U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

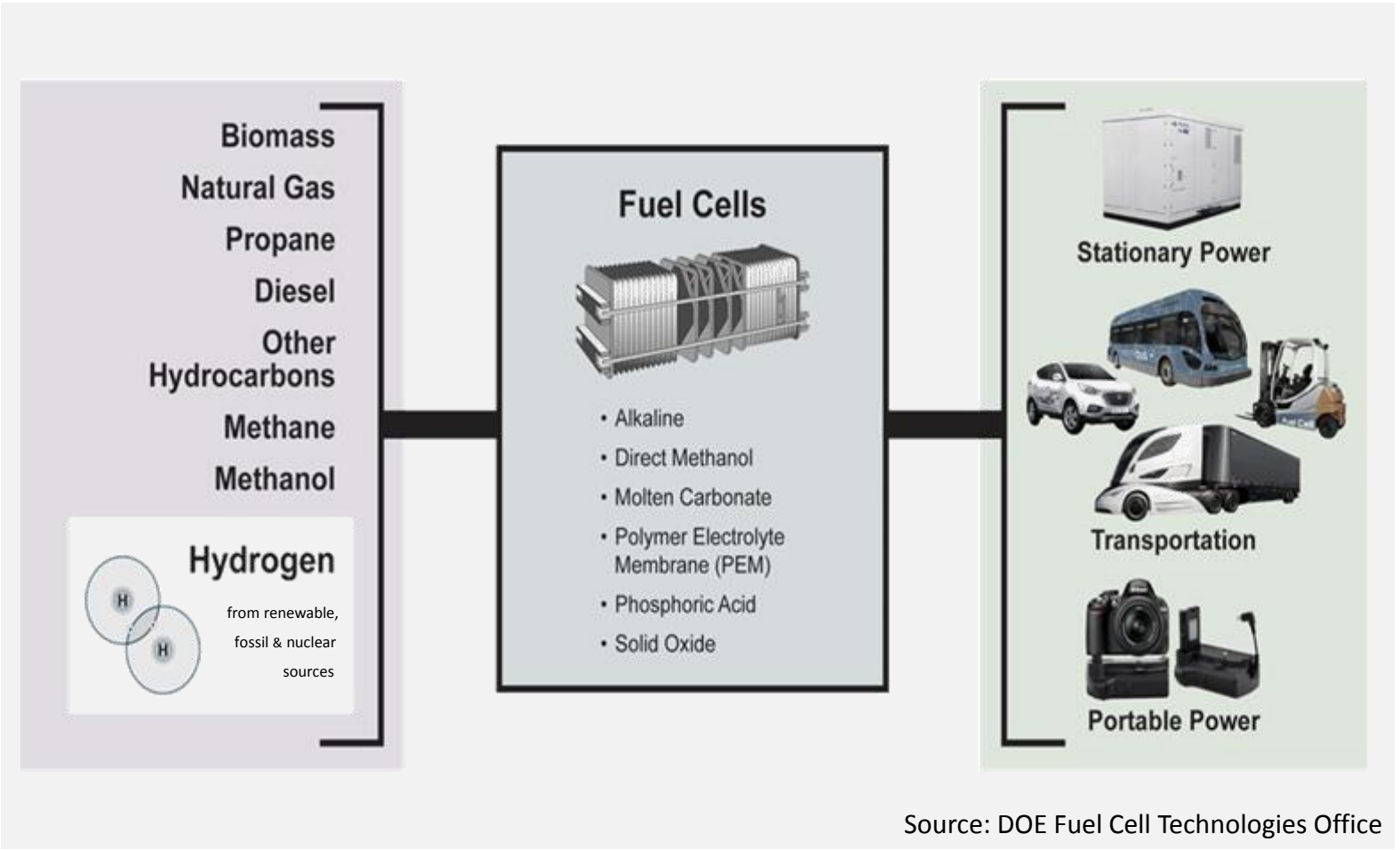
U.S. Department of Energy Hydrogen and Fuel Cell Technology Overview

Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office

FC EXPO 2018

Tokyo, Japan – March 1, 2018

The Versatility of Fuel Cell Technologies



Source: DOE Fuel Cell Technologies Office

Domestic Energy Sources

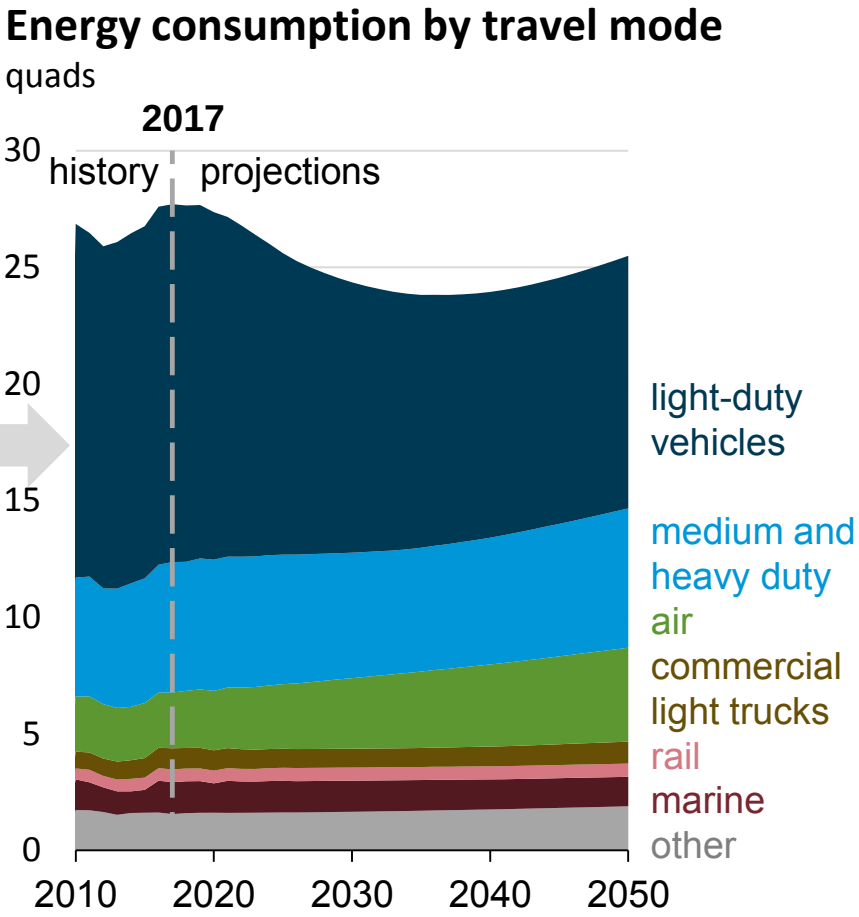
Clean, Efficient Energy Conversion

Multiple, Diverse and Versatile Uses

U.S. Transportation Sector

Over 90% of transportation sector relies on petroleum

Focus has been on light duty vehicles but interest is growing in other applications



Source: DOE EIA Annual Energy Outlook 2018

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….

Honda Clarity

Over **3,800** | **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

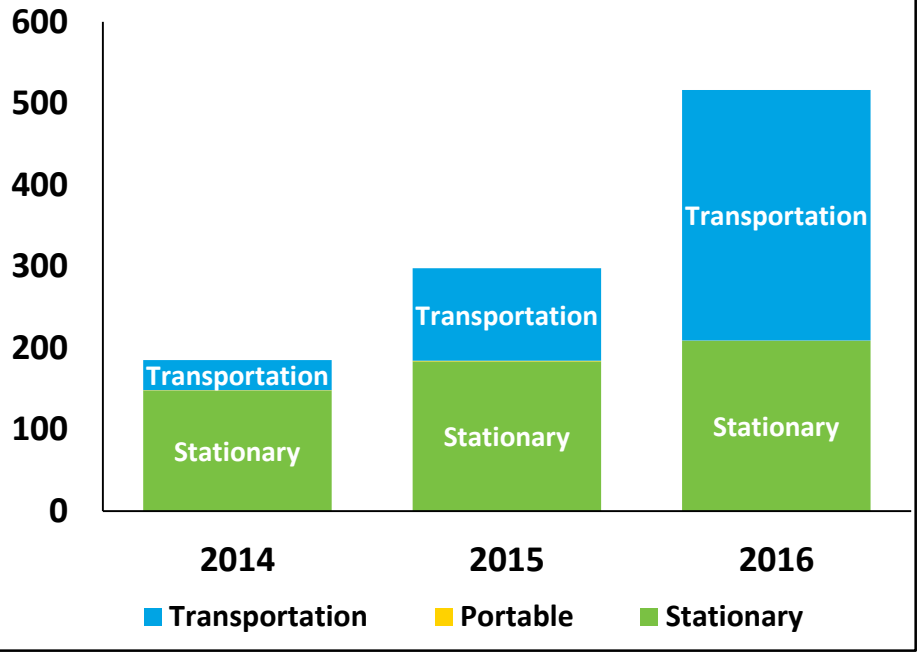
- No petroleum, no pollution
- Refuels in minutes
- More than 360 mi driving range
- Over 60 mpgge

Progress

Unprecedented Growth in the Fuel Cell Industry

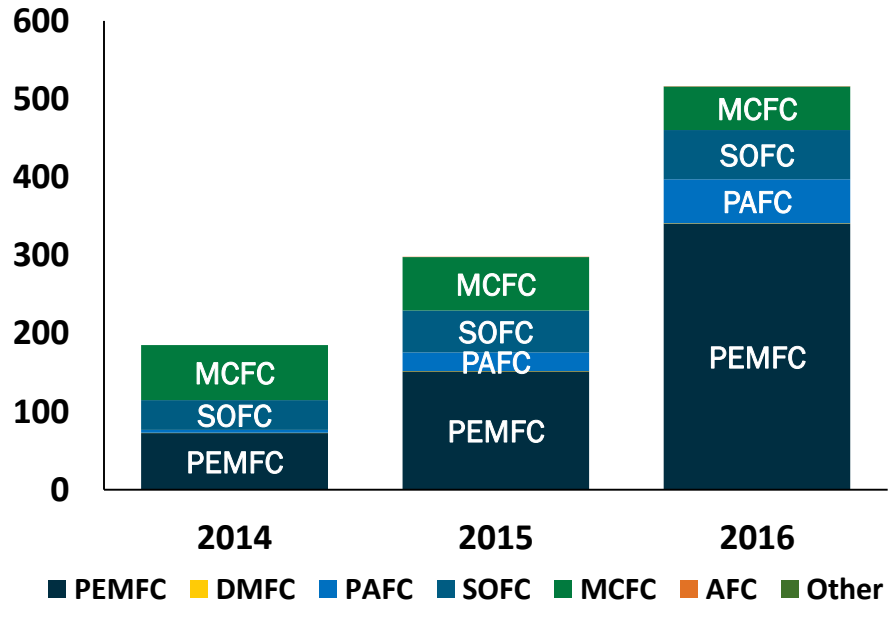
Total power (in MW) shipped by application

Growth in Transportation



Total power (in MW) shipped by fuel cell chemistry

Growth in PEMFC



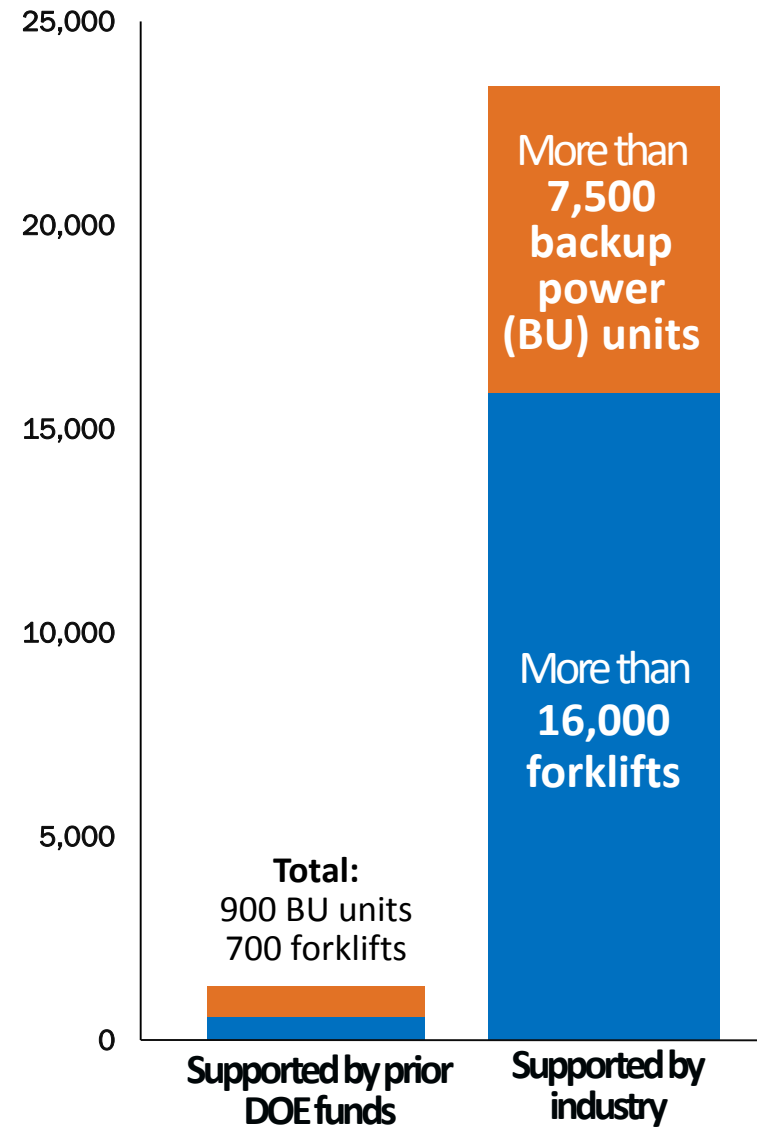
500 MW fuel cell power shipped worldwide

62,000 fuel cell units shipped worldwide

Approximately **$1.6 Billion** fuel cell revenue

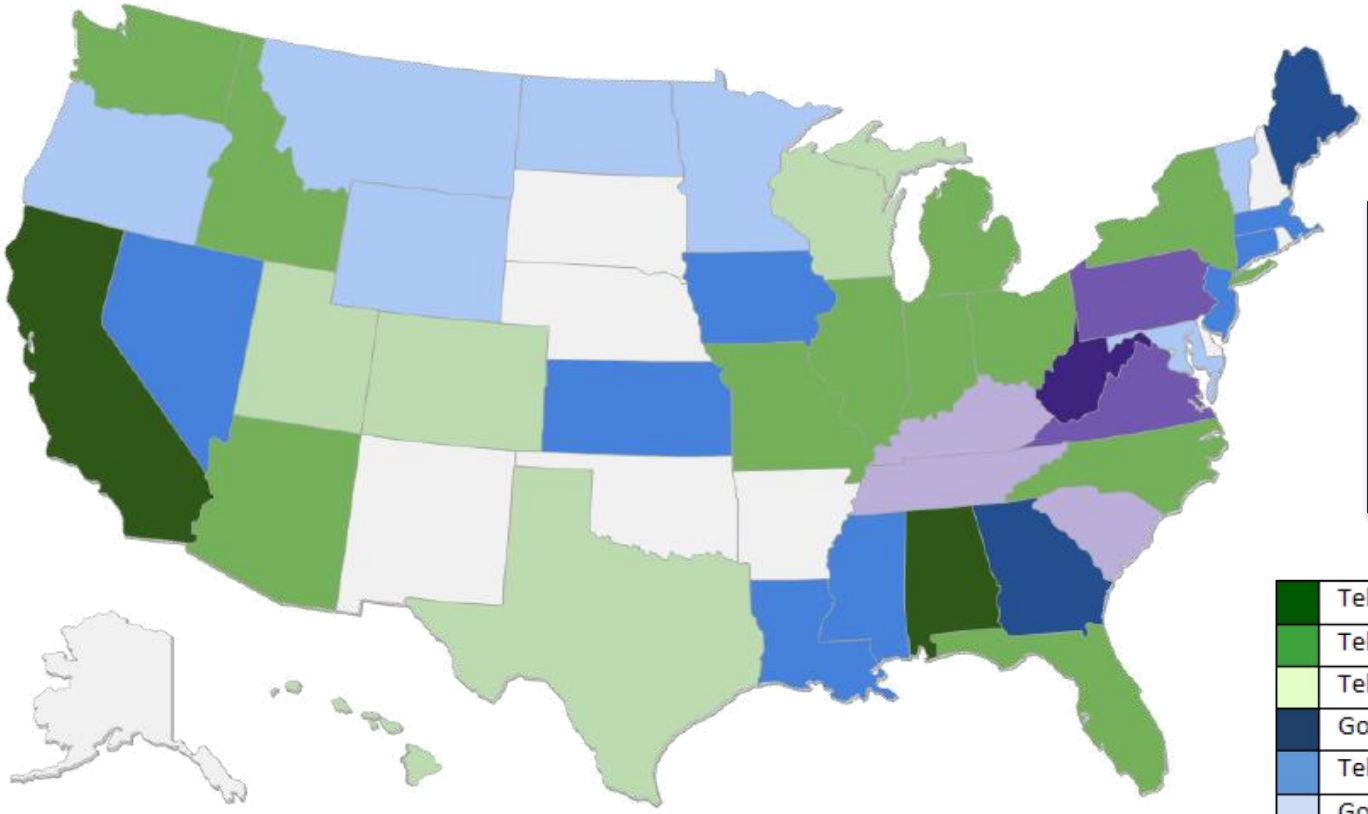
Source: DOE Fuel Cell Technologies Market Report. Available at: https://energy.gov/eere/fuelcells/market-analysis-reports

Forklifts and Backup Power Units on the Rise



Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states



Over 235MW

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

Bus and Long-Range, Heavy Duty Applications Emerging

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

Fuel cell buses in CA surpass 17M passengers

Industry demonstrates first heavy duty fuel cell truck in CA

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).

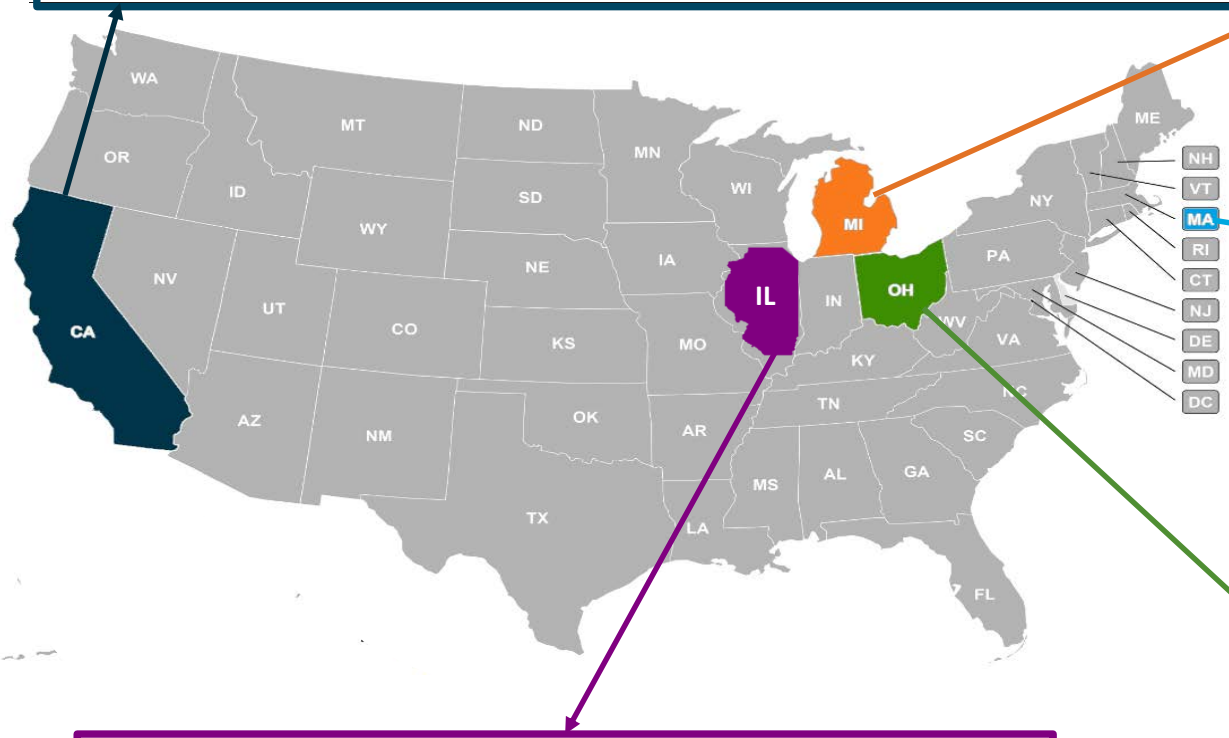
Planned: Over 30 Buses

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

Hydrogen and Fuel Cell Applications in the U.S.

U.S. Snapshot

>235MW
Backup Power

>16,000
Forklifts

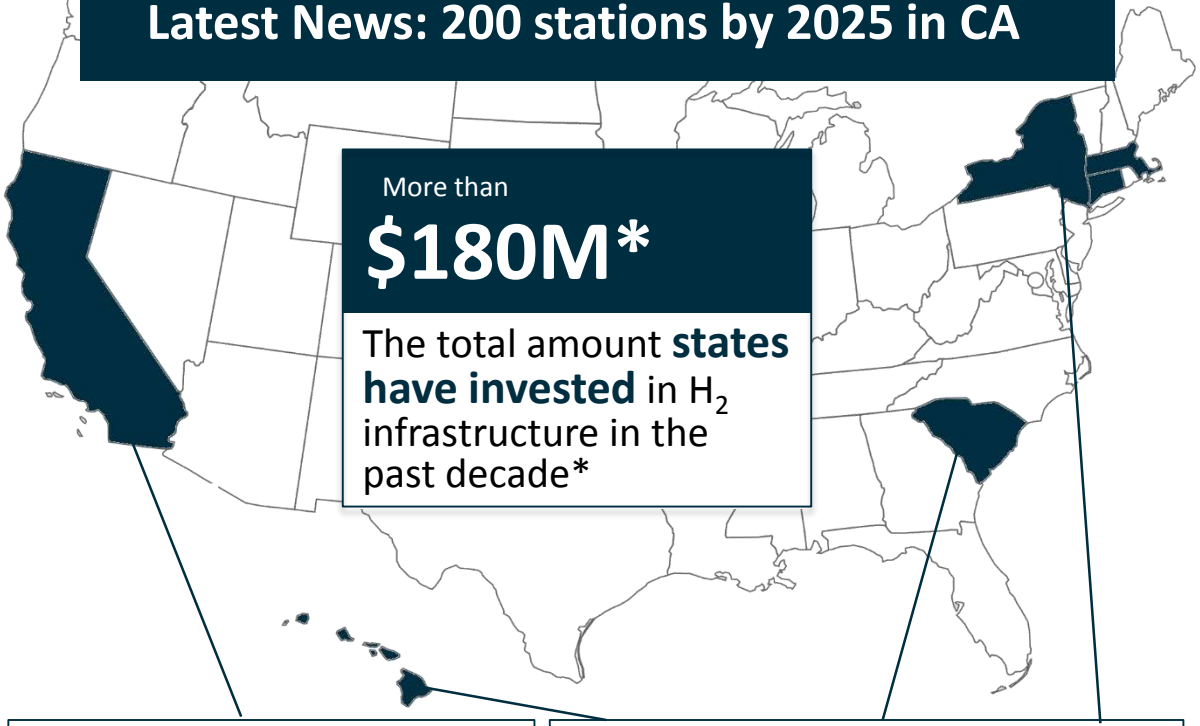
>25
Fuel Cell Buses

>30
H_2 retail stations

More than
3,800
fuel cell cars

Cumulative State Funding

Latest News: 200 stations by 2025 in CA



More than
$180M*

The total amount **states have invested** in H_2 infrastructure in the past decade*

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

HI, SC, NY, CT, MA and others
- Over $27M invested
- 12-25 stations planned in the NE

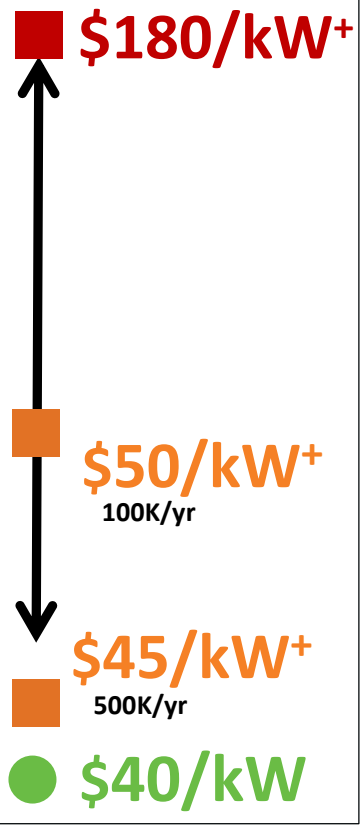
*Excludes recent announcement from CA to invest $235M in electric vehicles


Challenges
and Gaps

DOE Cost Status and Targets for R&D

Fuel Cell R&D

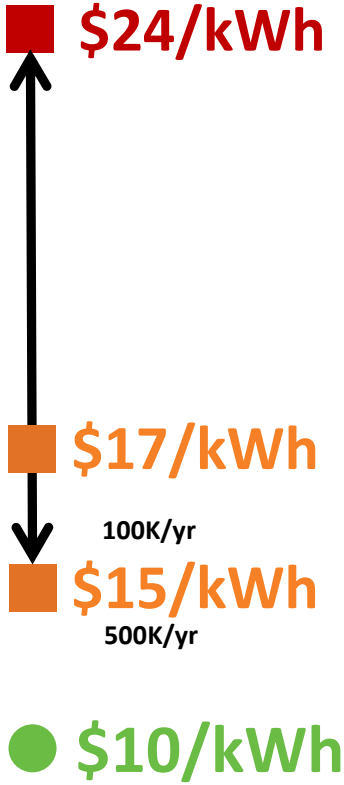
System



Hydrogen R&D

Production, Delivery & Dispensing

Onboard Storage
(*700-bar compressed system*)



Targets | High-Volume Projection | Low-Volume Estimate

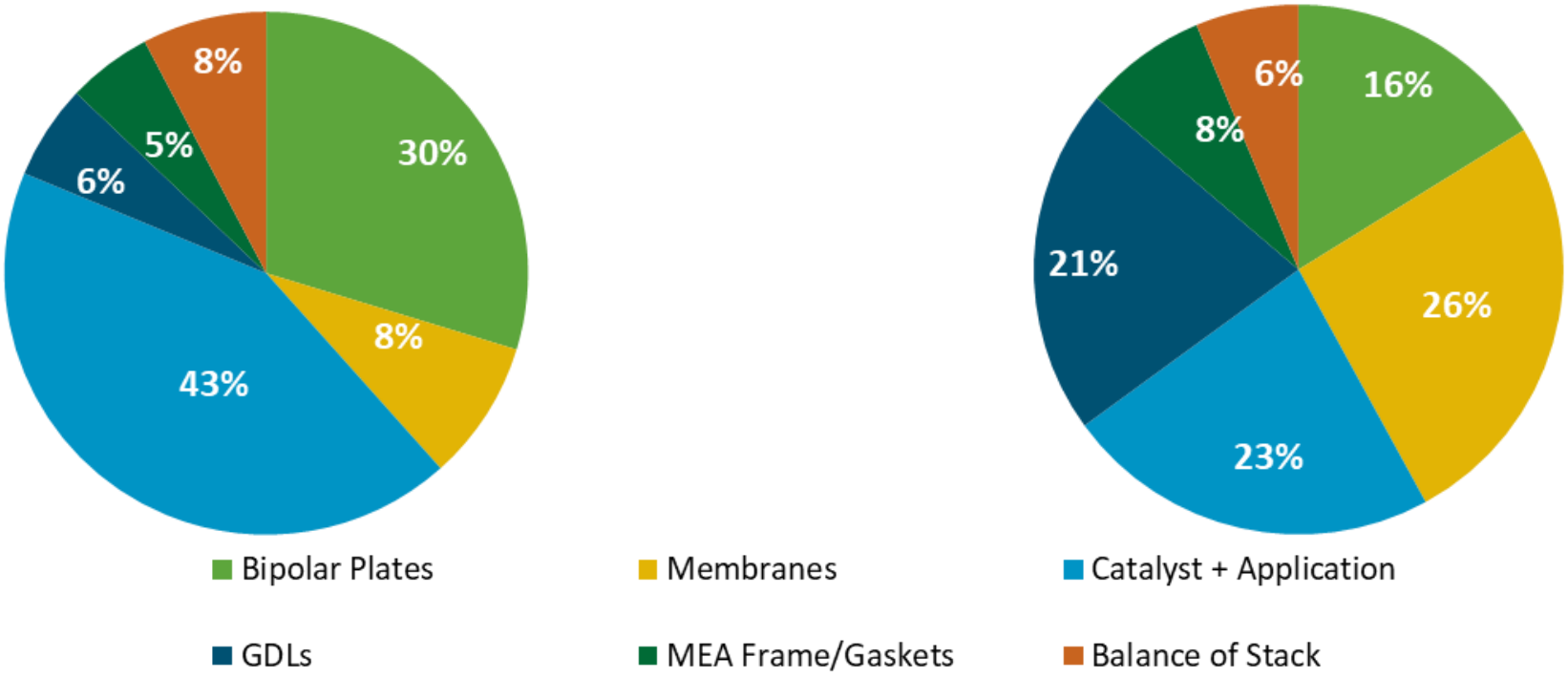
*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

Note: Graphs not drawn to scale and are for illustration purposes only.
Data through 2017

Fuel Cell Major Cost Components – Example

Cost contributors depend on manufacturing volumes & scale

Cost by Component – DOE Independent peer-reviewed analysis



High- Volume (500,000/yr)

Challenges: Catalyst and Bipolar Plates

Low- Volume (1,000/yr)

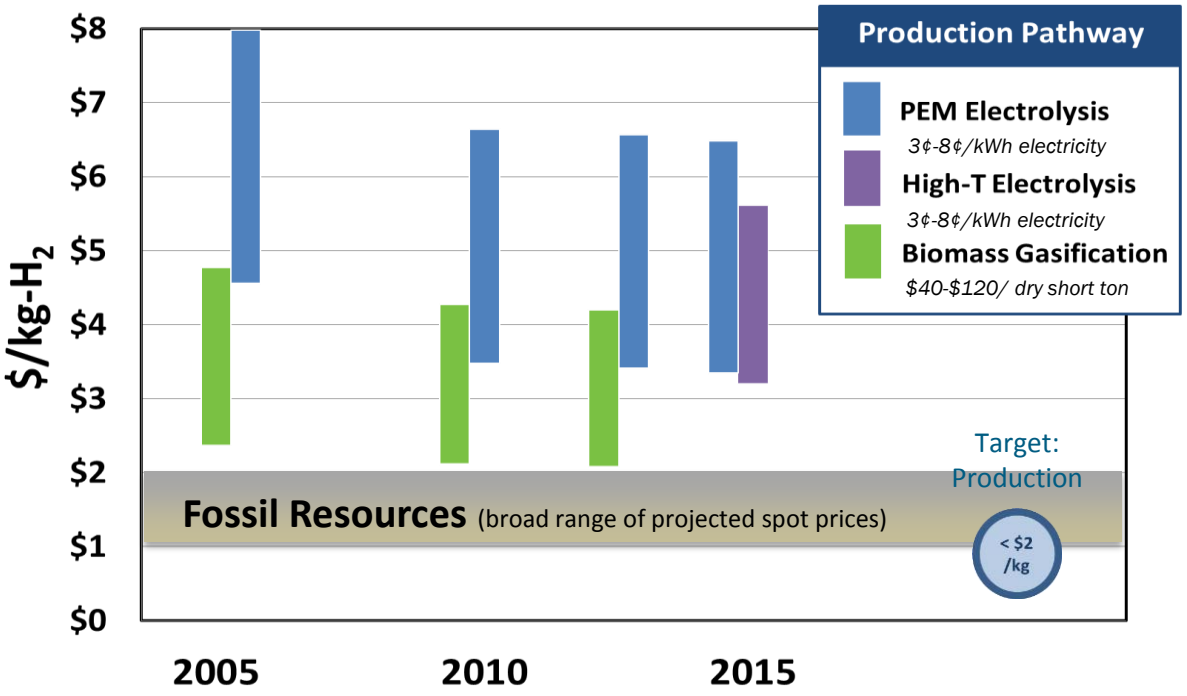
Challenges: Membrane, GDL, Catalyst

**https://www.hydrogen.energy.gov/pdfs/15015_fuel_cell_system_cost_2016.pdf*

Hydrogen Production

Production cost goal: <$2/kg (excludes delivery, storage, dispensing)

Projected Production Cost* by Pathway



*Ranges with sensitivities to feedstock price variations

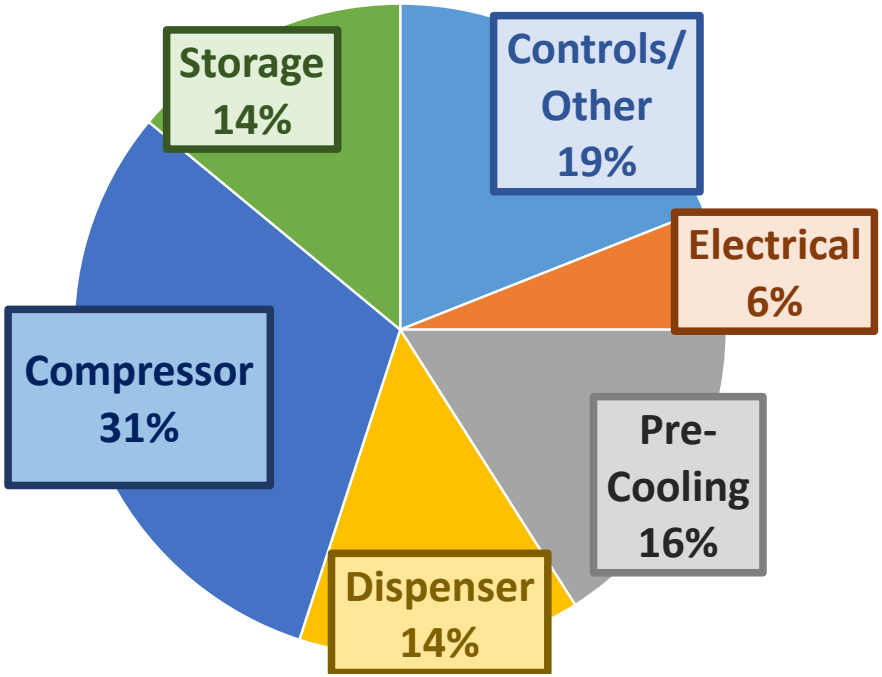
Early Stage R&D Examples

- Innovative Reactor Concepts
- Novel Devices and Components
- Materials Development
- PEC, thermochemical methods, advanced electrolysis, biological methods

Hydrogen Delivery

Delivery cost goal: <$2/kg** (includes dispensing at the station)

Cost by Component
Tube Trailer Delivery Example



Early Stage R&D Examples

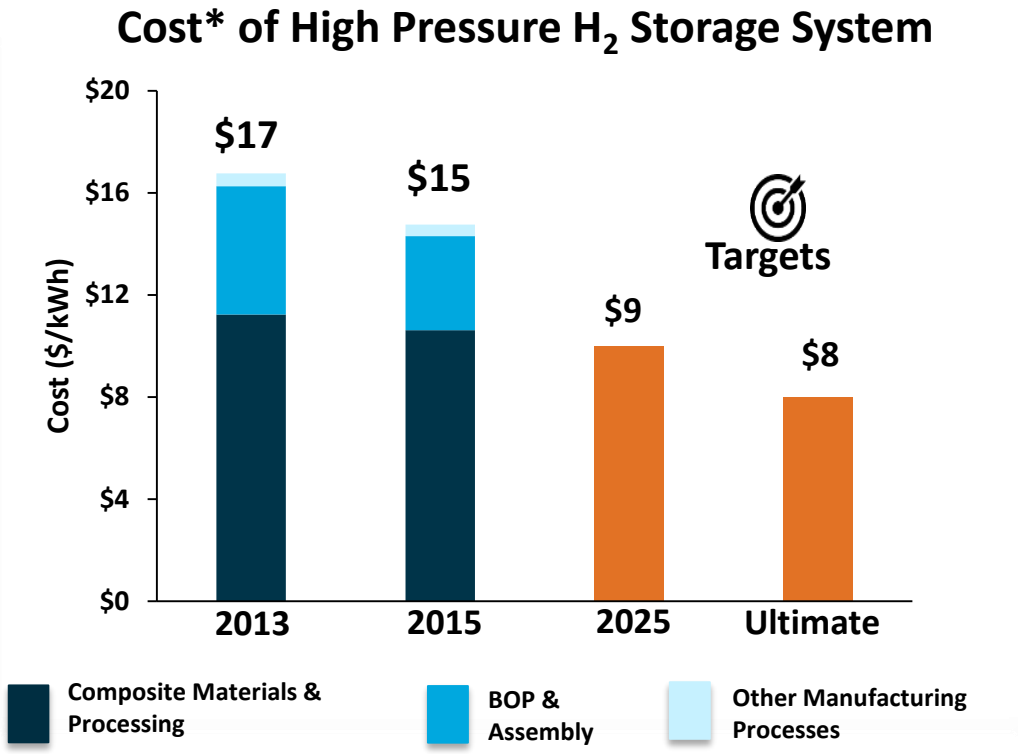
Innovative concepts on:

- Gaseous & Liquid Delivery
- Compressors
- Storage
- Dispensers
- Materials Compatibility
- Liquefaction
- Pipeline & joining materials
- Other innovations (e.g. liquid carriers, etc.)

**gge = gallon of gasoline equivalent

Hydrogen Storage

Storage goal: <$8/kWh, > 300 mile range, no space compromises



Early Stage R&D Examples

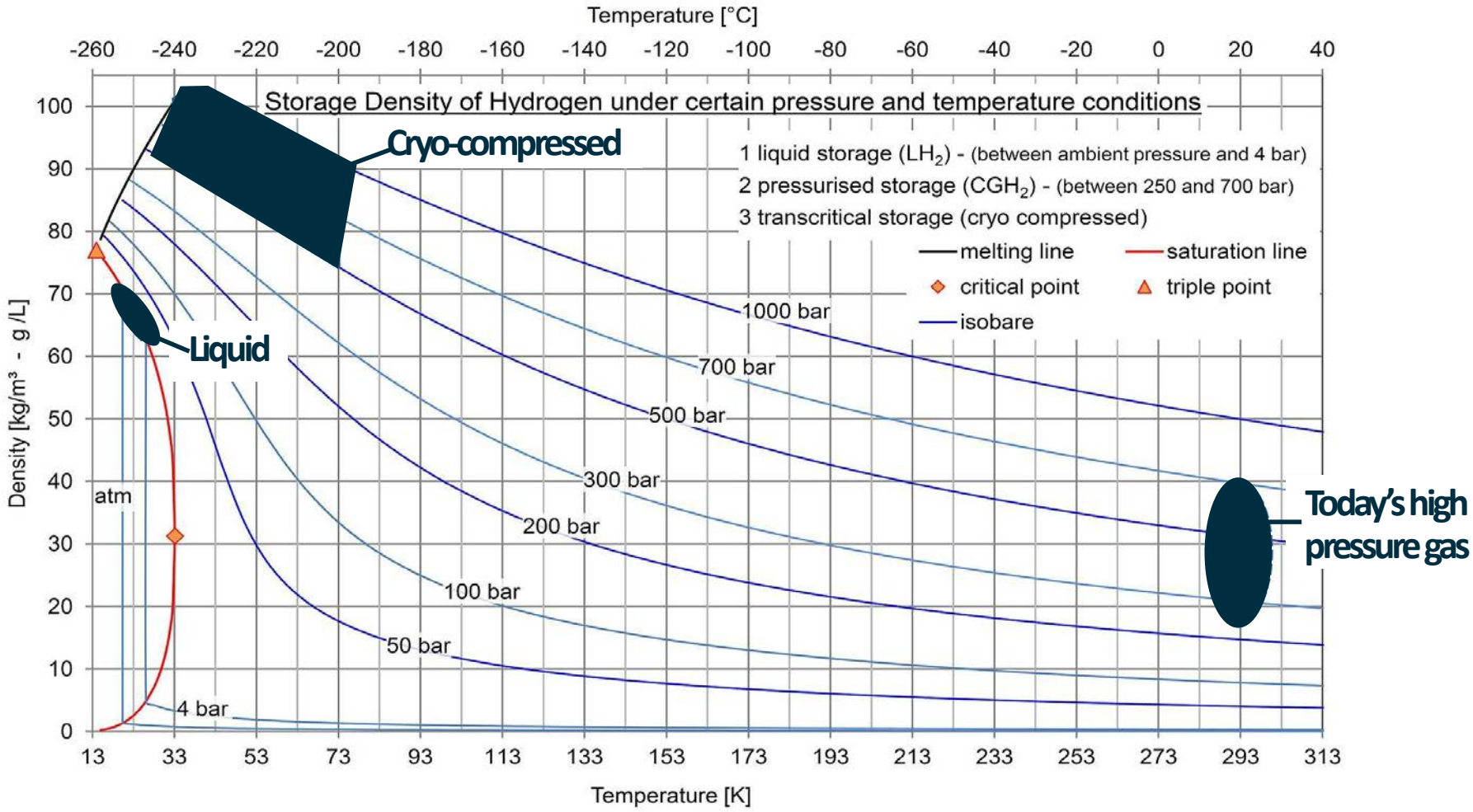
- **Low- cost carbon fiber precursors** for high pressure H_2 storage
- **Advanced hydrogen storage materials** with higher energy densities and favorable thermodynamics

Still need to increase storage density

*Assumes high volume (500K/yr.), 2007$, 700-bar type IV single tank system.
Based on program record 15013

Example: Potential Option for Heavy Duty Vehicles

Cryo-compression can offer densities higher than liquid hydrogen



https://en.wikipedia.org/wiki/Hydrogen_storage#/media/File:Storage_Density_of_Hydrogen.jpg

The Hydrogen Infrastructure Challenge

- Cost
- Reliability
- Availability

What can we learn from history?

Fuel was made widely available

before

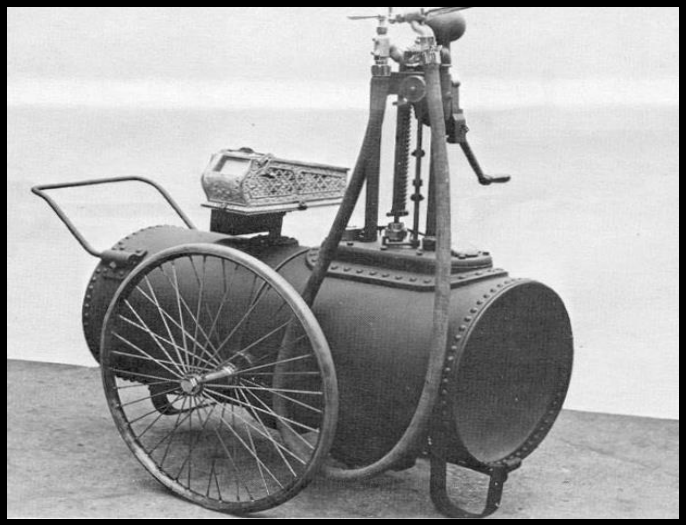
the retail stations of today

Gasoline History: Many diverse options

Cans, barrels, home models, mobile refuelers

Source: M. Melaina 2008.

Source: Vieyra, 1979



Source: Milkues, 1978

Complementing Retail Stations: H2Refuel H-Prize

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

www. hydrogenprize.org

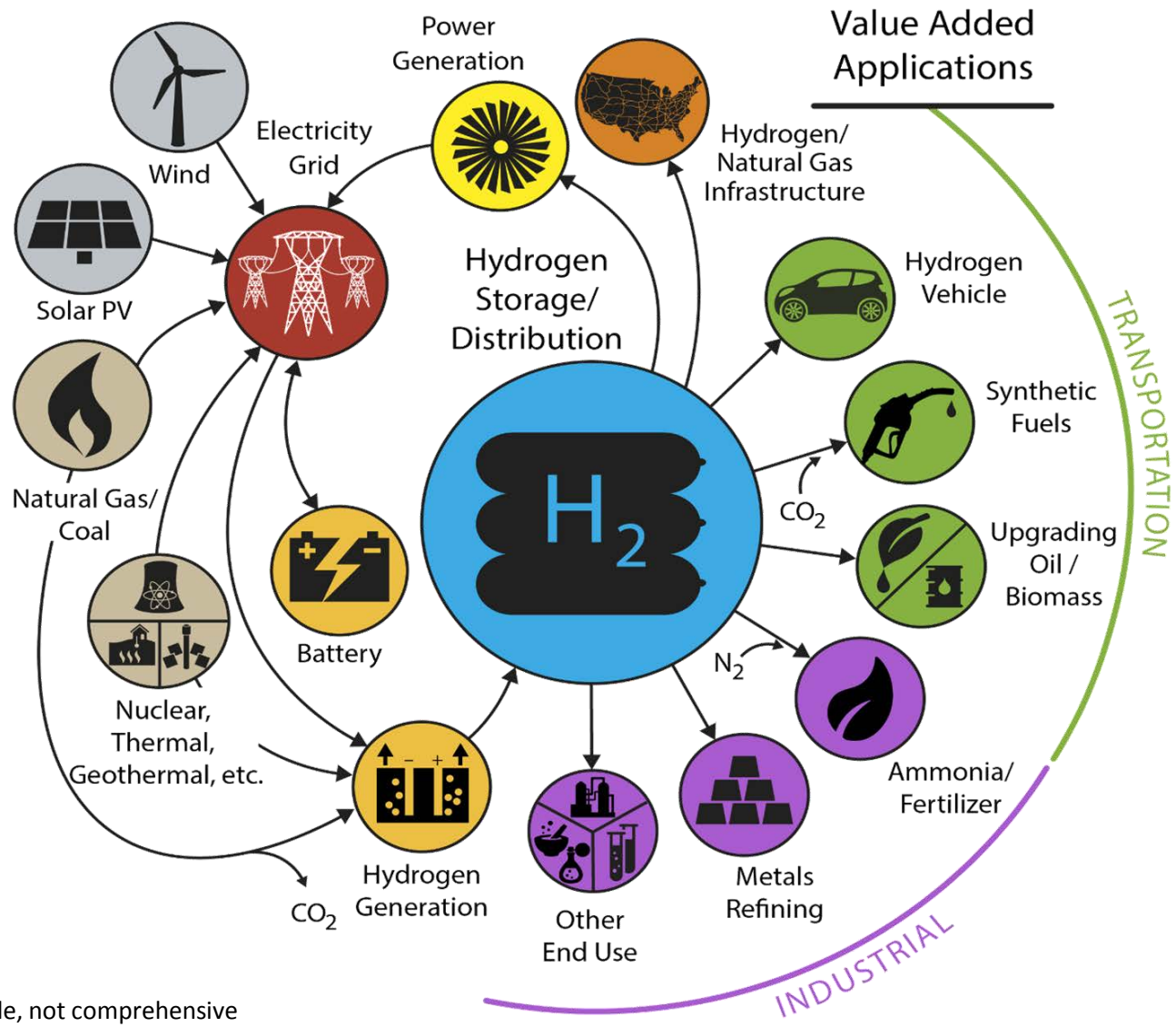
simple.fuel.™

Email: connect@ivysinc.com
More info: www.teamsimplefuel.com

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

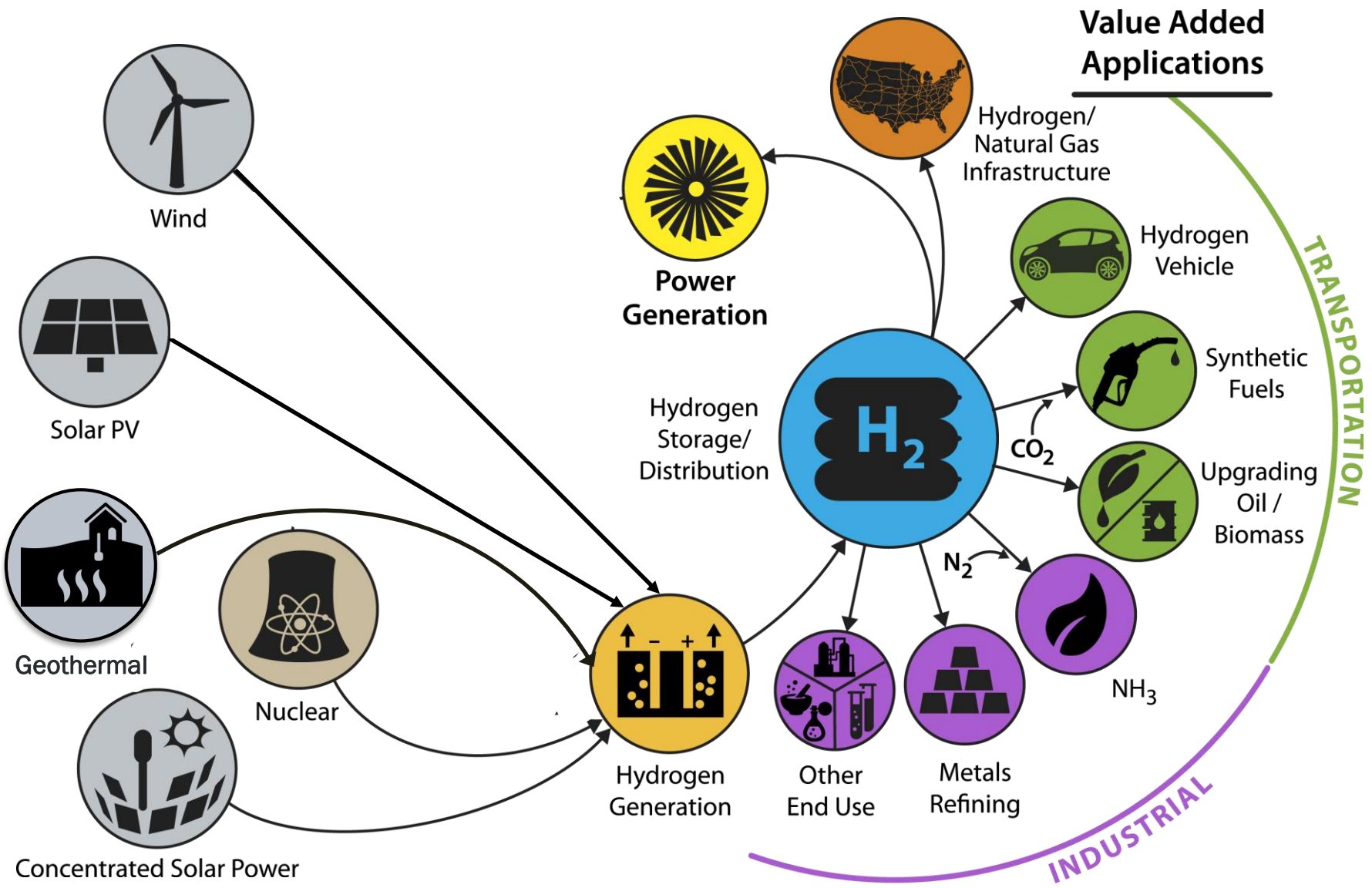
Opportunities and Focus Areas "H2@Scale"

H2@Scale Energy System



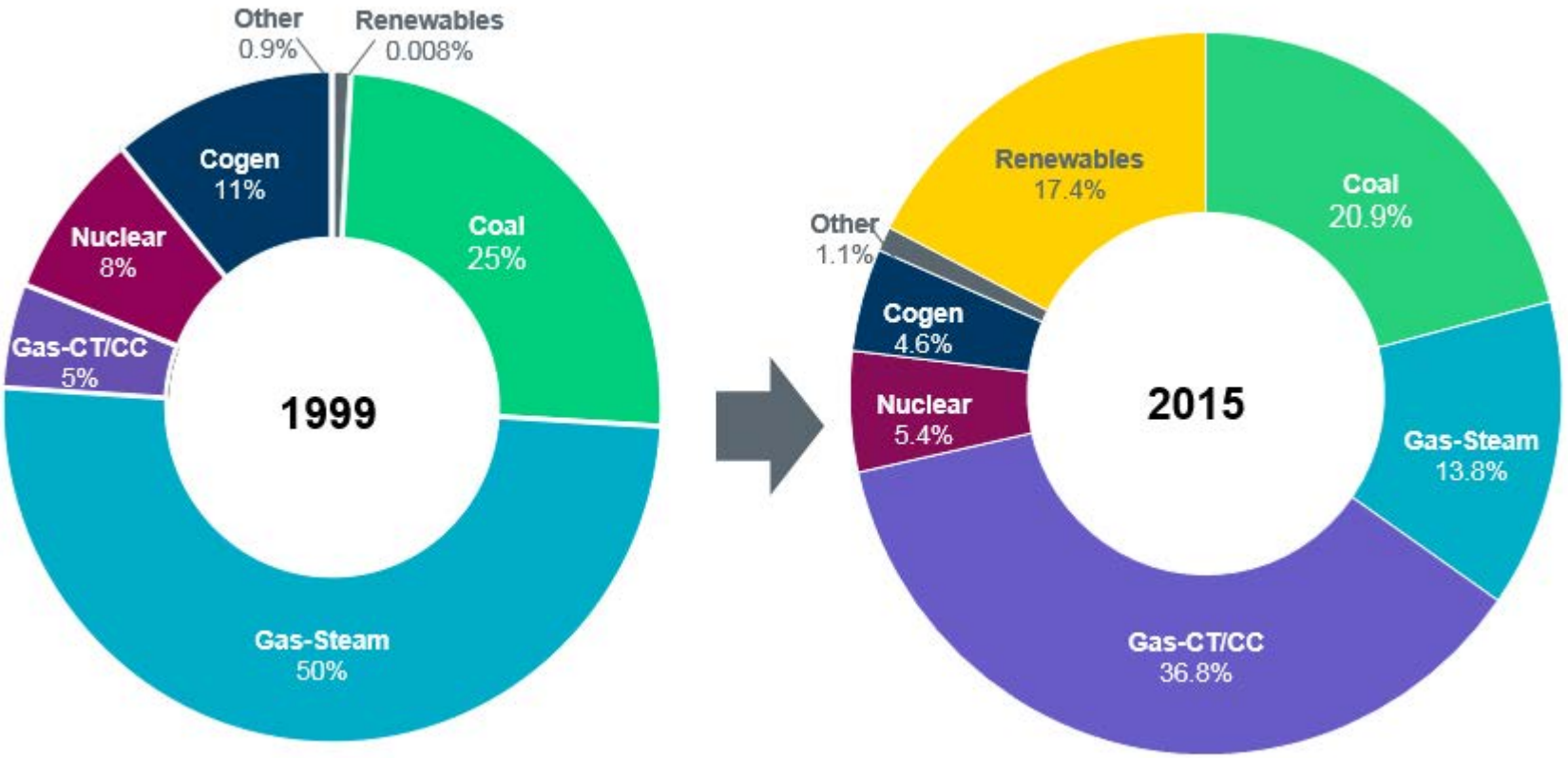
*Illustrative example, not comprehensive
Source: NREL

H2@Scale Energy System



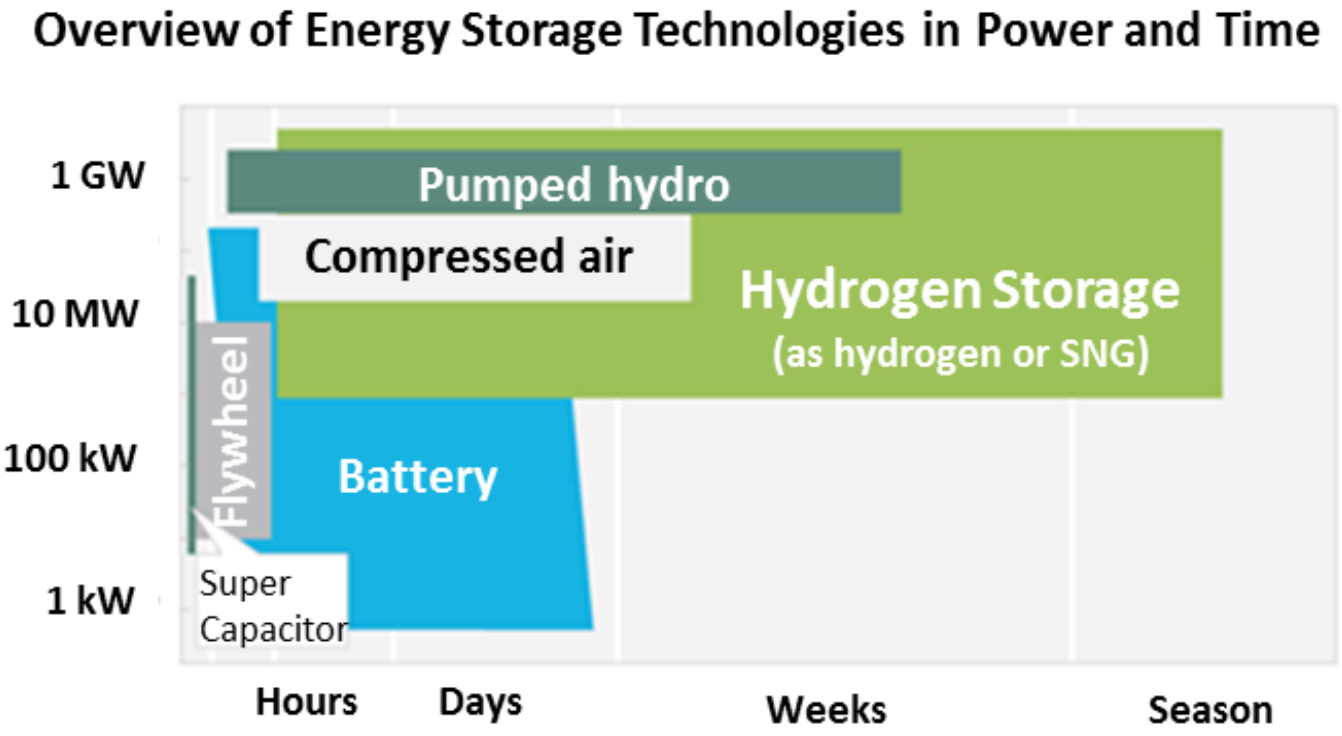
Electricity Mix Landscape is Changing- Example

Example: Installed Capacity in Texas



Source: ERCOT

Hydrogen Energy Storage is Scalable



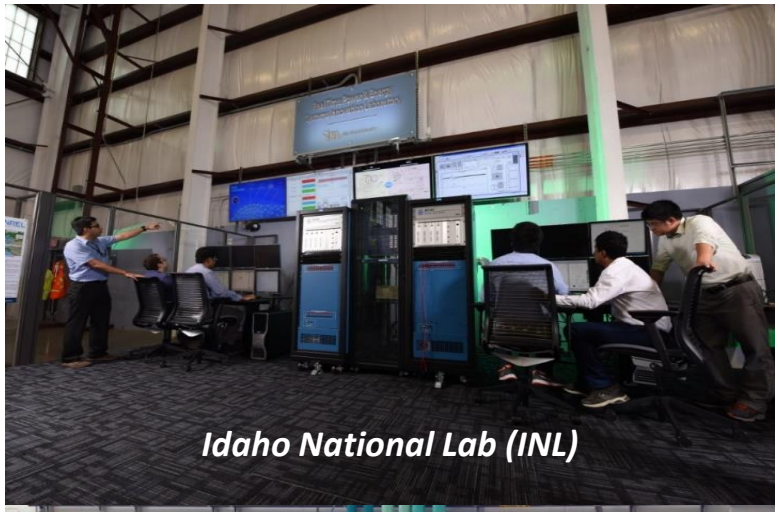
One hydrogen cavern could provide **~ 100 GWh energy storage**

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.

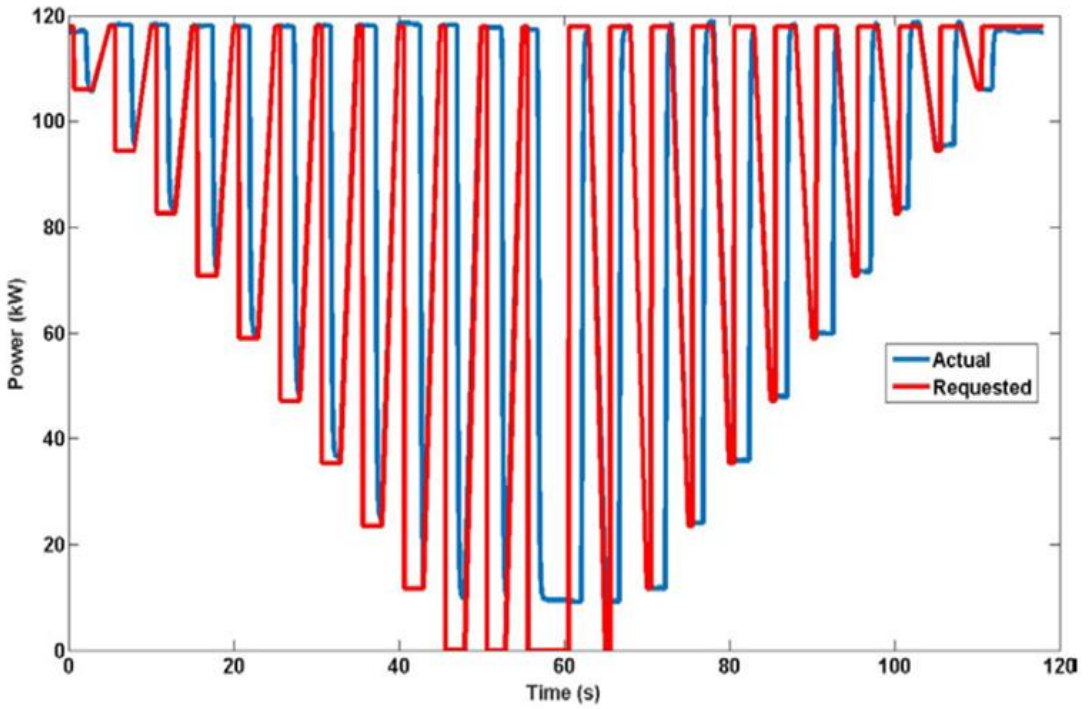
DOE National Lab R&D Test Lab Examples

First Ever Validation of Frequency Regulation with Electrolyzers



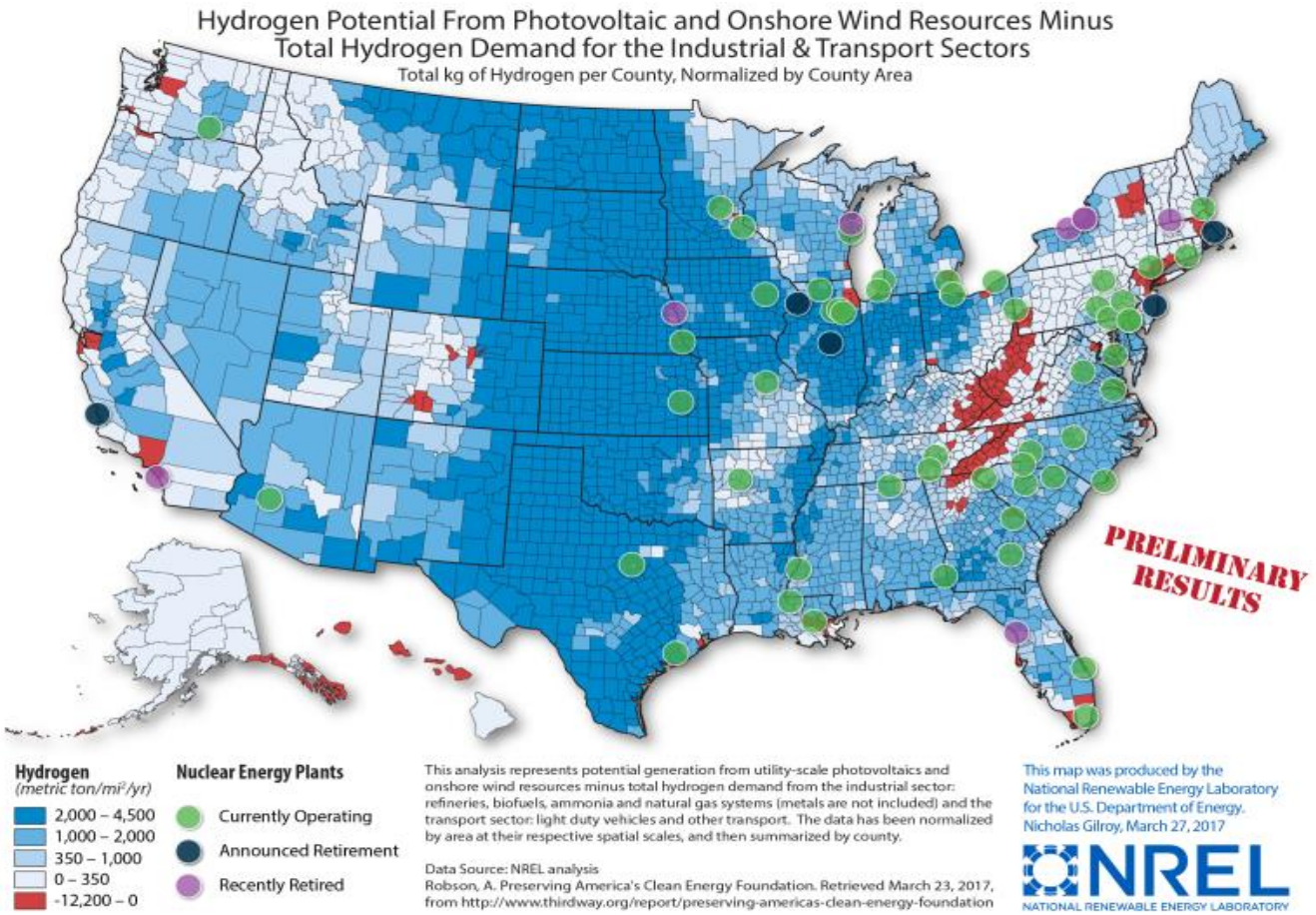
Idaho National Lab (INL)

National Renewable Energy Lab (NREL)



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

H2@Scale: Nationwide Resource Assessment



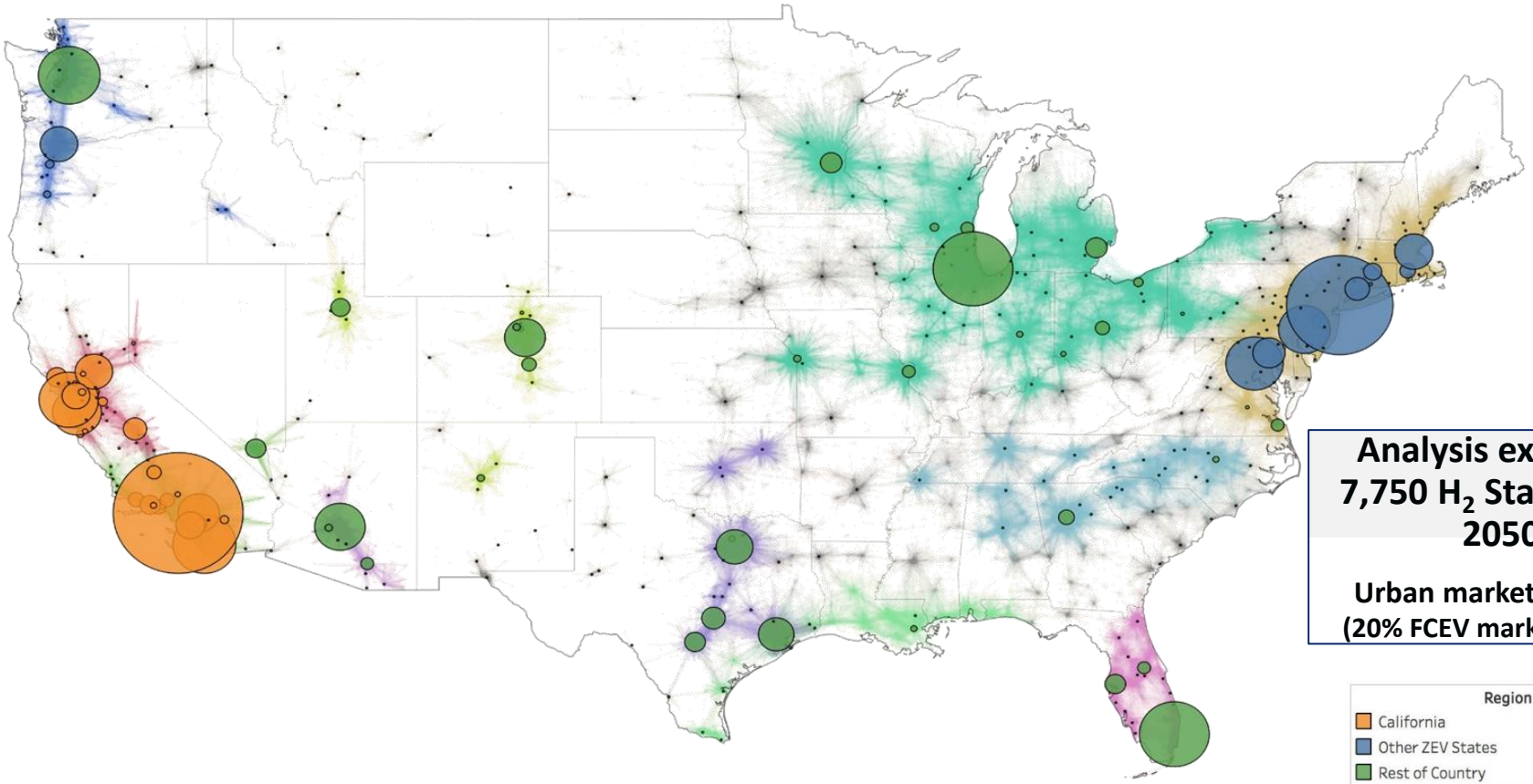
Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

Labs assess resource availability. Most regions have sufficient resources.

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

Hydrogen Station Analysis - Example

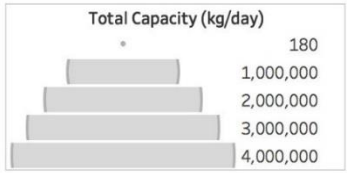
NREL's Station Rollout Scenario Analysis in support of H_2USA



Analysis example: 7,750 H_2 Stations by 2050

Urban markets scenario (20% FCEV market share*)

*Nationwide

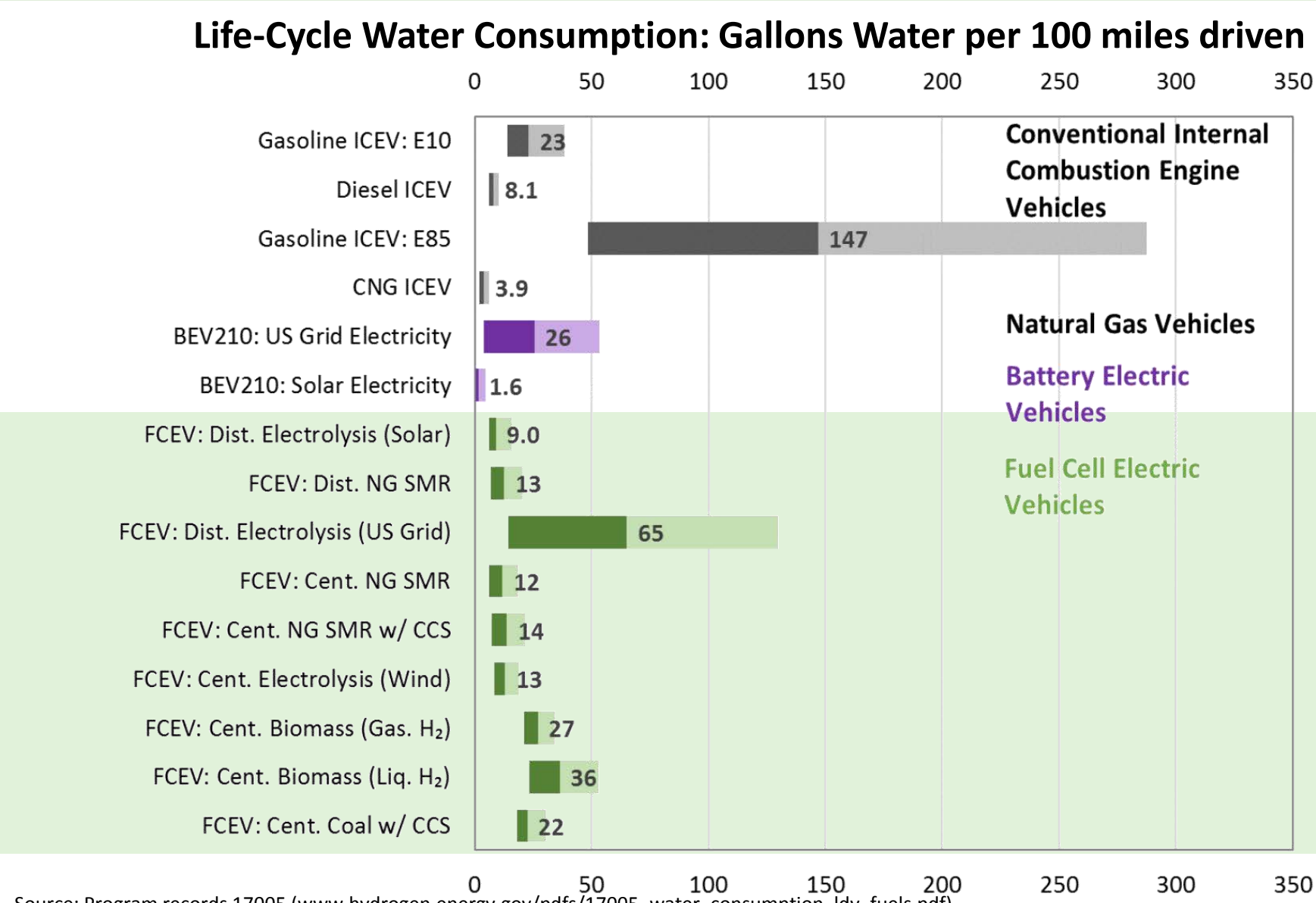


Examples of variables considered in scenarios:

- Consumer adoption
- Station Expansion Network

Source: Marc Melaina, et al, NREL

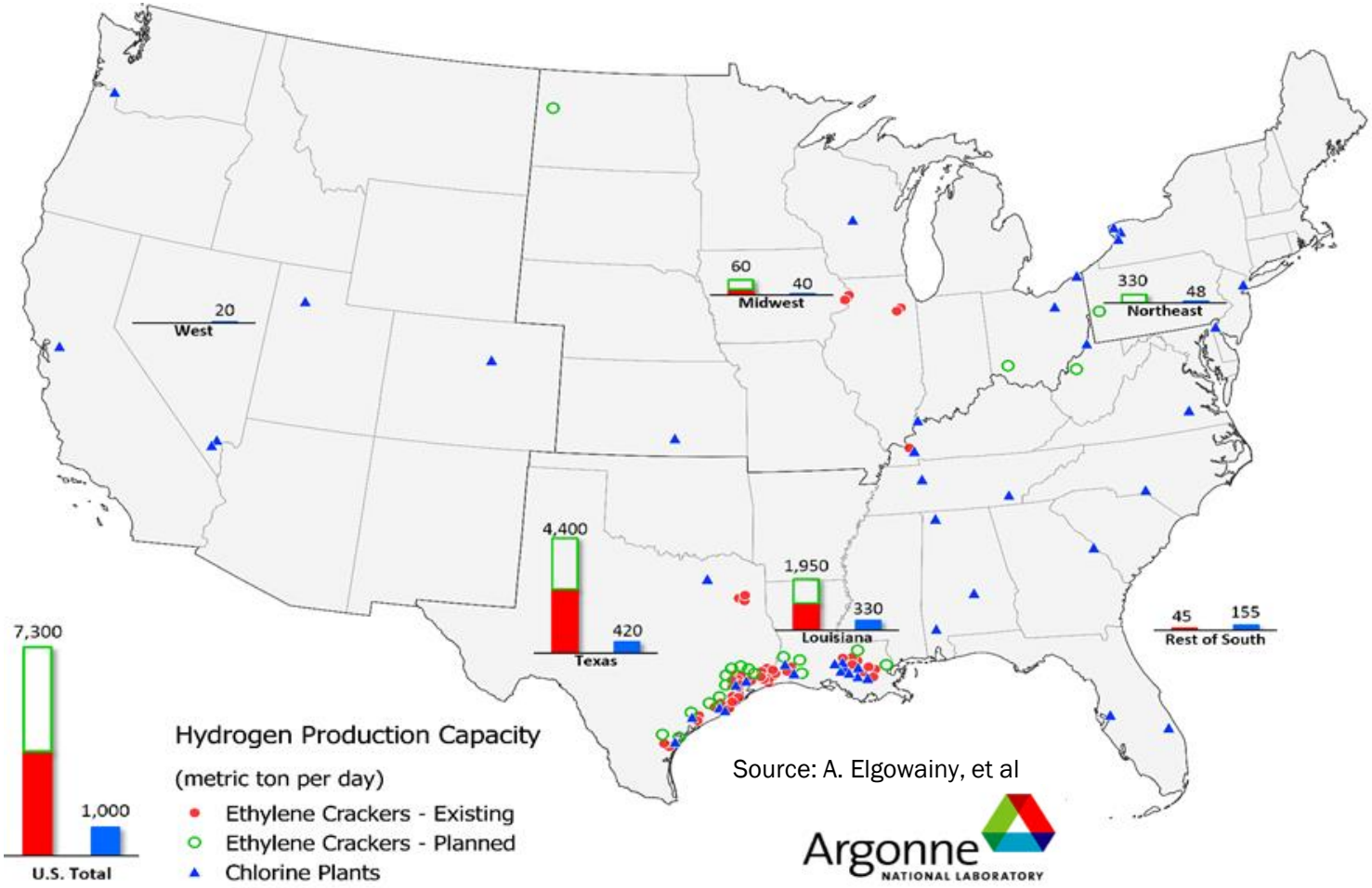
Water Consumption Analysis



Source: Program records 17005 (www.hydrogen.energy.gov/pdfs/17005_water_consumption_ldv_fuels.pdf)

Argonne Analysis on Byproduct Hydrogen

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

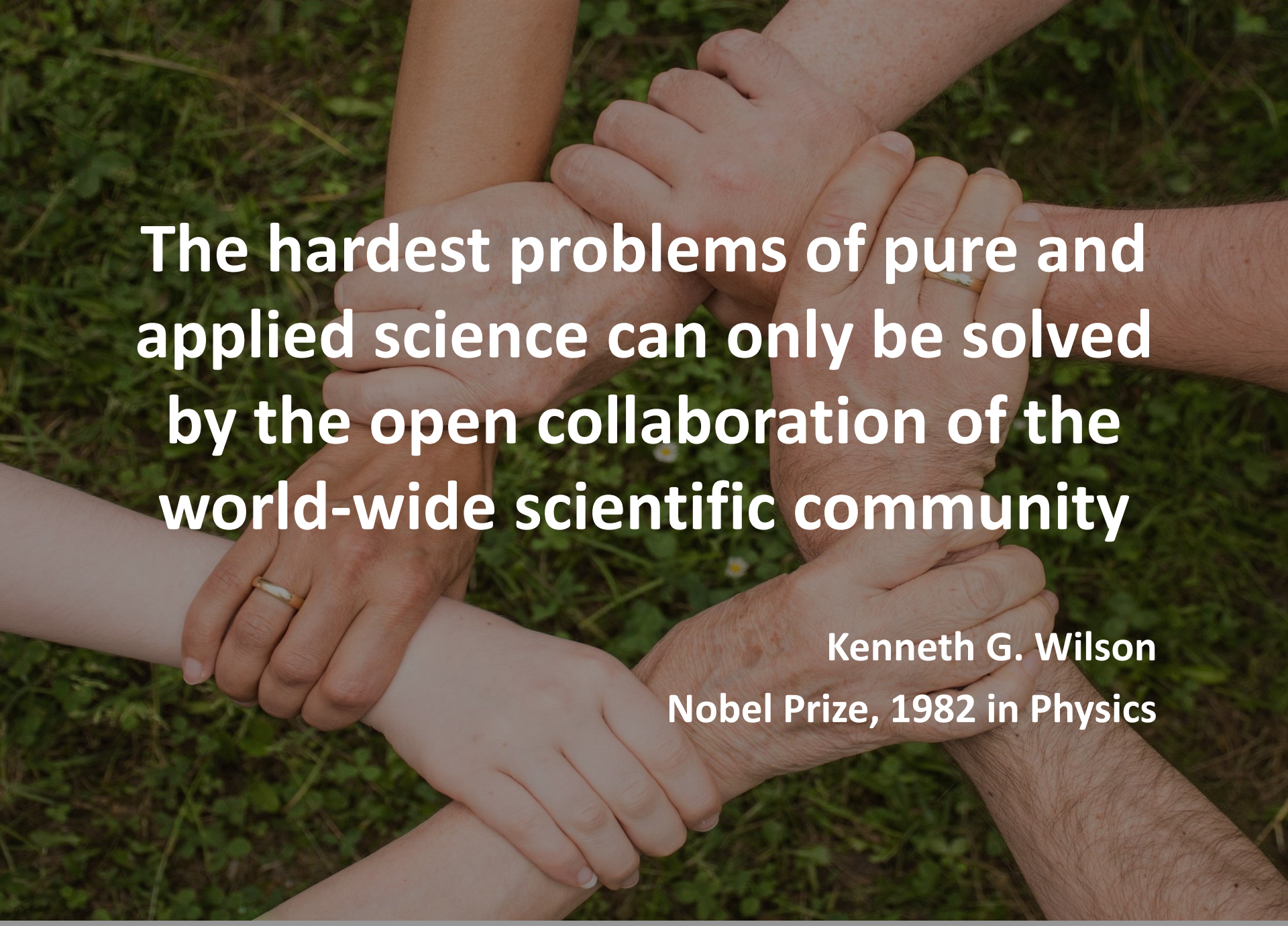


Existing hydrogen byproduct production capacity could serve

8 Million hydrogen fuel cell cars

=1M fuel cell cars

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

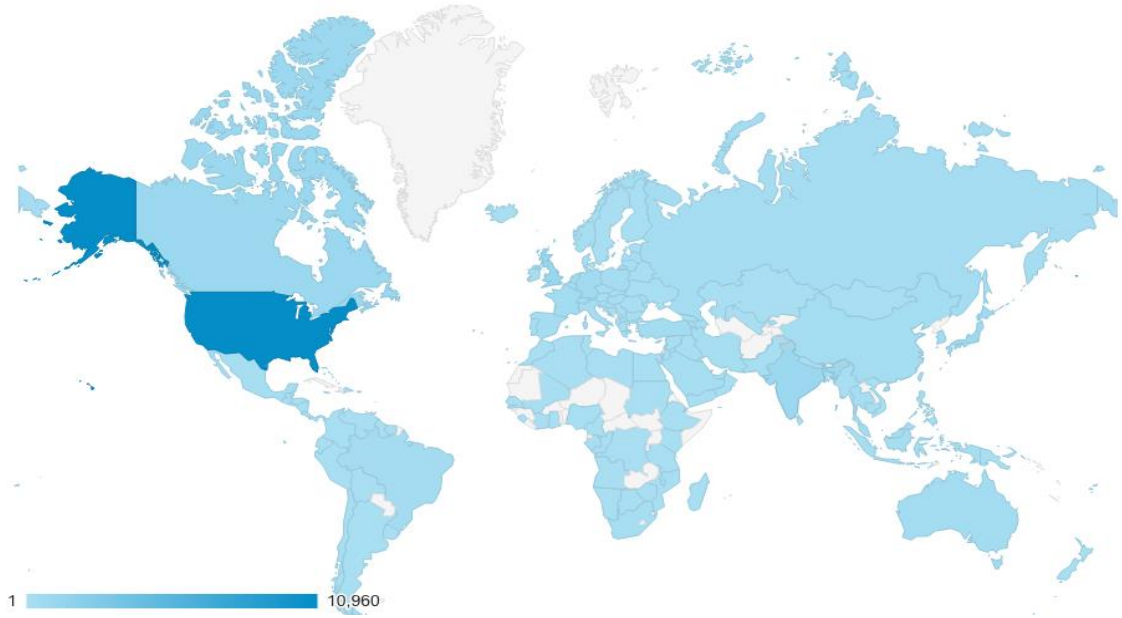

The hardest problems of pure and applied science can only be solved by the open collaboration of the world-wide scientific community
Kenneth G. Wilson
Nobel Prize, 1982 in Physics

Collaboration Tools: H_2 Safety Information Sharing

H_2Tools.org : A one stop resource for hydrogen safety

h2tools.org

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



- Site visit tracking shows a **global reach: 50%** of visits have been **international after launch**
- Over **150,000 site visits**
- Training resource **translated into Japanese. Interest in other languages.**

Recently Announced!

NEDO 国立研究開発法人
新エネルギー・産業技術総合開発機構

ホーム >ニュース >ニュースリリース一覧 > 米国エネルギー省とF･･･

News Release

米国エネルギー省とFCV・水素ステーション普及拡大に向けた情報交換の実施に合意

―日米の連携強化を目指す―

2017年10月10日

国立研究開発法人新エネルギー・産業技術総合開発機構
理事長 古川一夫

NEDOは10月10日、米国エネルギー省燃料電池技術室(DOE FCTO: Fuel Cell Technologies Office)と、燃料電池自動車(FCV)・水素ステーションの普及拡大に向け、情報交換を積極的に実施していくことに合意しました。
NEDOとDOE FCTOはFCVおよび水素ステーションの普及のための市場環境整備促進に向けて、共同ワークショップ開催などを通じて両国で取り組んできたFCV・水素ステーションに関する安全性や規制・基準、運用などに関する情報共有を進め、本分野における連携強化を図っていきます。

Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

FUEL CELL TECHNOLOGIES OFFICE

Energy Department Partners with Japanese Counterpart to Accelerate Hydrogen and Fuel Cell Technologies

OCTOBER 10, 2017

Japan-US and Global Collaboration in Action!

2013 Steering Committee Meeting Fukuoka, Japan *(left)*

2015 US DOE Annual Merit Review (AMR) Washington D.C. , USA *(lower left)*

2015 FC Expo Tokyo, Japan *(lower middle)*

2017 DOE *(lower right)*

International Inter-Governmental Partnership

- **Enables monitoring of global landscape**
- **Sharing** information on H_2 and fuel cells
- **Increases** international **collaboration**
- **Sharing** lessons learned

IPHE
International Partnership for Hydrogen and Fuel Cells in the Economy


Australia


Austria


Brazil


Canada


China


European Commission


France


Germany


Iceland


India


Italy


Japan


Republic of Korea


Norway


Russian Federation


South Africa


United Kingdom


United States

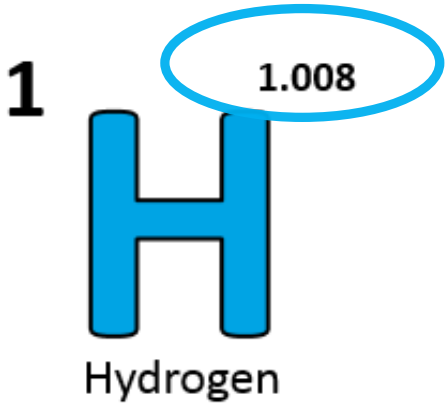
Launched 2003 and includes 18 countries and the European Commission

Collaboration Tools: Increasing Awareness

National Hydrogen & Fuel Cell Day

October 8 or 10/8

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



Save the Date

June 13-15, 2018

DOE AMR

Washington DC

First time ever

All Agencies working on hydrogen and fuel cell technologies at Annual Merit Review (AMR)

See www.hydrogen.energy.gov

Learn more:

energy.gov/eere/fuelcells

INCREASE YOUR H_2IQ

Download slide decks for free at at:

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

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energy.gov/eere/fuelcells