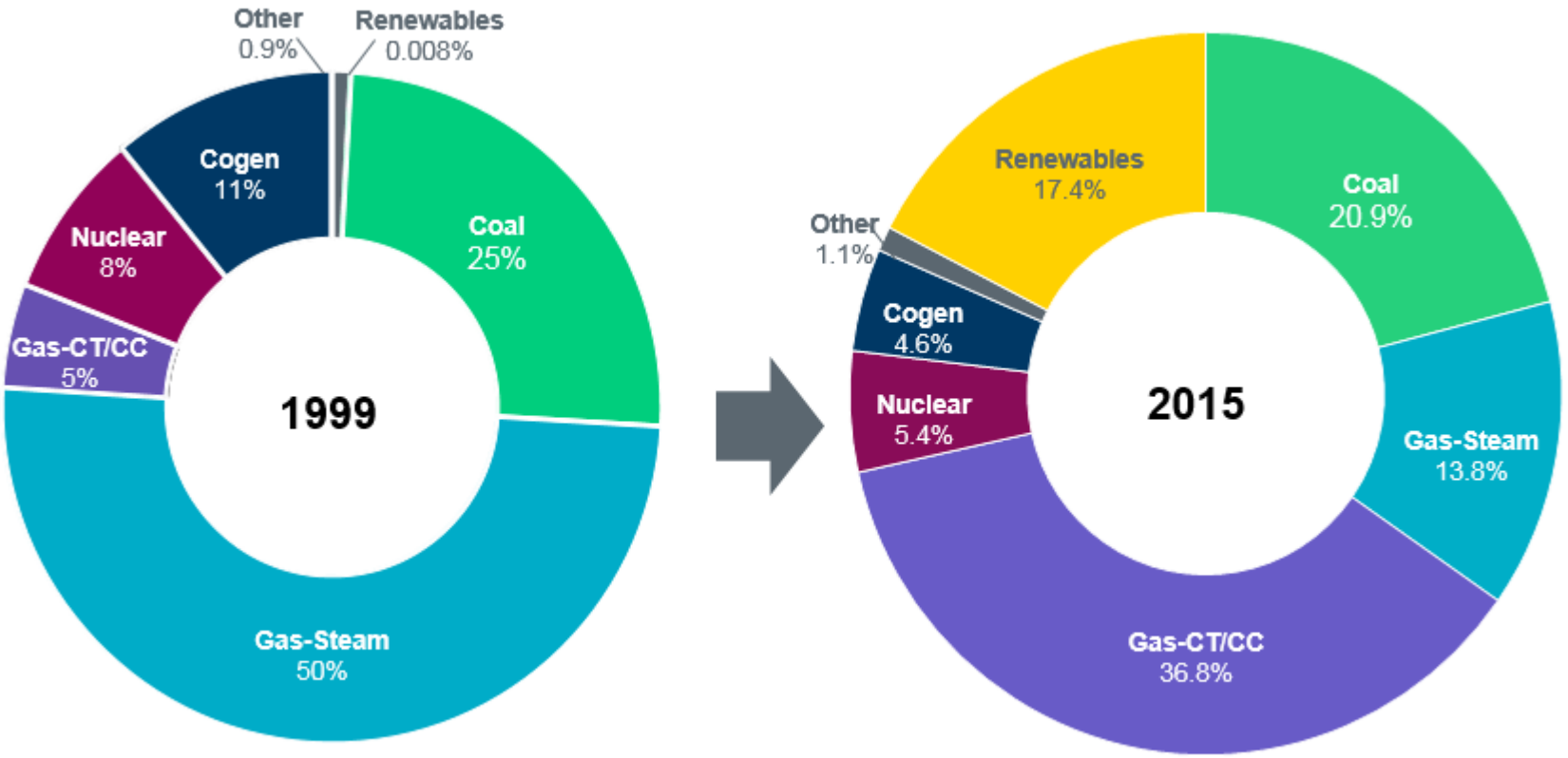


H_2@scale: Enabling affordable, reliable, clean, and secure energy across sectors



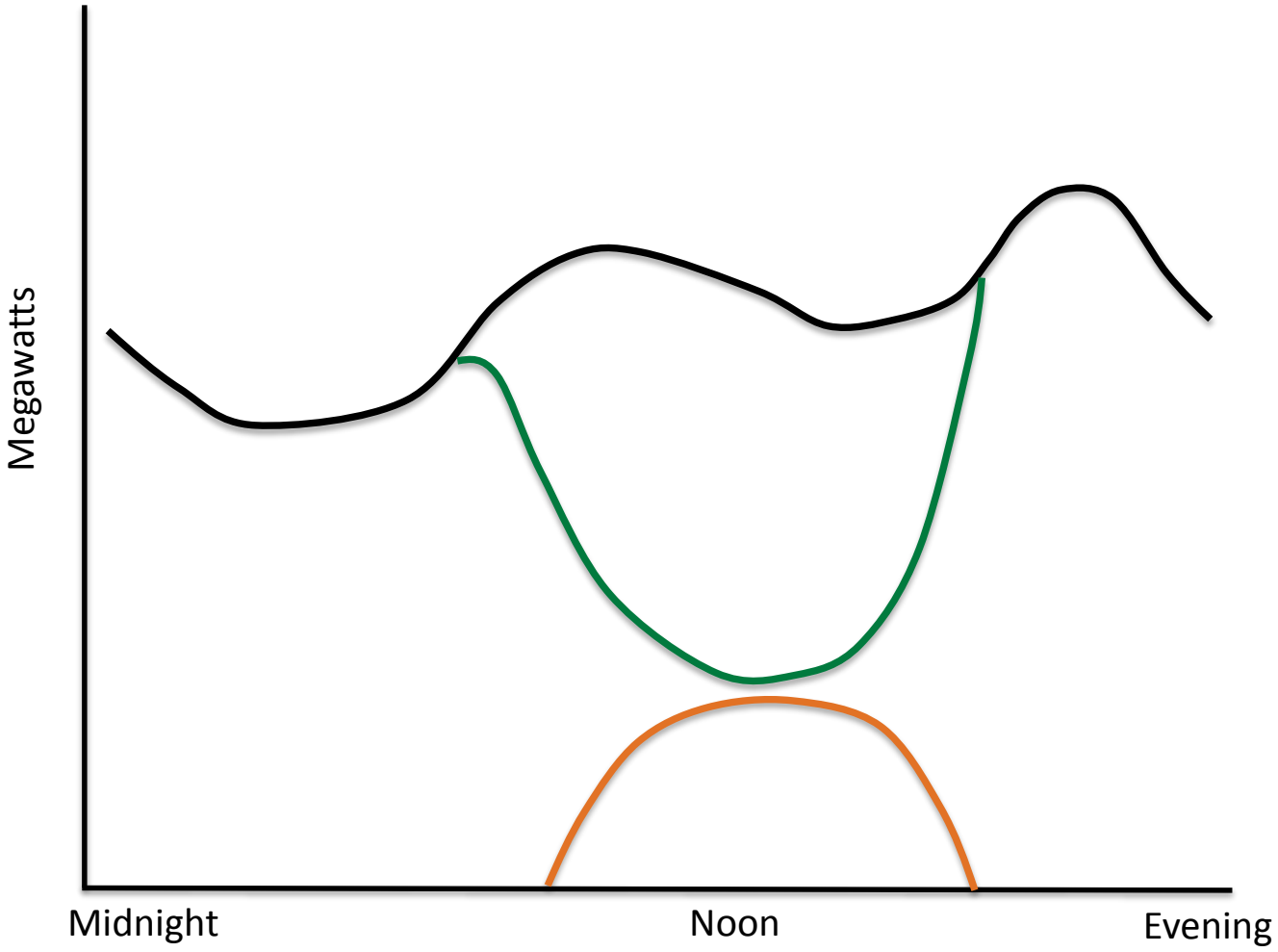
Electricity Mix Landscape is Changing- Example

Installed Capacity in Texas



Source: ERCOT

The Duck Curve 101 - Example

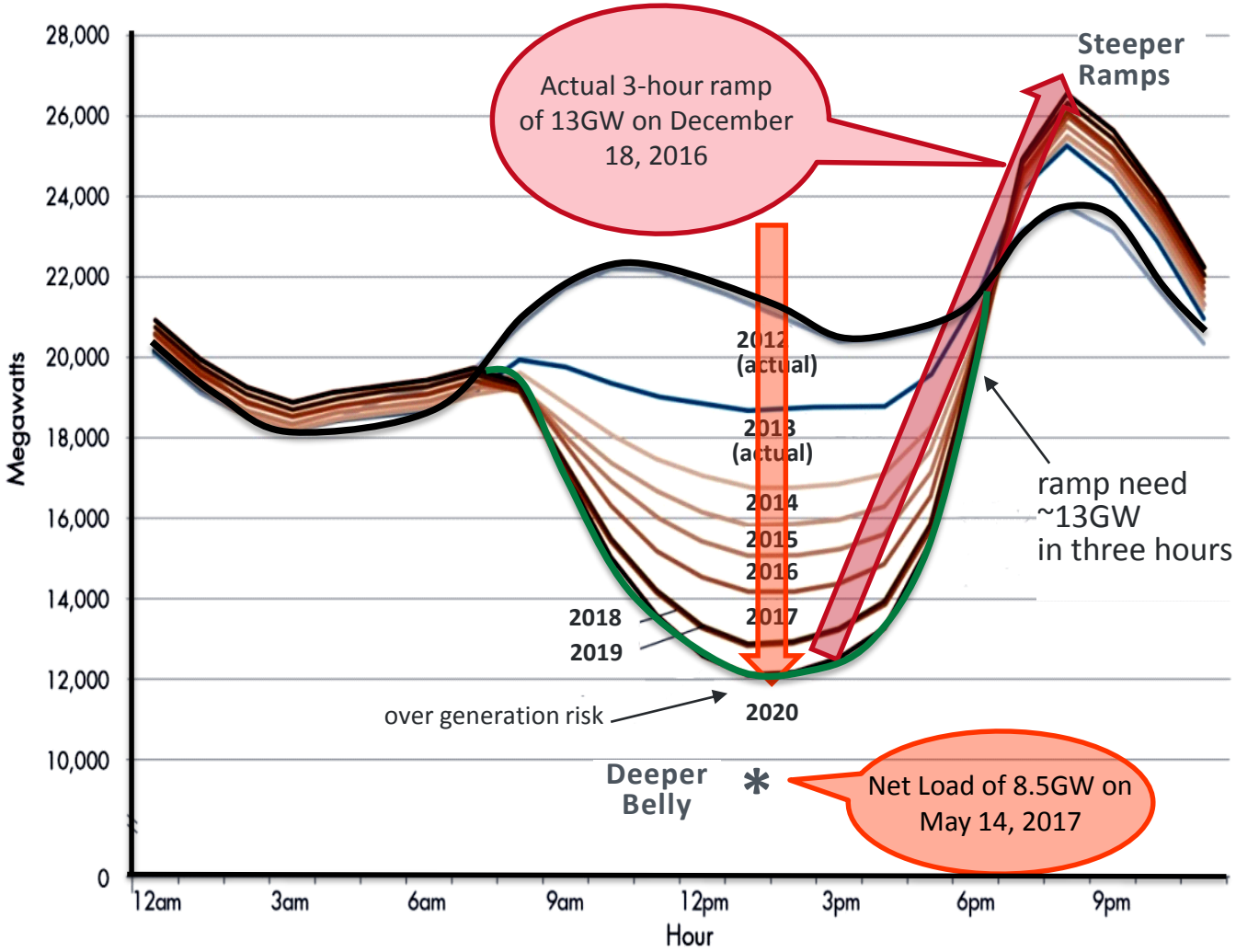


Total Load (demand)

Load (net) on commercial utility grid (duck belly forms)

Solar Production

The Duck's belly is getting bigger



Source U.S. DOE Solar Energy Technologies Office- California Example

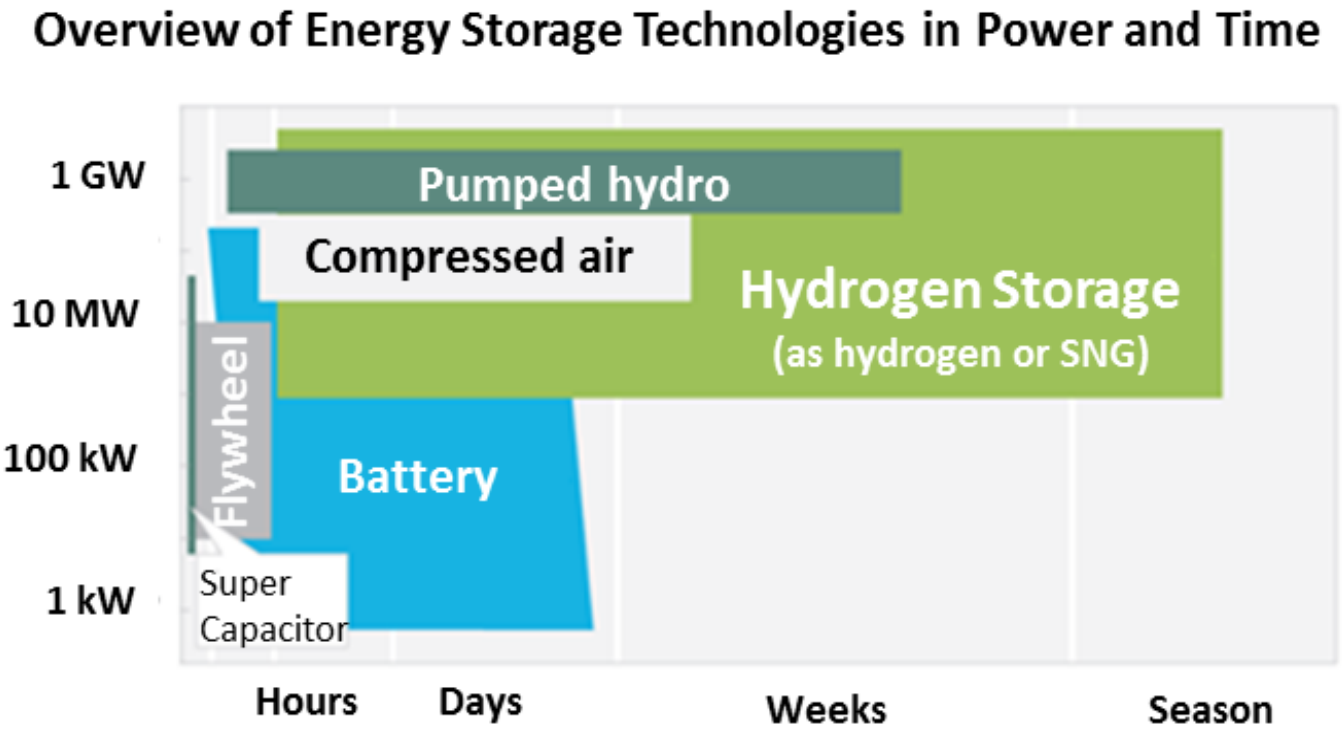
Two Concerns:

- **Low Net Load:** flexibility to reduce baseload generation resources is limited
- **High Ramp Rates in Evening:** flexibility of other generation to ramp up is limited

Can be addressed by

H2@Scale℠ U.S. Department of Energy

Hydrogen Energy Storage is Scalable



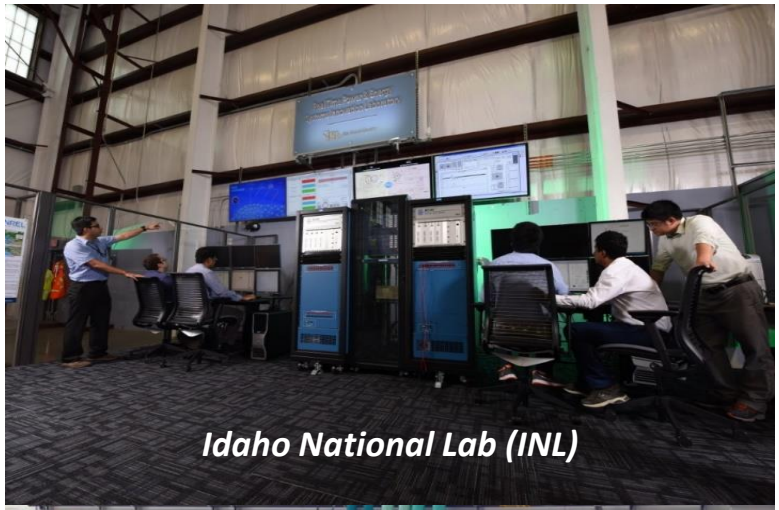
One hydrogen cavern could provide **~ 100 GWh energy storage**

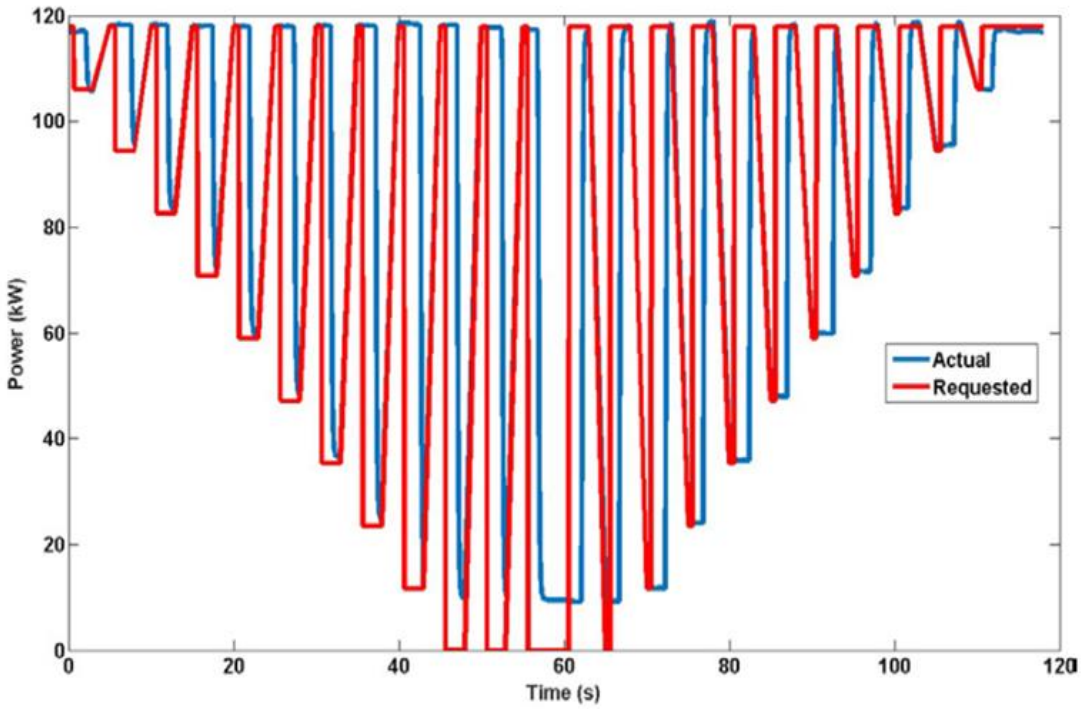
Image: Hydrogen Council

Hydrogen can be used to monetize surplus electricity from the grid, or remote, off-grid energy feedstock (e.g. solar, wind) for days to months.

Lab testing shows value of electrolyzers for ancillary services

First Ever Validation of Frequency Regulation with Electrolyzers





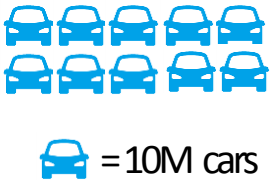
Lab testing shows dynamic response within seconds and potential for grid services

Scale: Simple Example

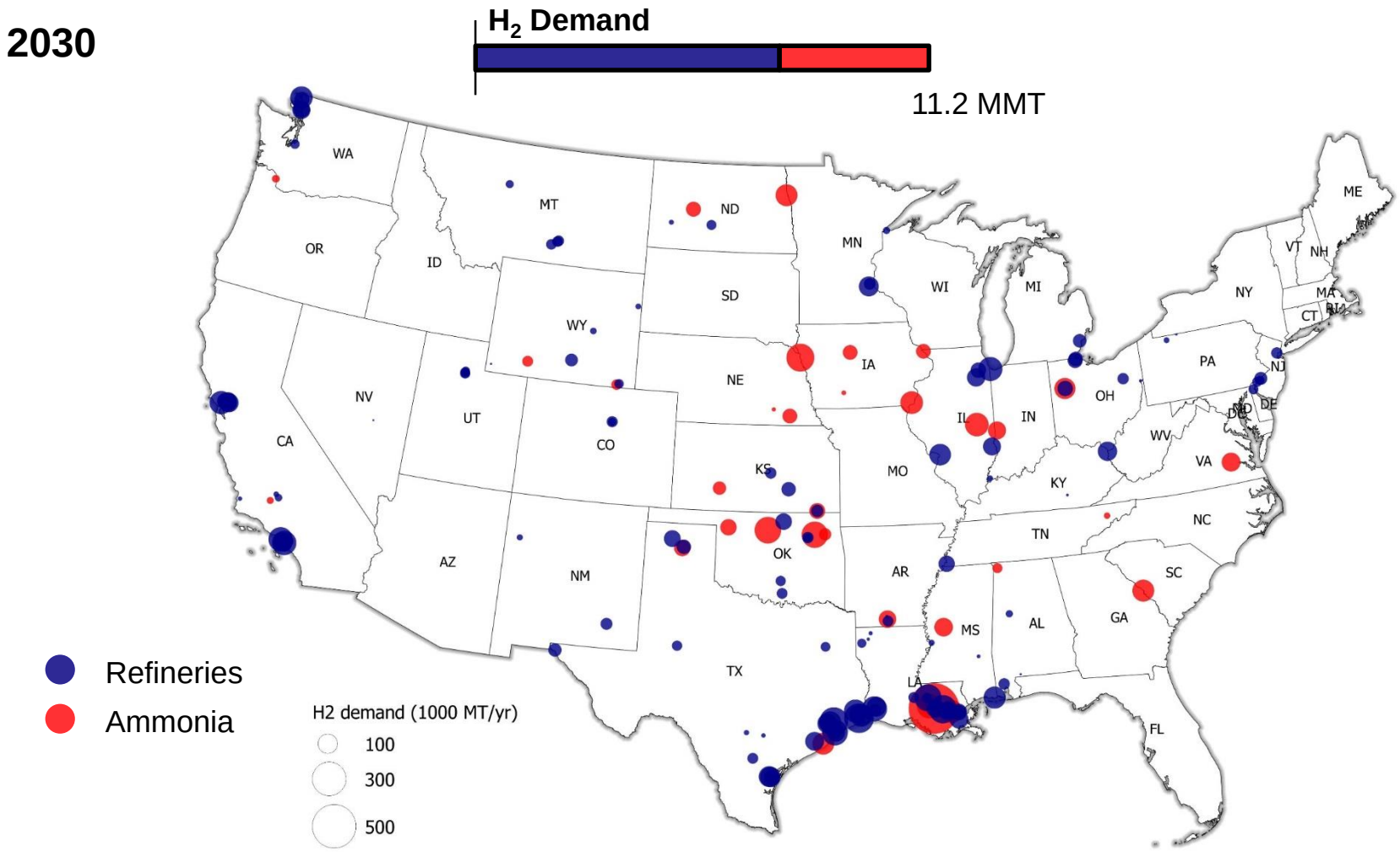
How much hydrogen for 1 car?

$$\frac{\textbf{12,000 miles} \text{ per year}}{\textbf{60 miles} \text{ per kilogram}} = \textbf{200 kg} \text{ per year} \quad \textbf{or} \quad \textbf{0.2 tonnes} \text{ per year}$$

How much hydrogen for many cars?

100 M cars	20M tons H_2 per year
 = 10M cars	**20 B kg** H_2 per year

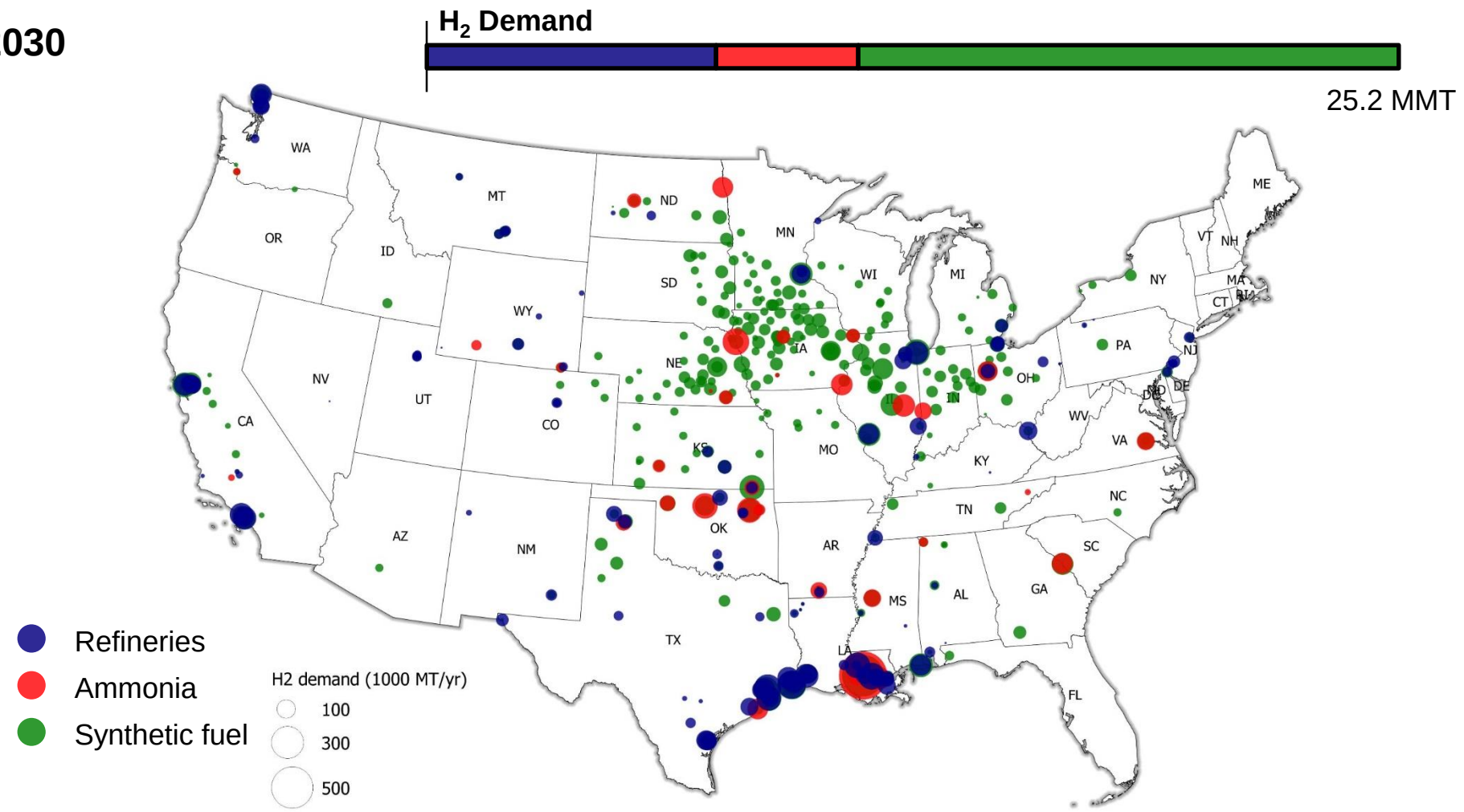
Ammonia & Refineries and Potential H_2 Demand



Source: Elgowainy, et al, ANL

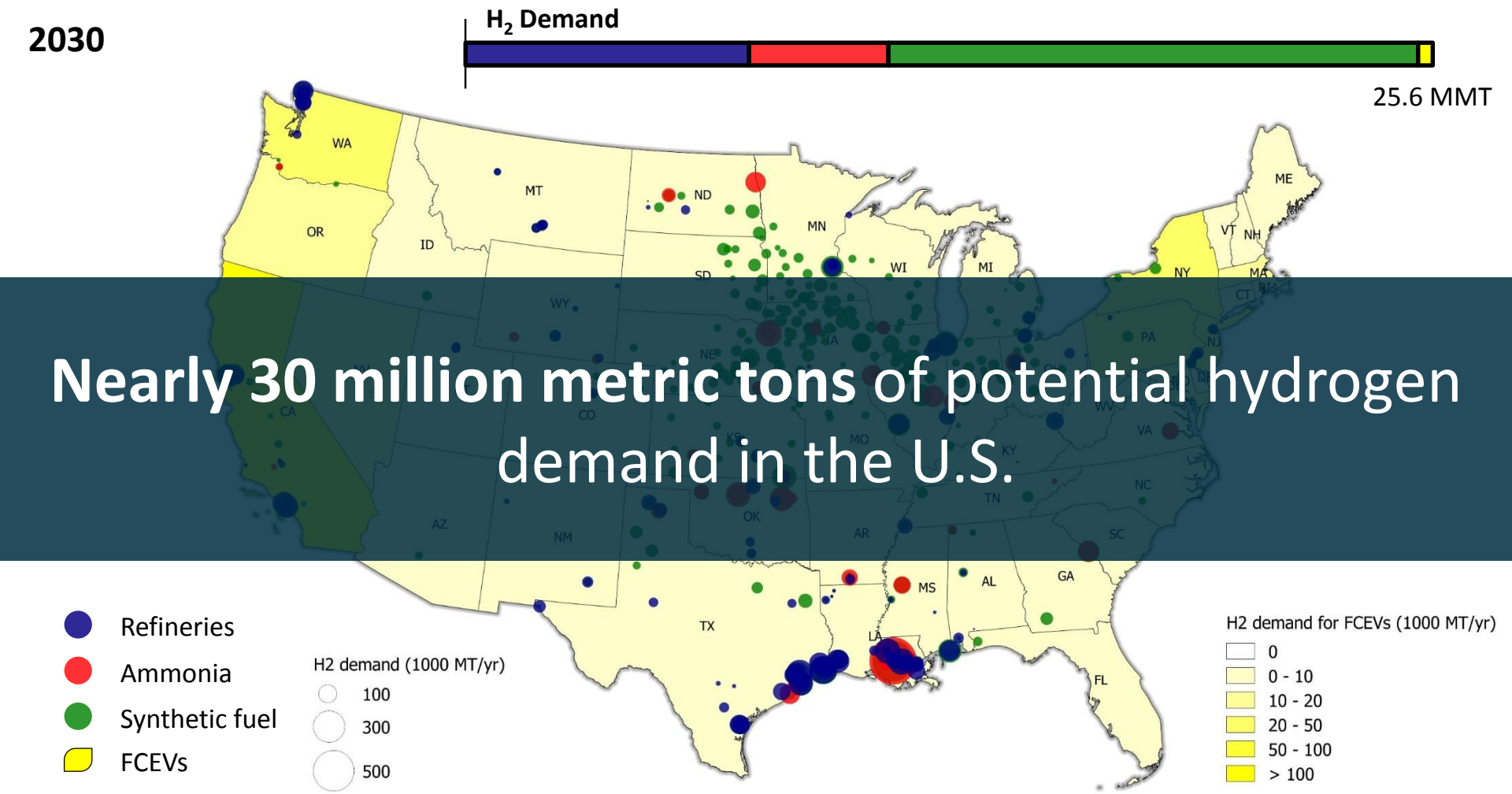
Plus demand from synthetic fuel production…

2030



Source: Elgowainy, et al, ANL

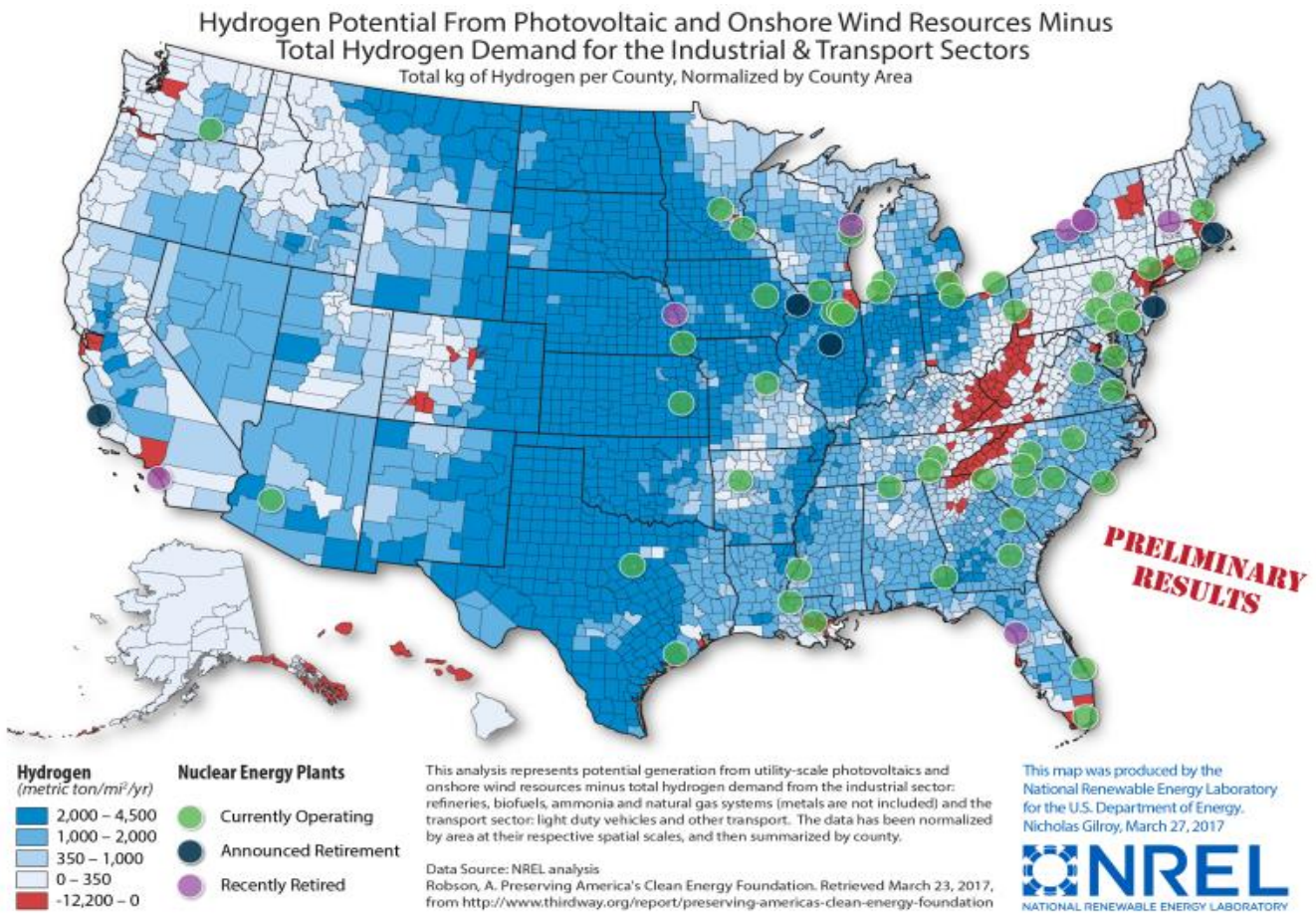
Hydrogen Demand Potential



Nearly 30 million metric tons of potential hydrogen demand in the U.S.

Source: Elgowainy, et al, ANL

H2@Scale: Nationwide Resource Assessment



Labs assess resource availability. Most regions have sufficient resources.

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

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

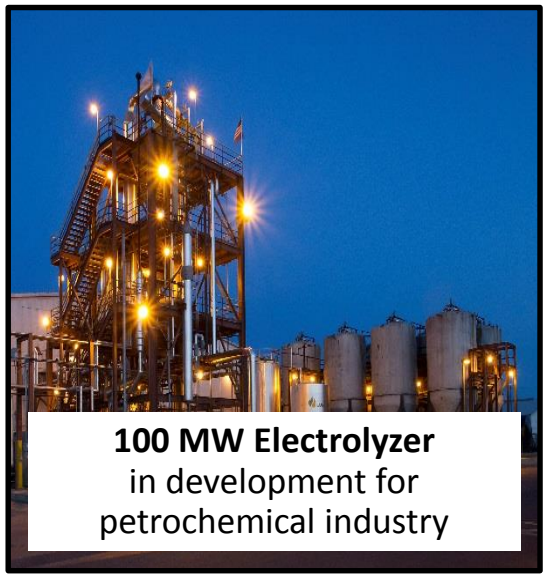
Value Proposition? Examples of Projects Worldwide

Germany 2016: 6-MW wind-to-H2 plant using electrolyzers commissioned

Austria 2017: 6-MW electrolyzer for steel plant

Electrolyzer for ammonia production at U. Minnesota

60-MW fuel cell park in South Korea- world's largest!



100 MW Electrolyzer in development for petrochemical industry

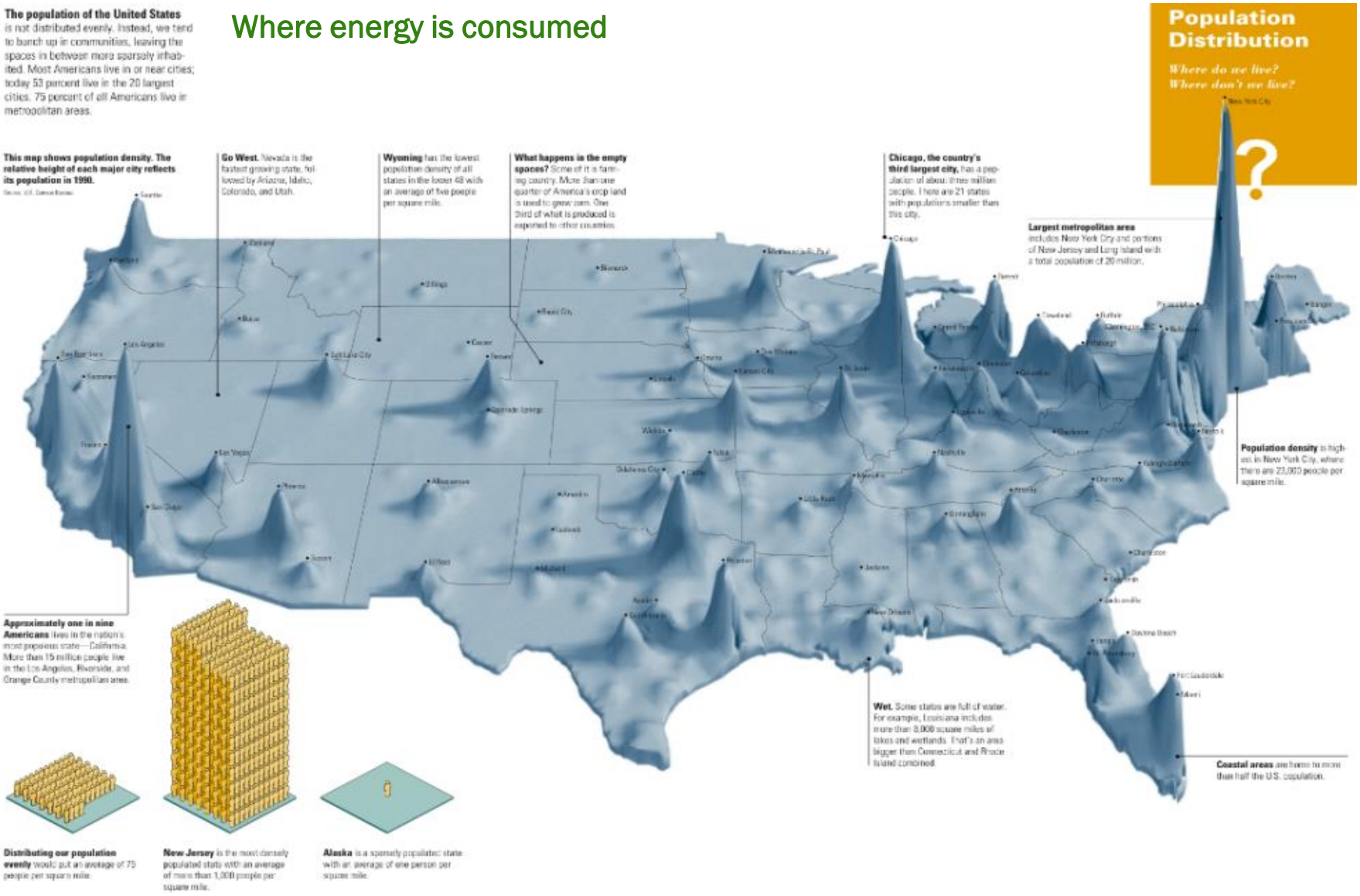
World's largest salt cavern for hydrogen storage commissioned in TX in 2017

H_2@Scale: Enabling renewable energy transport?

Where we find abundant solar and wind energy

…and deliver it or co-locate distributed generation with demand for certain applications

Where energy is consumed



H_2@Scale Stakeholder Feedback – Examples

Hundreds of stakeholders engaged
6 DOE Offices engaged
(EERE, FE, NE, OE, SC, ARPA-E)

2016 Session at Intermountain Energy Summit
Idaho Falls, ID

2017 Session at Fuel Cell Seminar
Long Beach, CA

Planned: 2018 Kickoff
Chicago, IL

2017 Session at FCTO's Annual Merit Review
Washington, D.C.

Planned: 2018 AMR
Washington, D.C.

2017 Workshop
Houston, TX

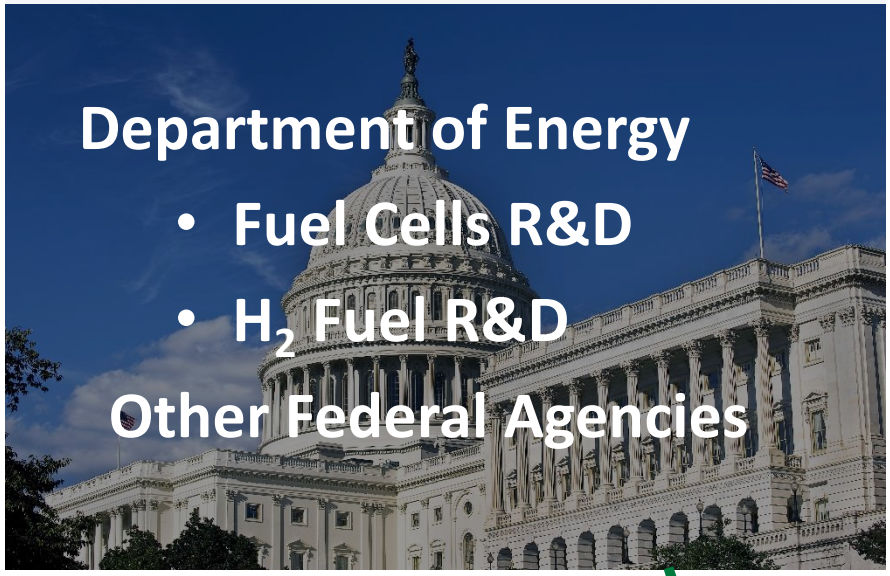
2016 Workshop
Golden, CO

Examples of additional presentations:

- Utah (2017)
- Michigan (2017)
- Minnesota (2017)
- Germany (2017, 2018)
- Japan (2018)

Strategy: Partnerships to enable H_2@Scale

Early- Stage R&D



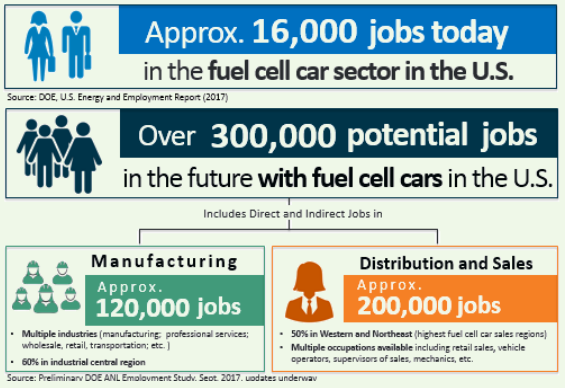
Demonstration, Deployment & Commercialization

H2@Scale U.S. Department of Energy

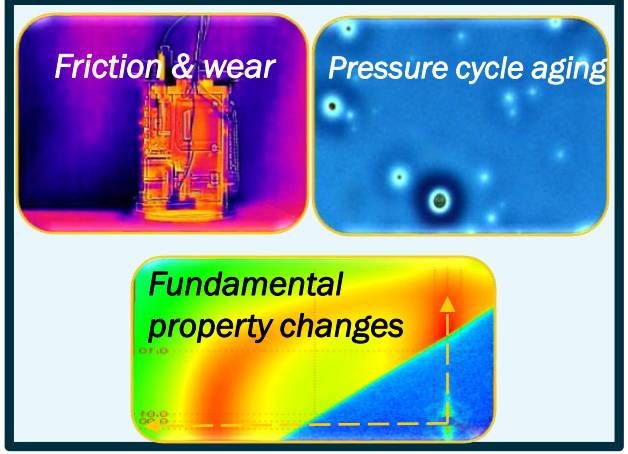
H_2@Scale Consortium

H_2@Scale R&D Lab Capabilities– Examples

Techno economic Modeling and Analysis



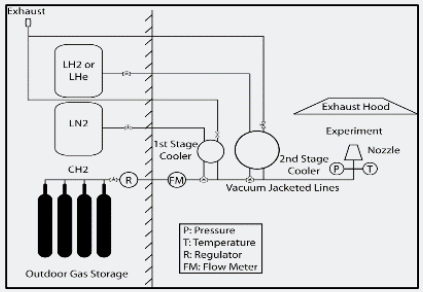
Hydrogen Materials R&D



Grid simulation and Testing R&D

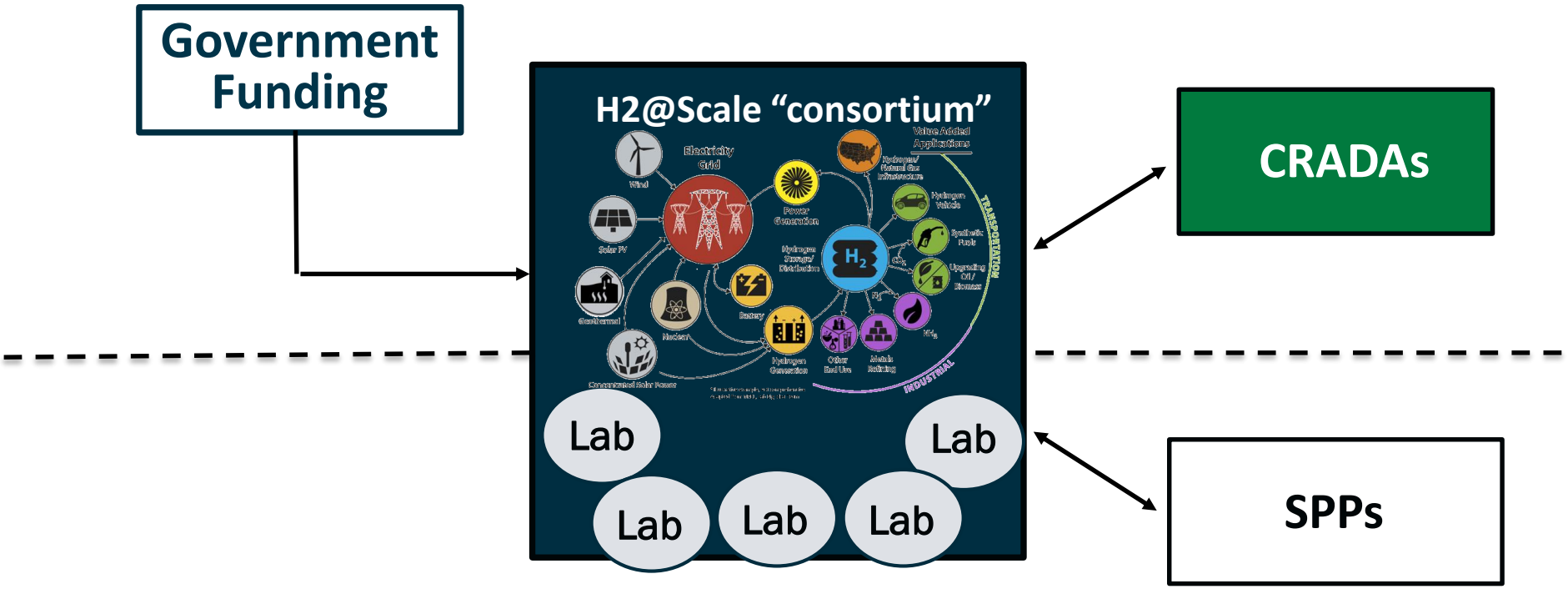
Safety and Infrastructure R&D

HyRAM
HYDROGEN RISK ASSESSMENT MODELS



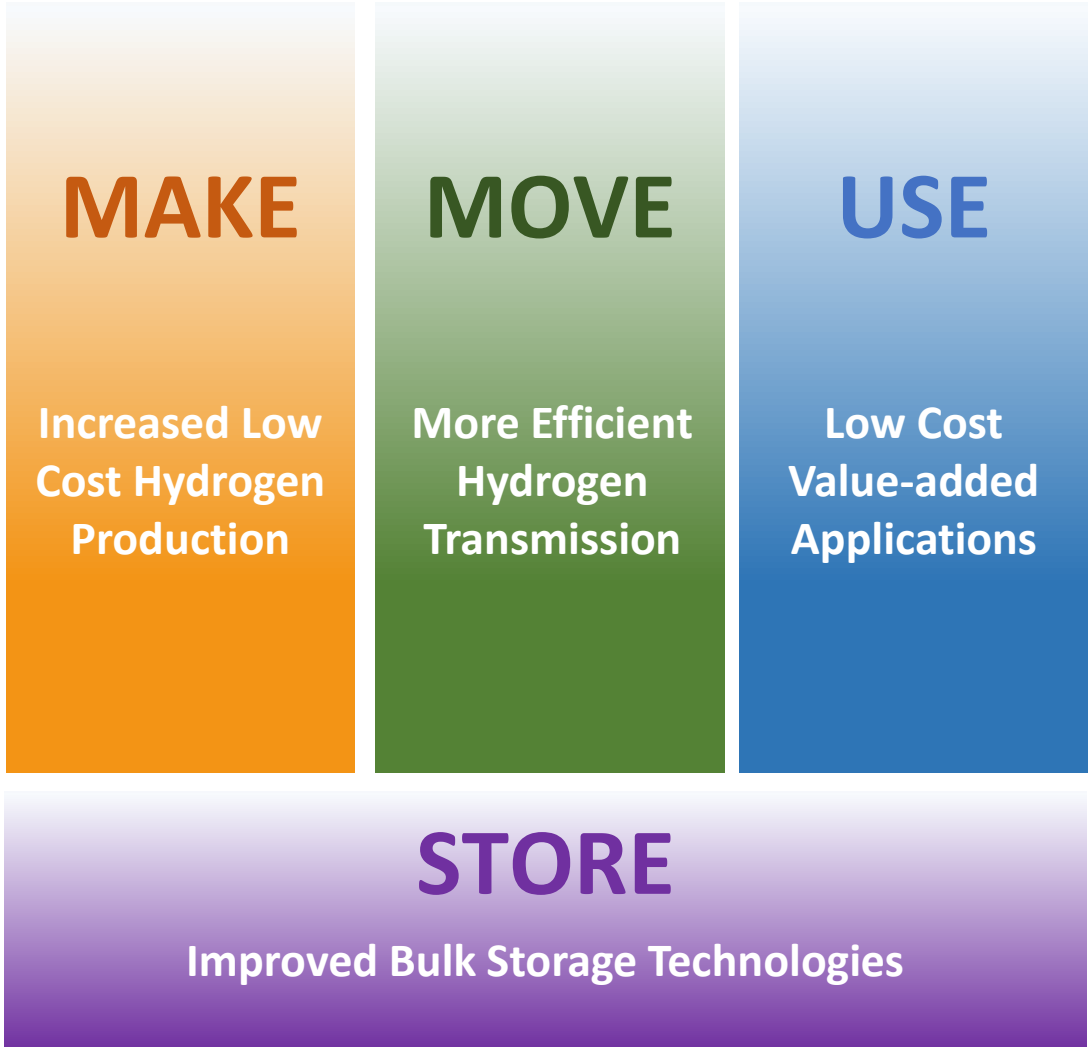
H_2@Scale – Lab CRADAs

- **Leverages Lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.**
- **Round 1 in 2017.**



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

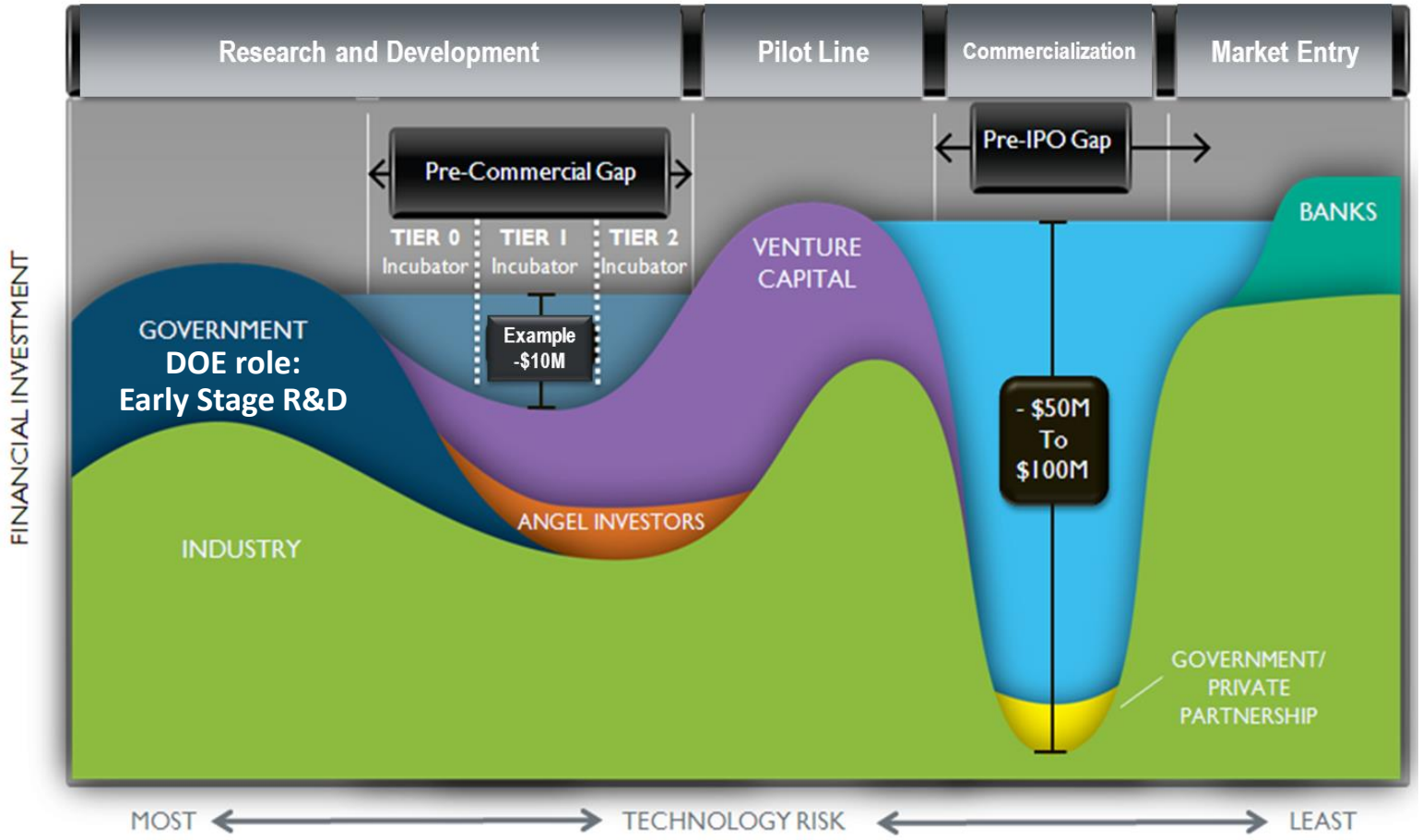
Key focus areas to realize the H_2@scale vision



4. Collaboration

Government vs. Private Sector Roles

Example— illustrative timeline for innovation & commercialization



Fuel Cell Technologies Office- adapted from SunShot Incubator briefing.

Pictorial example, not representative of all industry start ups

FCTO Example: Innovation Driving Impact

Innovation

730 H_2 and fuel cell **patents** **enabled by DOE funds**

Approx. **35%** of H_2 and fuel cell patents **come from National Labs**

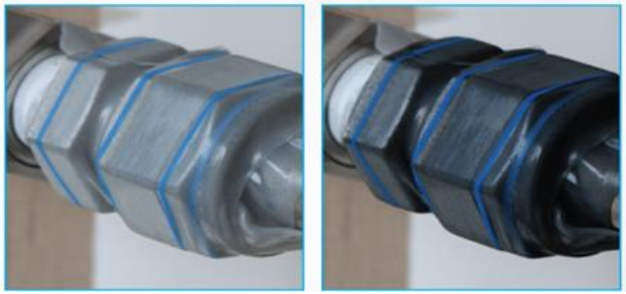
Market Impact

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

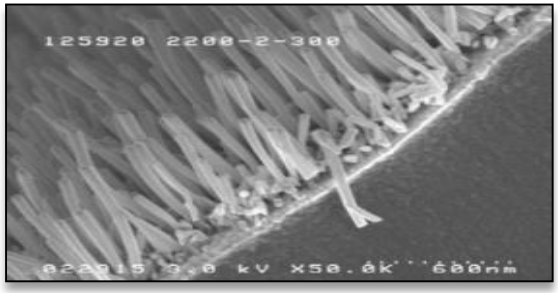
and over **75** **with potential** to be commercial in the next 3-5 years

can be traced back to DOE R&D

Innovation to Market Technologies - Examples



Hydrogen Detection Tape – Element One



Catalyst and Supports for PEM Fuel Cells – 3M

Hydrogen Tube Trailers – Hexagon Lincoln

Example- Northeast Hydrogen Fuel Cell Cluster

Preliminary Analysis- Economic Impact Summary

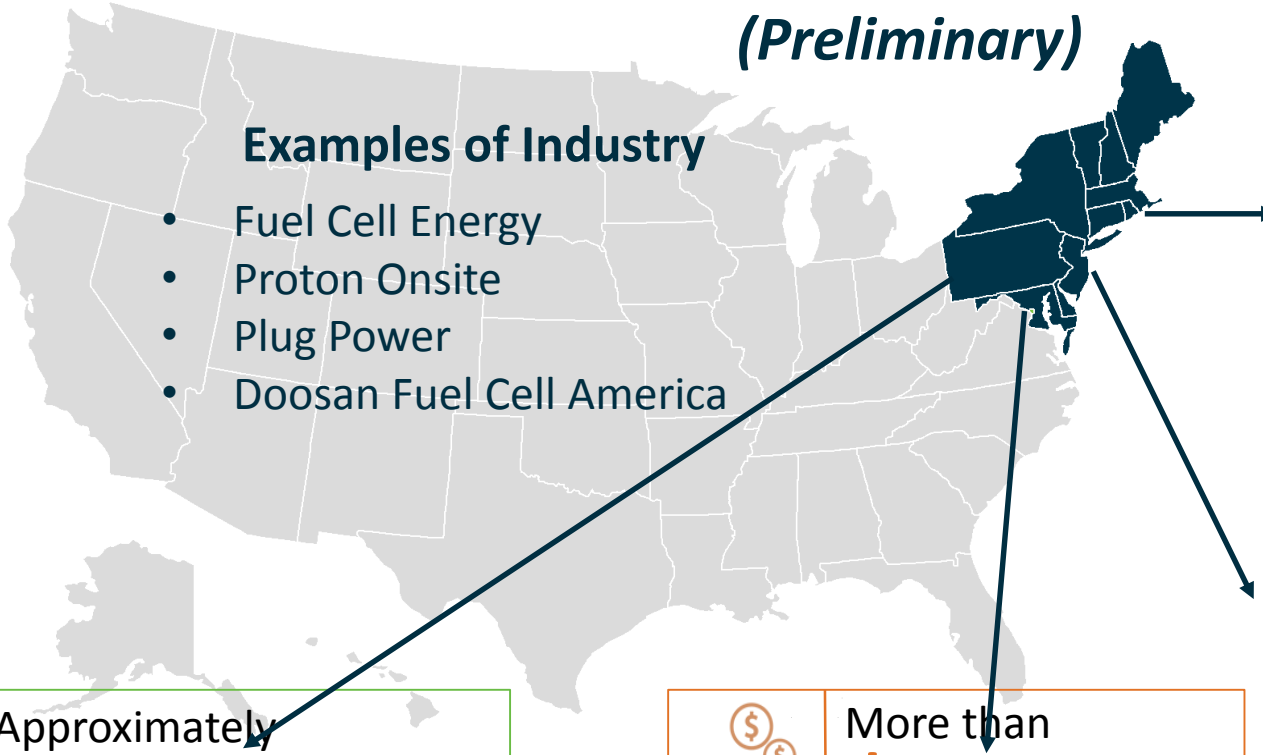
	CT	NY	MA	ME	NH	RI	VT	NJ	Regional
Total Employment	2,529	1,728	964	18	45	32	16	111	**5,443**
Total Revenue / Investment in 2010 ($ million)	$496	$292	$171	$2.9	$8.7	$6.9	$3.3	$26.5	**$1,009**
Total Supply Chain Companies	599	183	322	28	25	19	5	8	**1189**

The Connecticut Center for Advance Technology, Inc.- 2012- CT State funded analysis. More info: www.ccat.us

Update: Industry Growth in the Northeast

Hydrogen and Fuel Cell Industry in the Northeast Growth

(Preliminary)



Examples of Industry

- Fuel Cell Energy
- Proton Onsite
- Plug Power
- Doosan Fuel Cell America

Revenue and Investment

$1.4 billion

More than

6,000 Jobs

Direct, Indirect and Induced

Approximately

$600 million

in Labor Income

More than

$83 million

in State and Local Tax Revenue

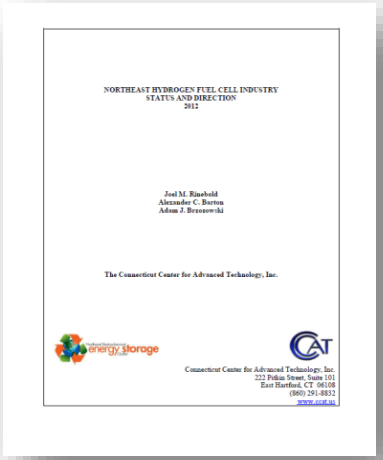
Data Reference:

Independent IMPLAN economic analysis of the region's hydrogen and fuel cell industry by the Northeast Electrochemical Energy Storage Cluster (NEESC)

For press release: https://globenewswire.com/news-release/2016/03/17/820796/10161124/en/Economic-Study-Reveals-Growth-of-Northeast-Region-s-Hydrogen-and-Fuel-Cell-Industry.html

Northeast State Reports – Examples

Northeast Hydrogen and Fuel Cell Industry and Direction


NORTHEAST HYDROGEN FUEL CELL INDUSTRY
STATUS AND DIRECTION
2012

Joel M. Rinebold
Alexander C. Barton
Adam J. Brzozowski

The Connecticut Center for Advanced Technology, Inc.

Connecticut Center for Advanced Technology, Inc.
222 Pitkin Street, Suite 101
East Hartford, CT 06108
(860) 291-8832
www.ccat.us

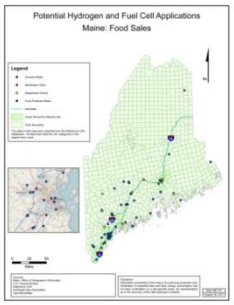
1.85 GW opportunity identified (updates ongoing)

Source: Joel M. Rinebold et al. Connecticut Center for Advanced Technology, Inc.

State by state plans identifying fuel cell opportunities and potential implementation strategies (drafts in process)

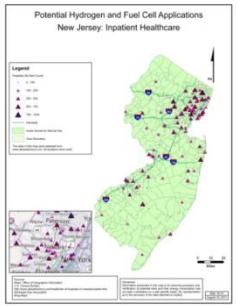
Targets: Geographic Information System (GIS) Mapping

Food Sales

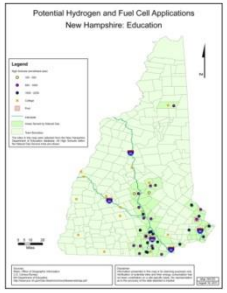


Food Services

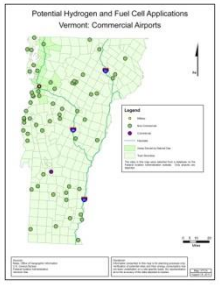
Inpatient Healthcare



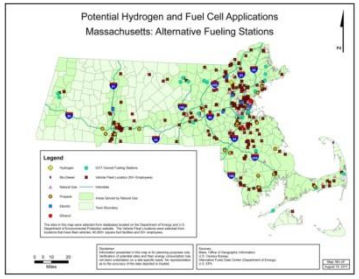
Education



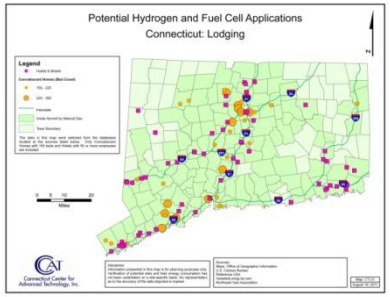
Airports (Military)



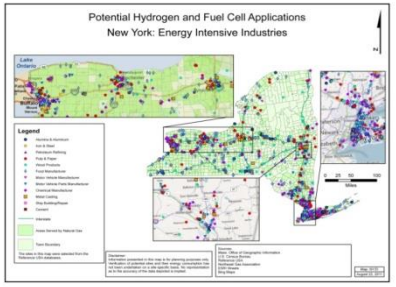
Alternative Fueling Stations



Lodging



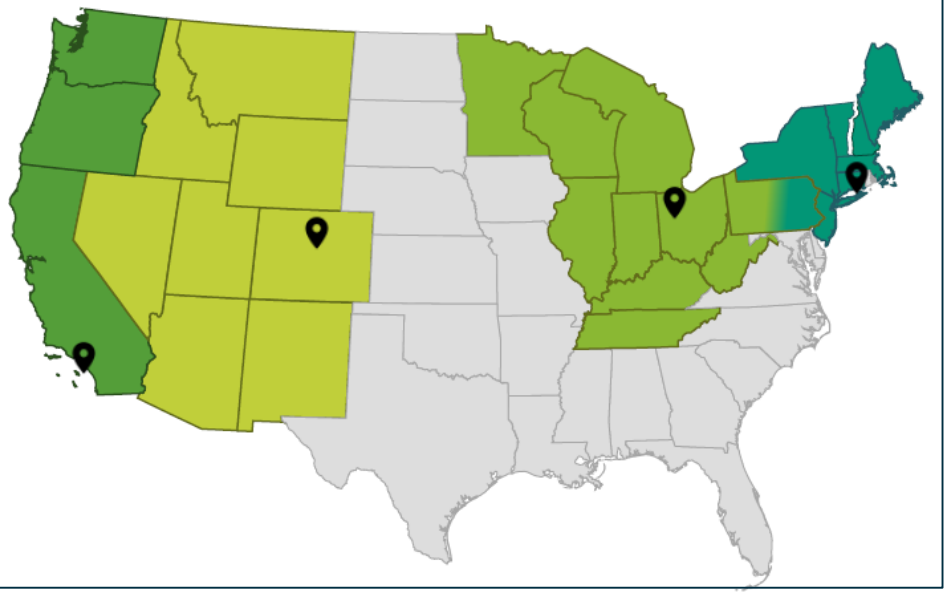
Energy Intensive Industry



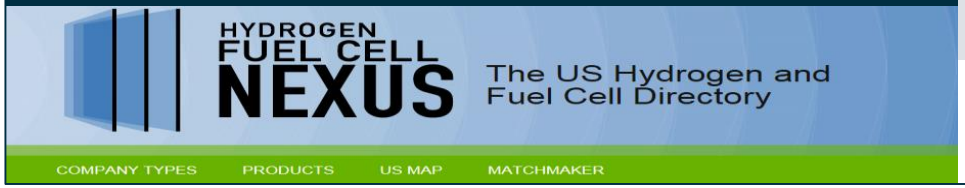
Enabling H_2 and Fuel Cell Component Supply Chain

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

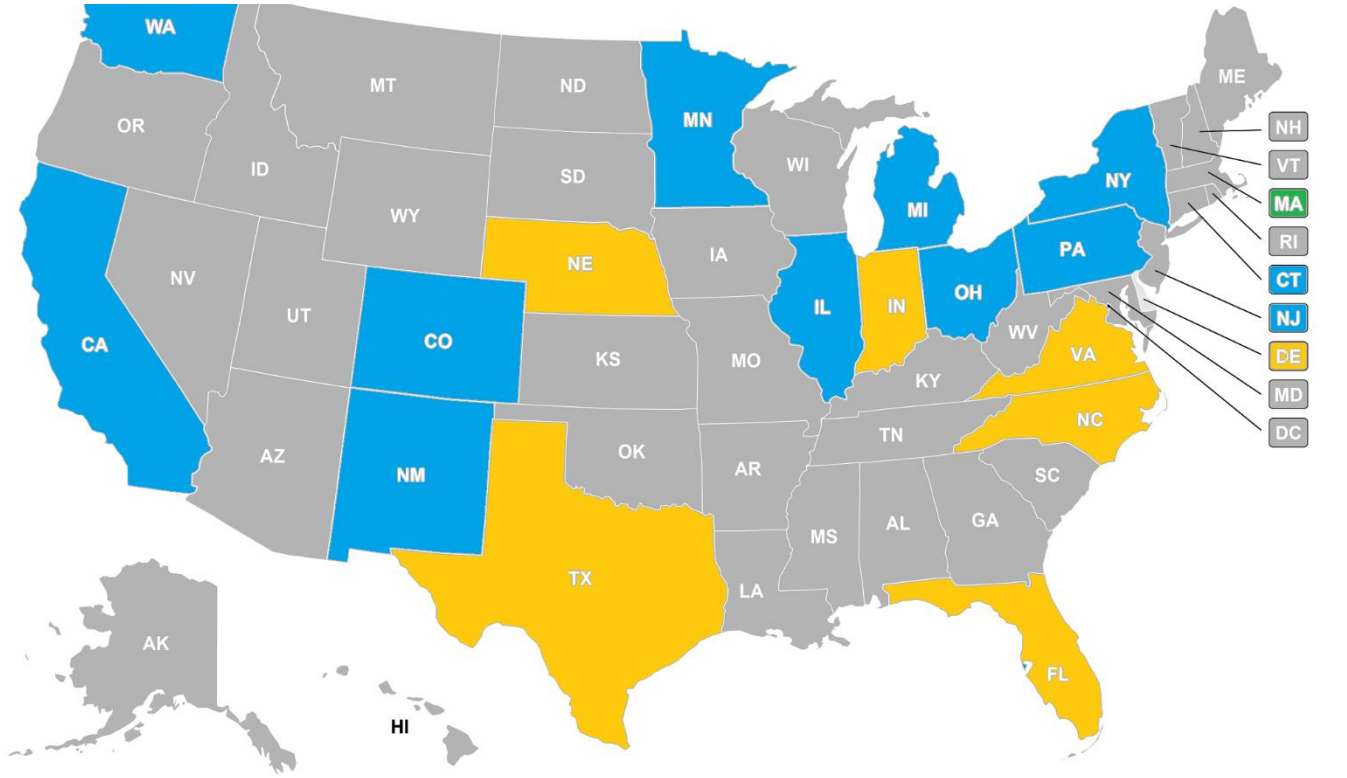


Connect at

HFCnexus.com

Over 300 companies included

FCTO Enabled Technologies & Innovations by State



50 Commercial Technologies

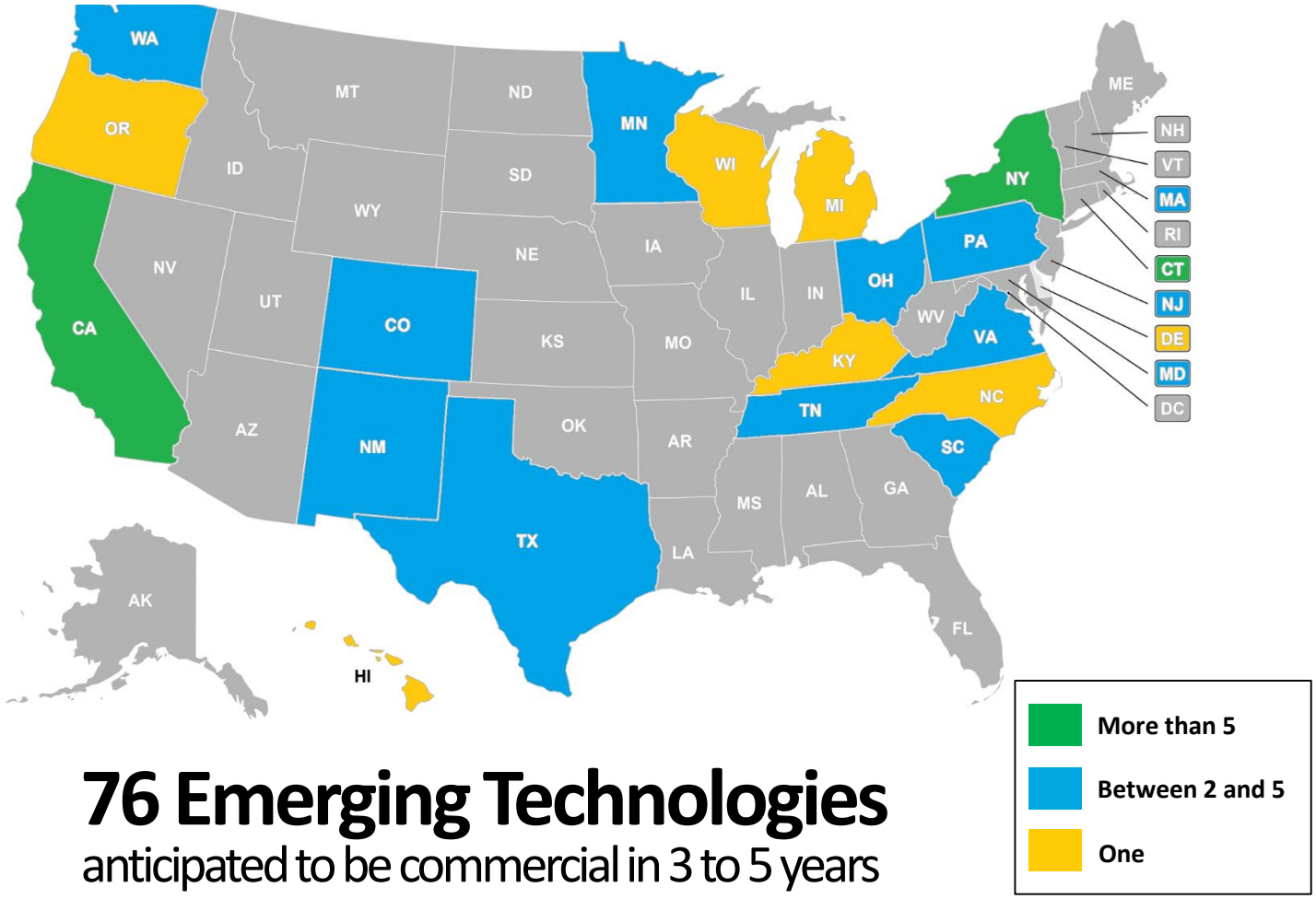
Enabled by FCTO funding by 2016

State	Total
MA	9
CT	5
OH	5
NY	4
CO	3
NJ	3
CA	2
IL	2
MI	2
MN	2
NM	2
PA	2
WA	2
DE	1
FL	1
IN	1
NC	1
NE	1
TX	1
VA	1

Source: 2016 Pathways to Commercialization Report

Emerging Technologies by State

DOE-Enabled Emerging Technologies by State



State	Total
CA	12
CT	9
NY	8
CO	5
MA	5
TN	5
PA	4
WA	4
MN	3
OH	3
SC	3
MD	2
NJ	2
NM	2
TX	2
VA	2
DE	1
HI	1
KY	1
MI	1
NC	1

76 Emerging Technologies

anticipated to be commercial in 3 to 5 years

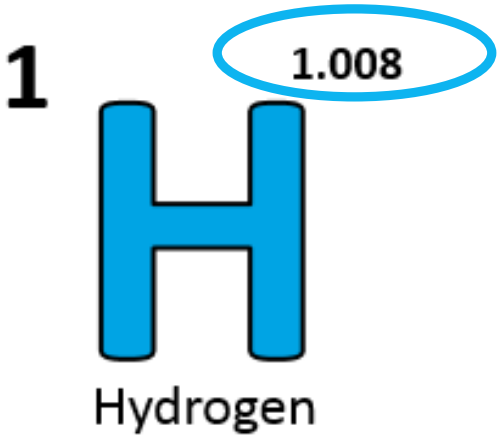
Source: 2016 Pathways to Commercialization Report

Opportunities for outreach and to increase awareness

Celebrate National Hydrogen & Fuel Cell Day

October 8 or 10/8

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



Information and Training Resources to Increase Awareness

H2tools.org

INCREASE YOUR H2IQ

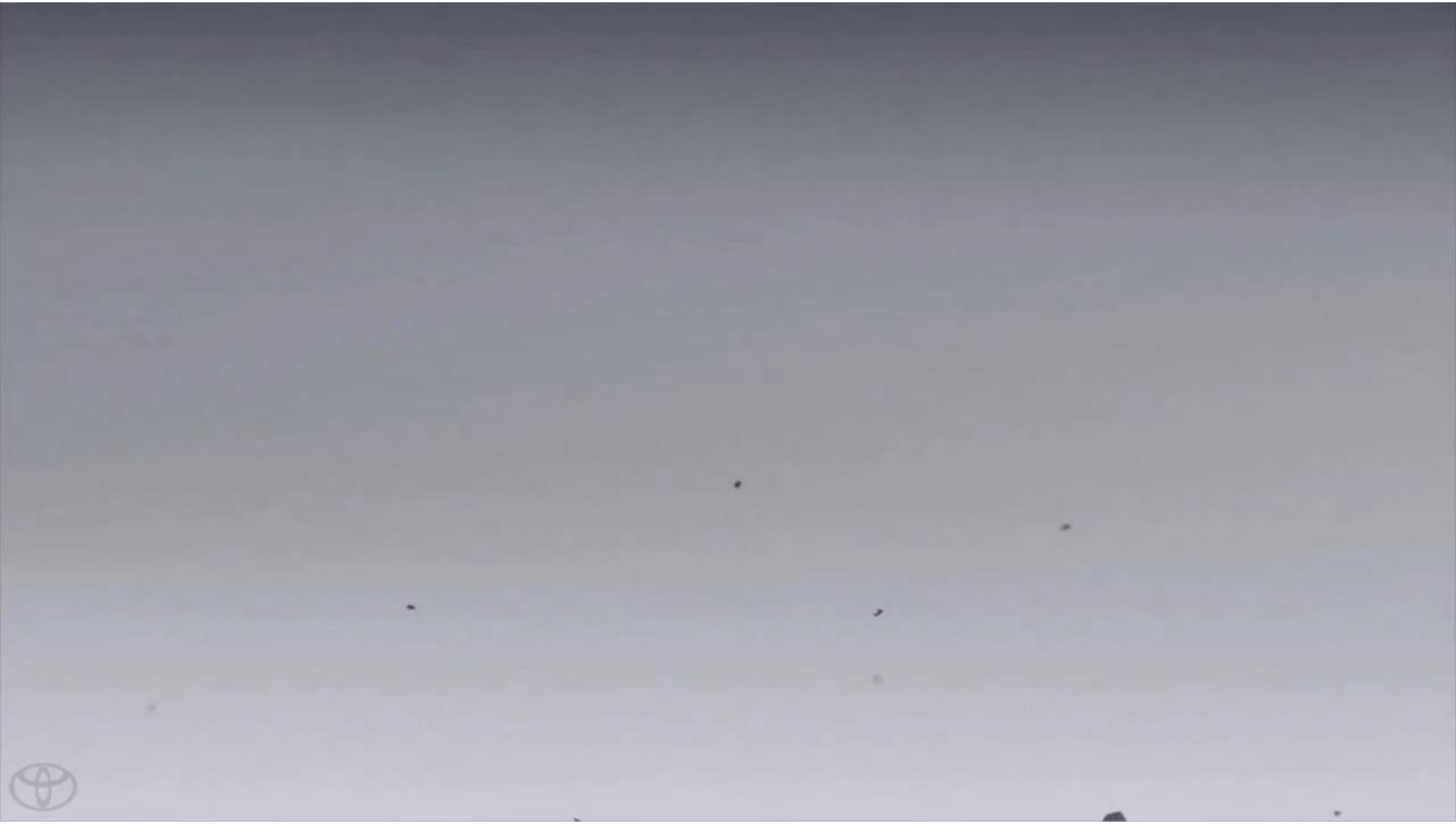
Download for free at:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Learn more at: energy.gov/eere/fuelcells

Asks

- How can DOE structure H2@Scale to better partner with states?
- What recommendations does STEAB have to help DOE in the area of outreach?
- How can DOE leverage private sector entities in the states to enable impact?

The Turning Point



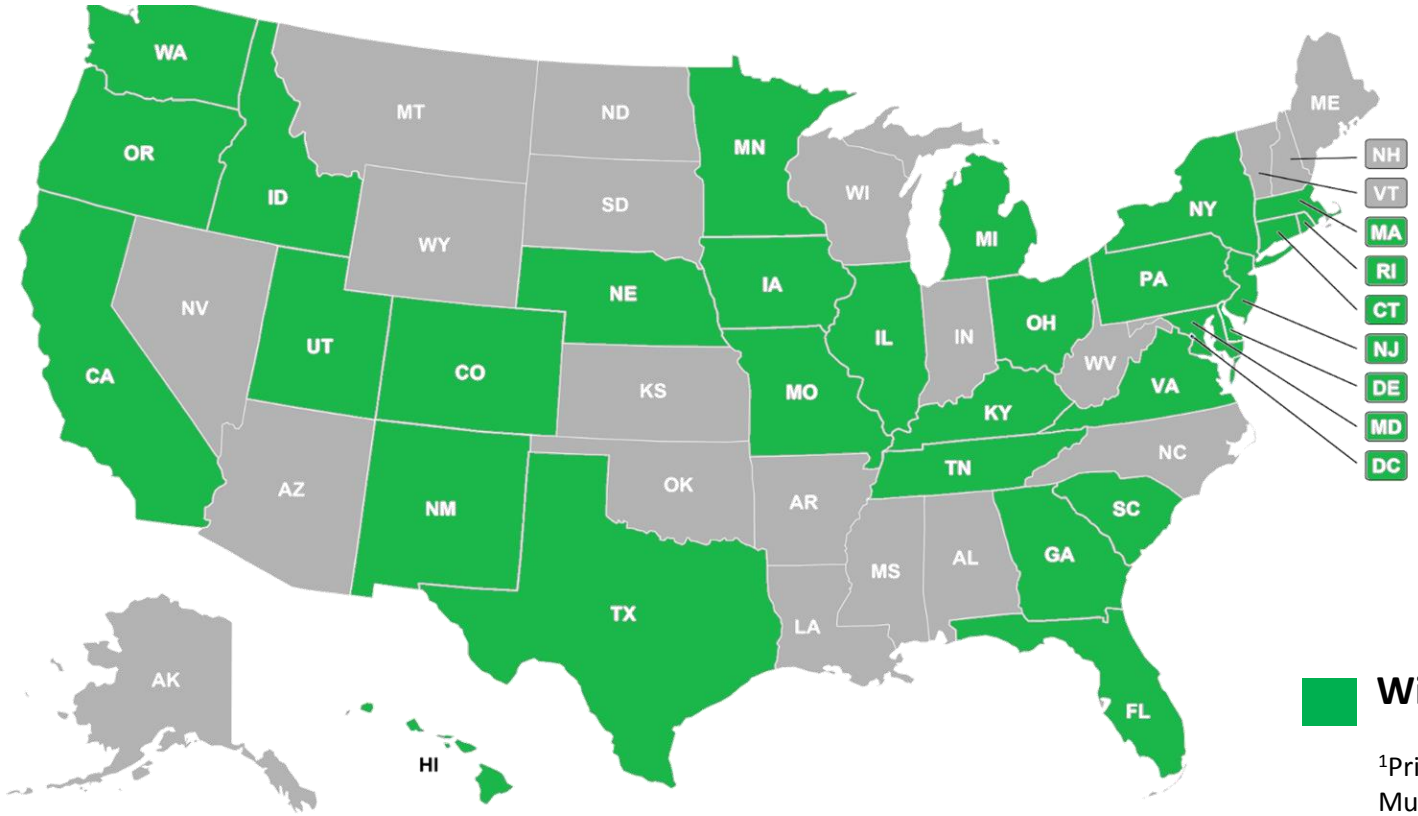
Thank You

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

www.hydrogen.energy.gov

Activities cover many States

EERE Fuel Cell Technologies Office Funding[1]
FY 2013 – FY 2017



With funding

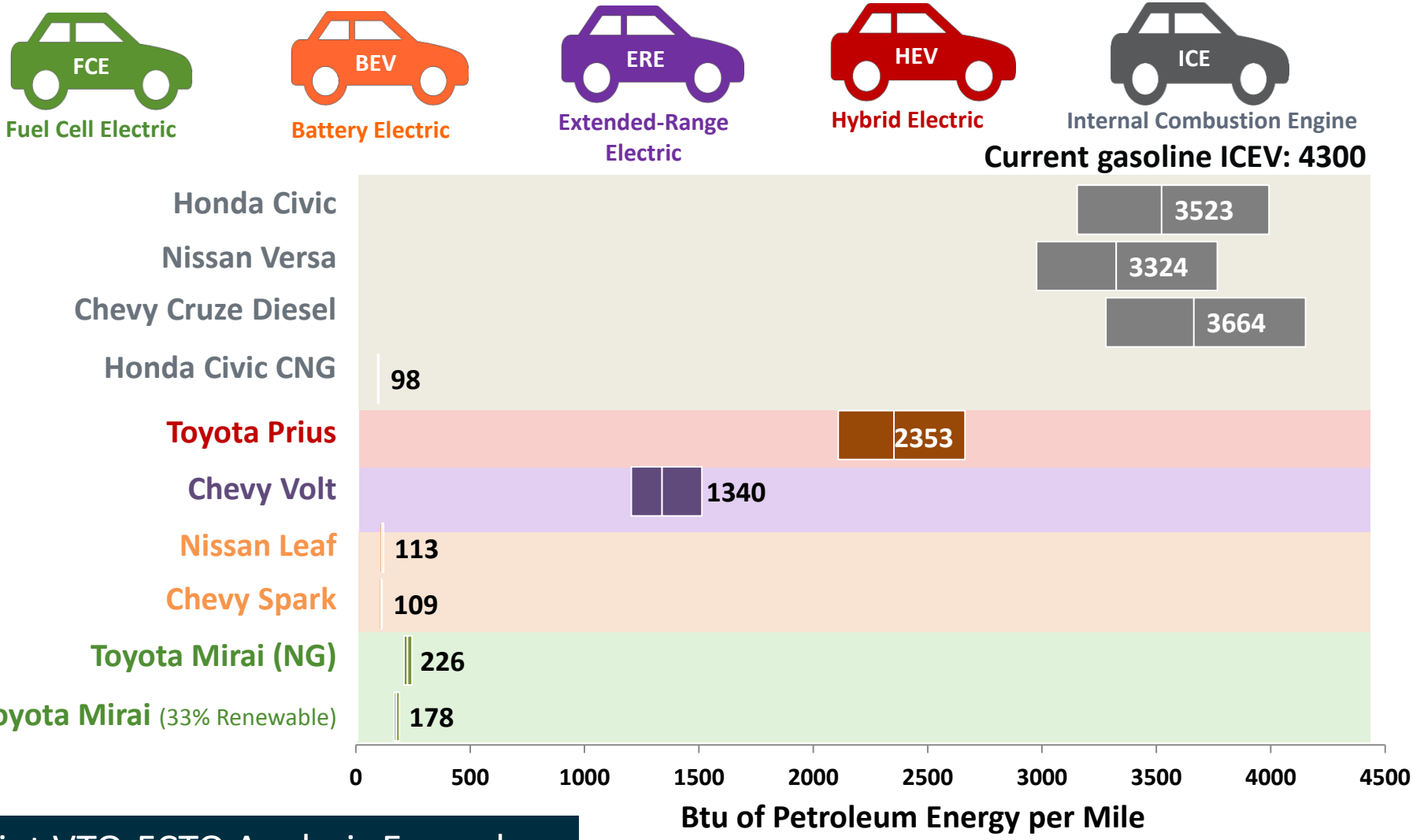
[1]Prime recipients only
Multiple additional States included as sub-recipients

From 2013 to 2017
$429M

Covering H_2 and Fuel Cell Activities in
30 states and DC

H_2 and fuel cells potential to reduce petroleum use

Low, Medium & High Petroleum Energy/Mile for 2015 Technology

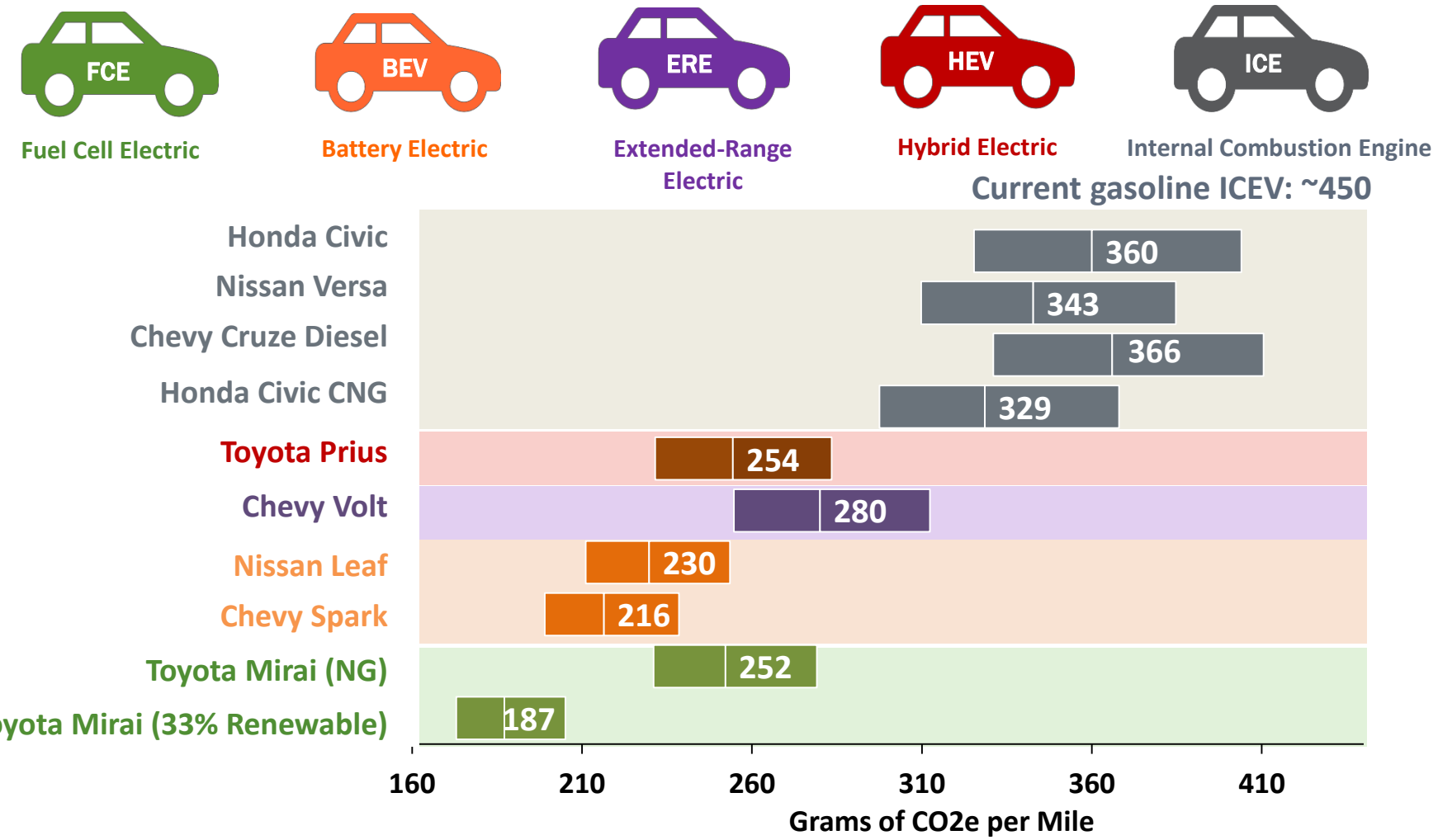


Joint VTO-FCTO Analysis Example

Source: Program Record 16004 (https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

And lifecycle emissions

Low, Medium & High Emissions/Mile for 2015 Technology



Joint VTO-FCTO Analysis Example

Source: Program Record 16004
(https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

Two Requests for Information to Enable H2@scale

Opportunities to facilitate widespread H2@scale adoption – coming

Reducing barriers to hydrogen infrastructure deployment – open now

Upcoming Events

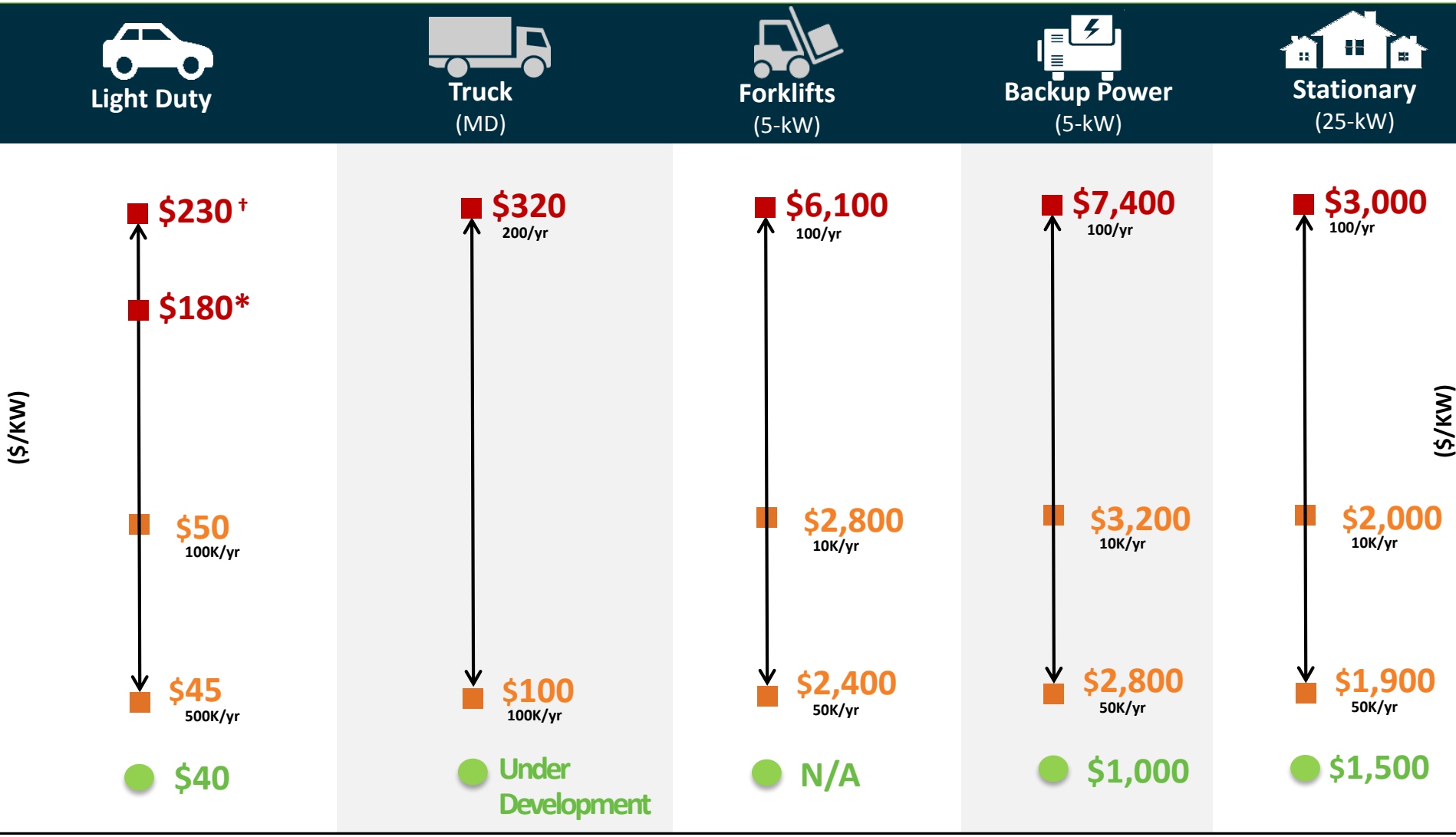
H2@Scale Kick Off Meeting

August 1, 2018
Chicago

Fuel Cell Truck Target Setting Workshop

July 30, 2018
Argonne National Lab - IL

Technology targets in various applications guide R&D



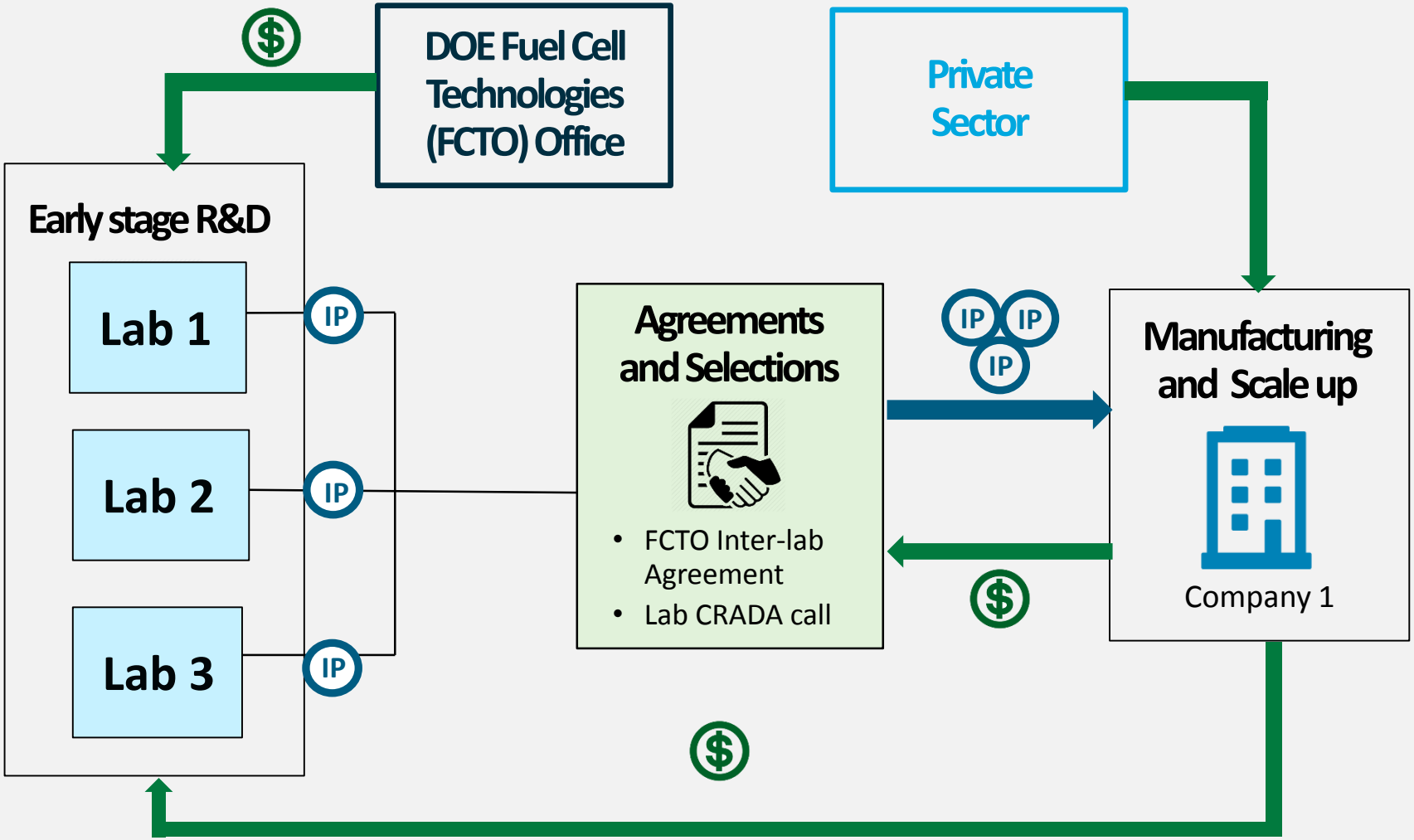
Targets | High-Volume Projection | Low-Volume Estimate

†Based on commercially available FCEVs †Based on state of the art technology

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

Innovations Provided to Industry & Investors

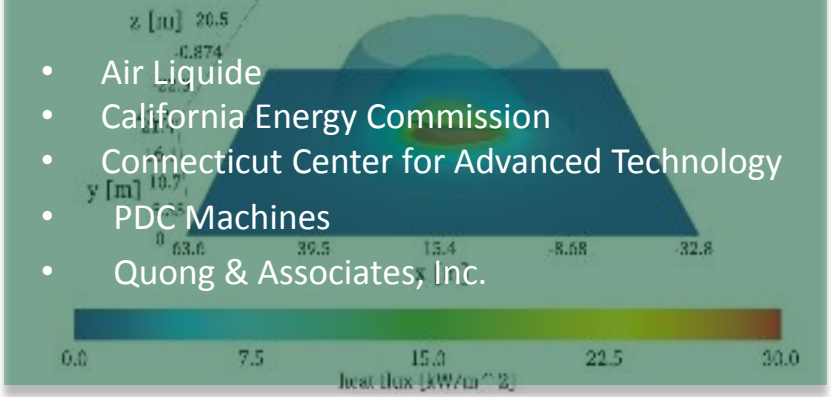
L'Innovator= "Lab Innovator" FCTO Pilot



H_2@Scale 2017 CRADA call selections

HYDROGEN QUANTITATIVE PERFORMANCE ANALYSIS AND OPERATION R&D

- Air Liquide
- California Energy Commission
- Connecticut Center for Advanced Technology
- PDC Machines
- Quong & Associates, Inc.

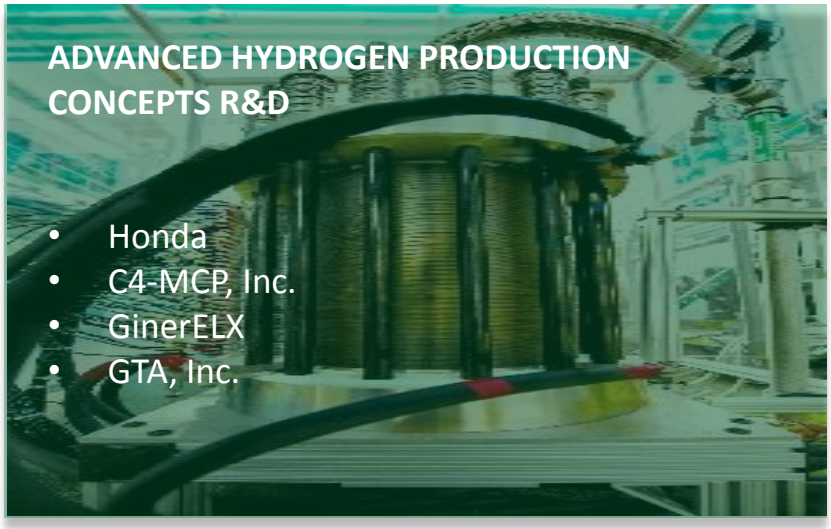


HYDROGEN DISTRIBUTION COMPONENT DEVELOPMENT R&D

- California Go-Biz Office
- Frontier Energy
- HyET
- Honda
- NanoSonic
- RIX
- Tatsuno

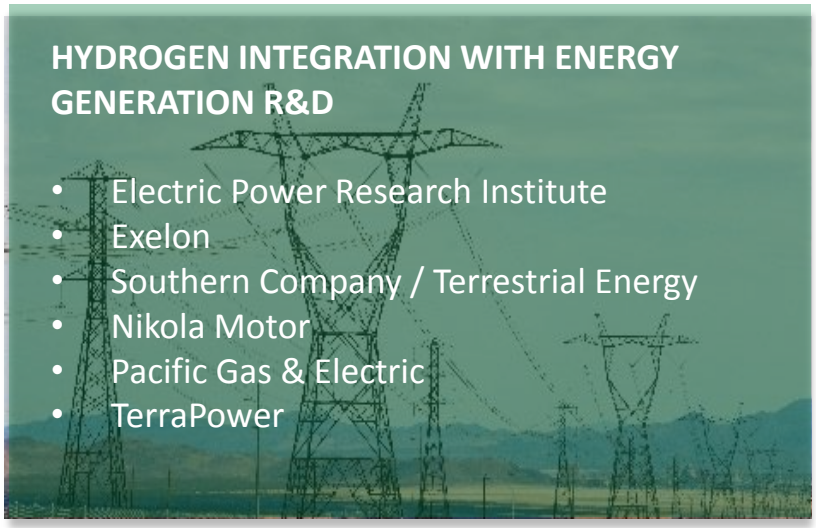
ADVANCED HYDROGEN PRODUCTION CONCEPTS R&D

- Honda
- C4-MCP, Inc.
- GinerELX
- GTA, Inc.



HYDROGEN INTEGRATION WITH ENERGY GENERATION R&D

- Electric Power Research Institute
- Exelon
- Southern Company / Terrestrial Energy
- Nikola Motor
- Pacific Gas & Electric
- TerraPower



Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · BERKELEY LAB · NREL NATIONAL RENEWABLE ENERGY LABORATORY · Pacific Northwest NATIONAL LABORATORY · Sandia National Laboratories · SRNL SAVANNAH RIVER NATIONAL LABORATORY OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS