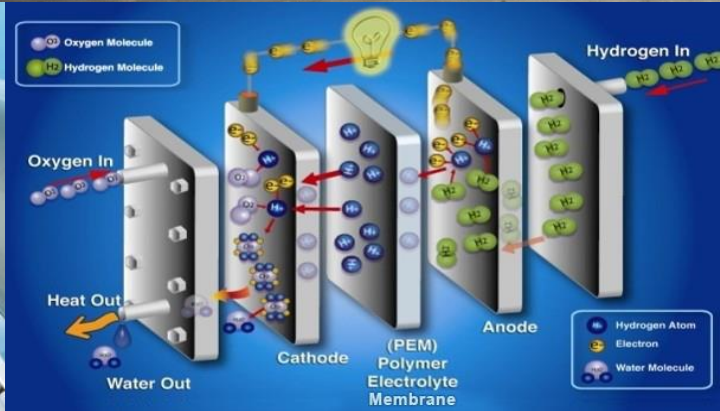


U.S. Department of Energy Hydrogen and Fuel Cells Program

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



2016 Annual Merit Review and Peer Evaluation Meeting

Washington, DC

June 6, 2016

Dr. Sunita Satyapal

Director
Fuel Cell Technologies Office
U.S. Department of Energy

- **History**
- **Progress**
- **Future**



Active in social media?
Share your thoughts using:

#H2AMR

#H2IQ

Fuel Cells: Big Leaps in the Last Year



Hyundai Tucson Fuel Cell SUV



Toyota Mirai

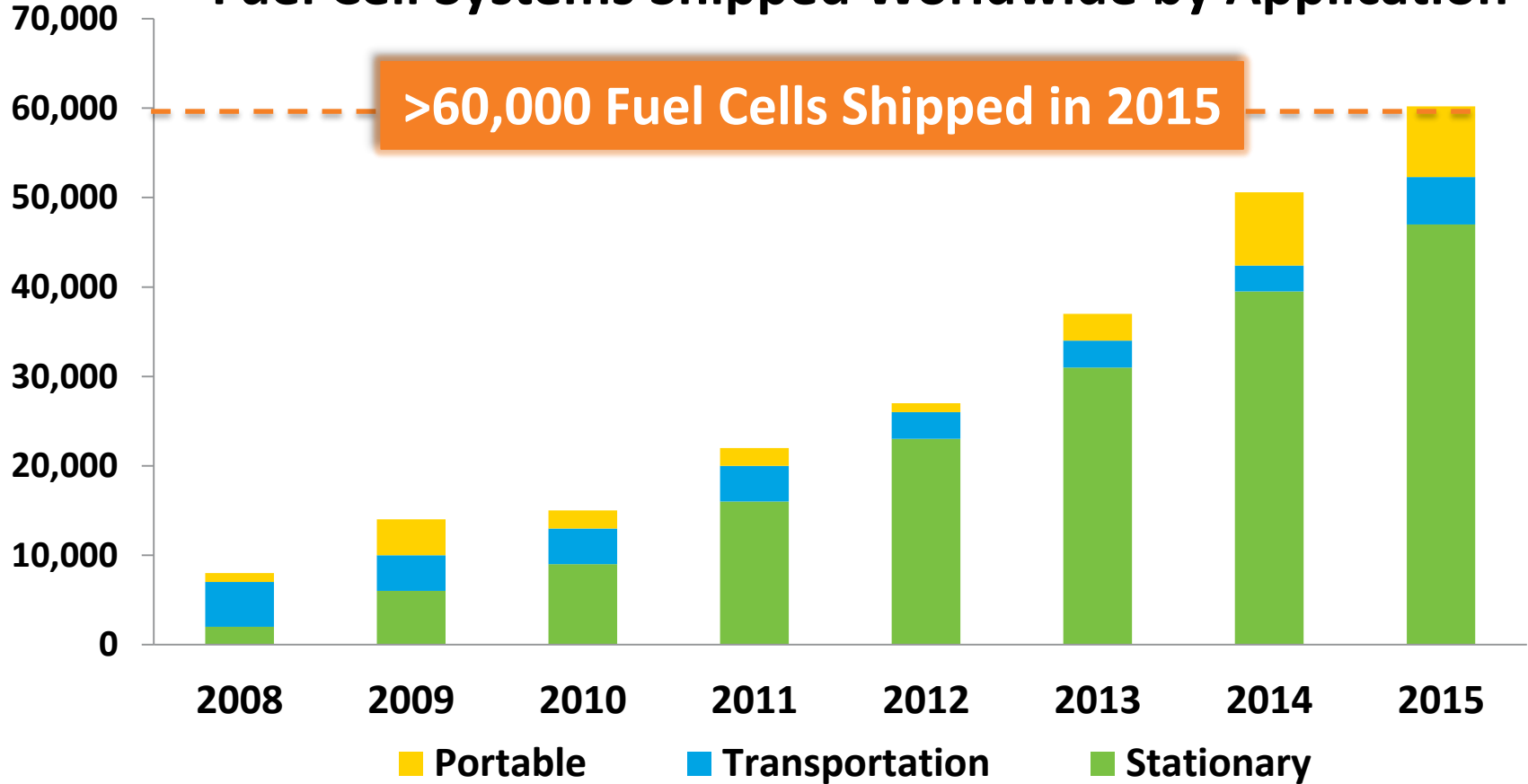


Honda FCV

Commercial
FCEVs are
here today!

FCEV: Fuel Cell Electric Vehicle

Fuel Cell Systems Shipped Worldwide by Application



>60,000 Fuel Cells Shipped in 2015

Capacity shipped in 2015 → Approximately **300 MW** & **~2X** → the capacity in 2014

Source: Navigant Research (2008-2013) & E4tech (2014-2015)

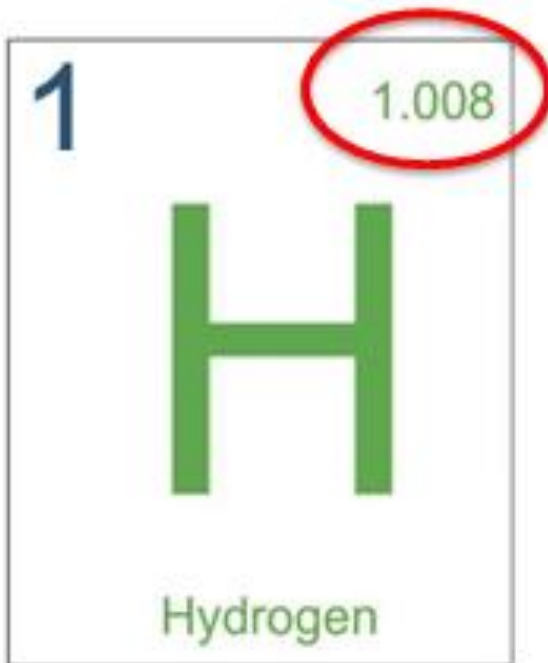
Consistent ~30% annual growth since 2010



Fuel cell powered lights at the Superbowl



National Hydrogen &
Fuel Cell Day | 10-08



The First Ever
National
Hydrogen &
Fuel Cell Day
(Held on its very
own atomic-
weight-day)

DOE Activities Span from R&D to Deployment



1.

Research & Development

Fuel Cells

- **>50% decrease** in cost since 2006
- **5X less** platinum
- **4X increase** in durability

\$124/kW in 2006

\$53/kW in 2015*
at high volume

*\$280/kW low volume



2.

Demonstration

Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

>220 FCEVs, **>30** stations,
>6M miles traveled

World's first tri-gen station

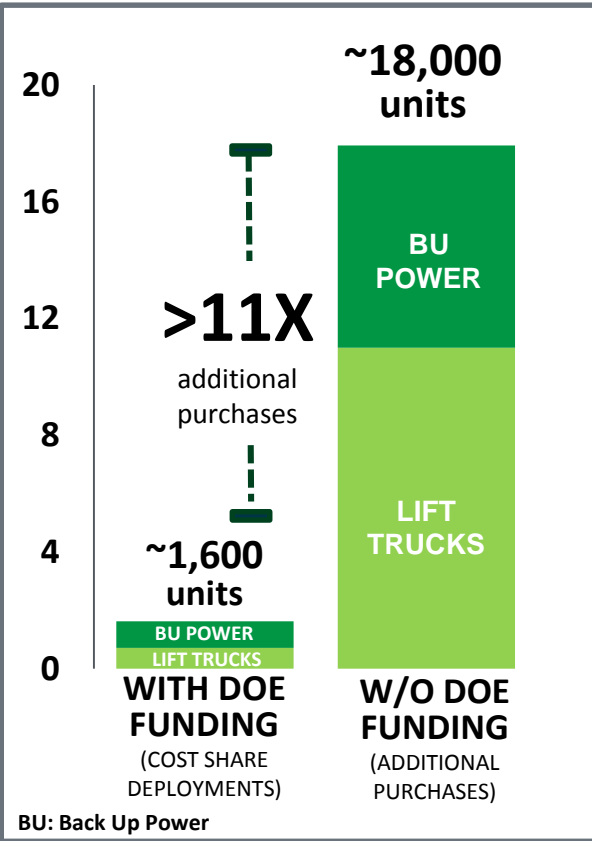


FCEV: Fuel Cell Electric Vehicle

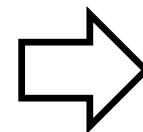


3.

Deployment



Savings from Active Project Management & Downselects

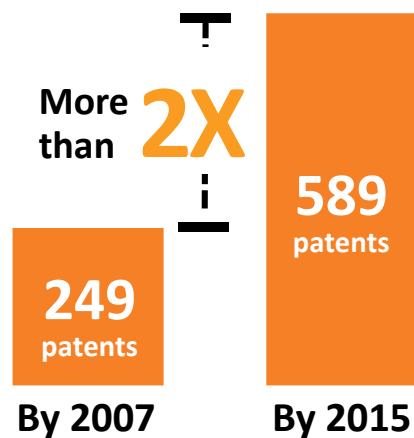


More than \$40M last 7 yrs



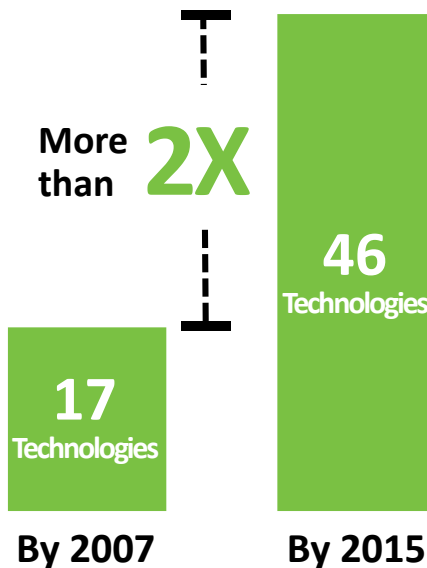
Innovation

Cumulative Number of Patents



Commercialization

Cumulative Number of Commercial Technologies Entering the Market



Jobs

From DOE-supported Commercial Technologies:

450 jobs average per year

From ARRA-supported Technology Deployments

1,400 jobs created or sustained

ARRA: American Recovery and Reinvestment Act

Examples of Commercial Technologies

- Catalysts
- Fuel Cell System Components
- Tanks
- Electrolyzers

Impact of DOE Investment on Industry

Revenues

More than **7X** the DOE Investment

Additional Investment

More than **5X** the DOE Investment

*for selected companies

**What can we learn
from history?**

Henry Ford and his first car, the Quadricycle, built in 1896



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.
Distributors

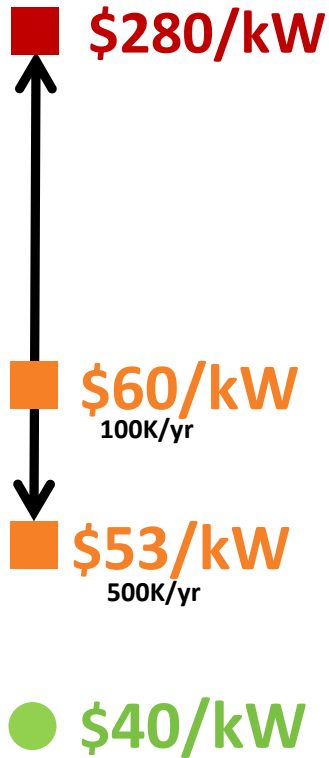
8-10 E. BIJOU STREET

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

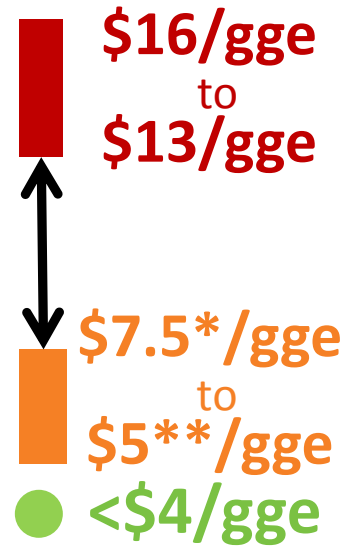


DOE Cost Targets and Status

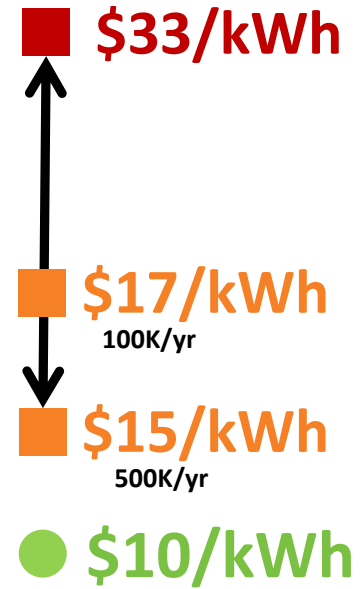
Fuel Cell System



H₂ Production, Delivery & Dispensing



Onboard H₂ Storage (700-bar compressed system)



● 2020 Targets

■ High-Volume Projection

■ Low-Volume Estimate

Key Challenges- Examples

- PGM loading
- Catalyst and membrane durability
- Electrode performance and durability

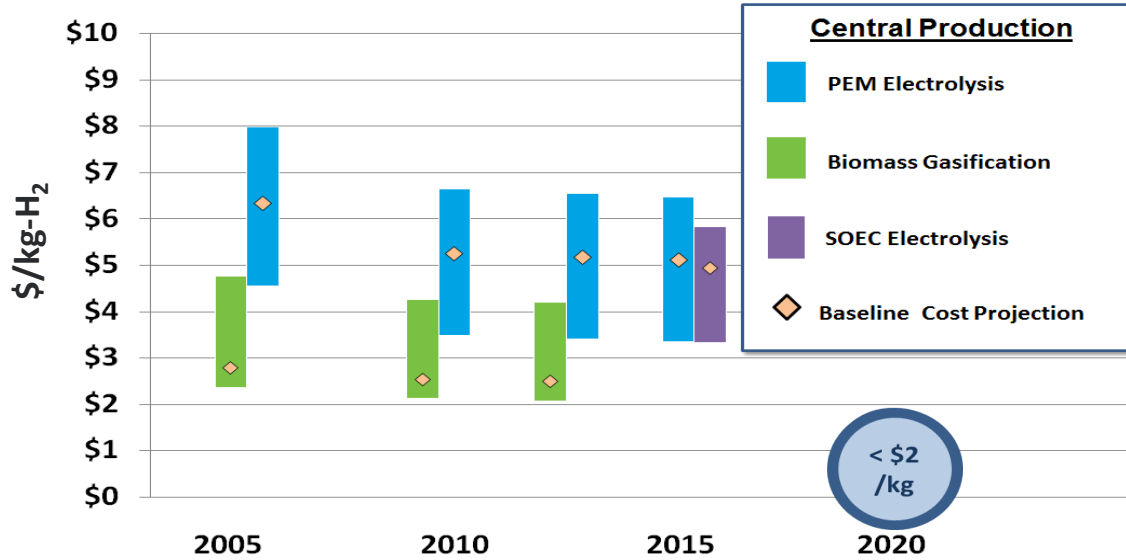
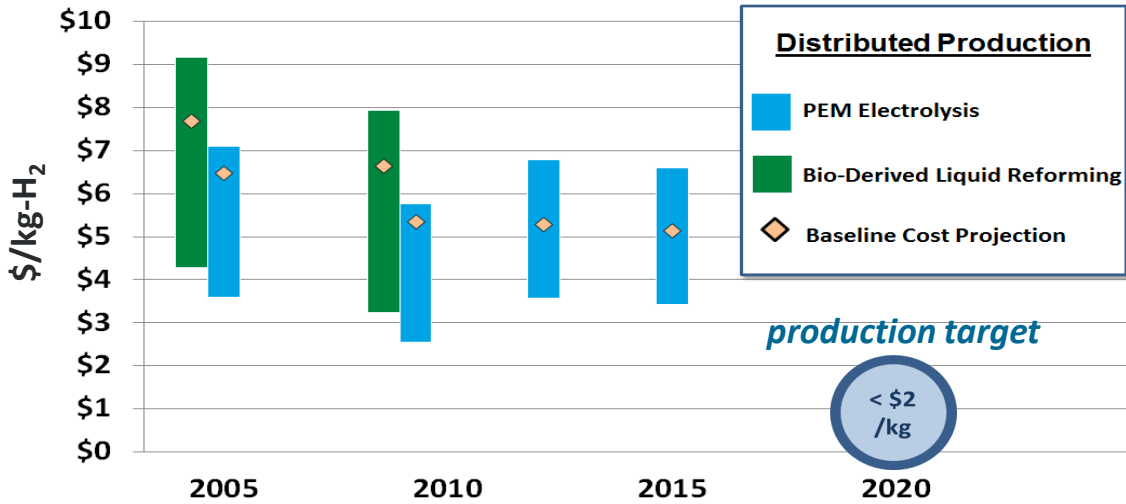
- Efficiency and Reliability
- Feedstock and Capital Costs
- Compression, Storage and Dispensing (CSD) Costs

- Carbon fiber precursors and conversion
- Composite/resin materials
- BOP and assembly costs

*Based on Electrolysis **Based on NG SMR

Highlights: Renewable H₂ Production

Cost* Renewable H₂ Production Pathways



*high volume cost projections. See DOE Record for details.

World Record

Solar-to-hydrogen Efficiency

16.4%

Benchmarked under outdoor sunlight at NREL

Source: NREL

H₂ Cost* Targets

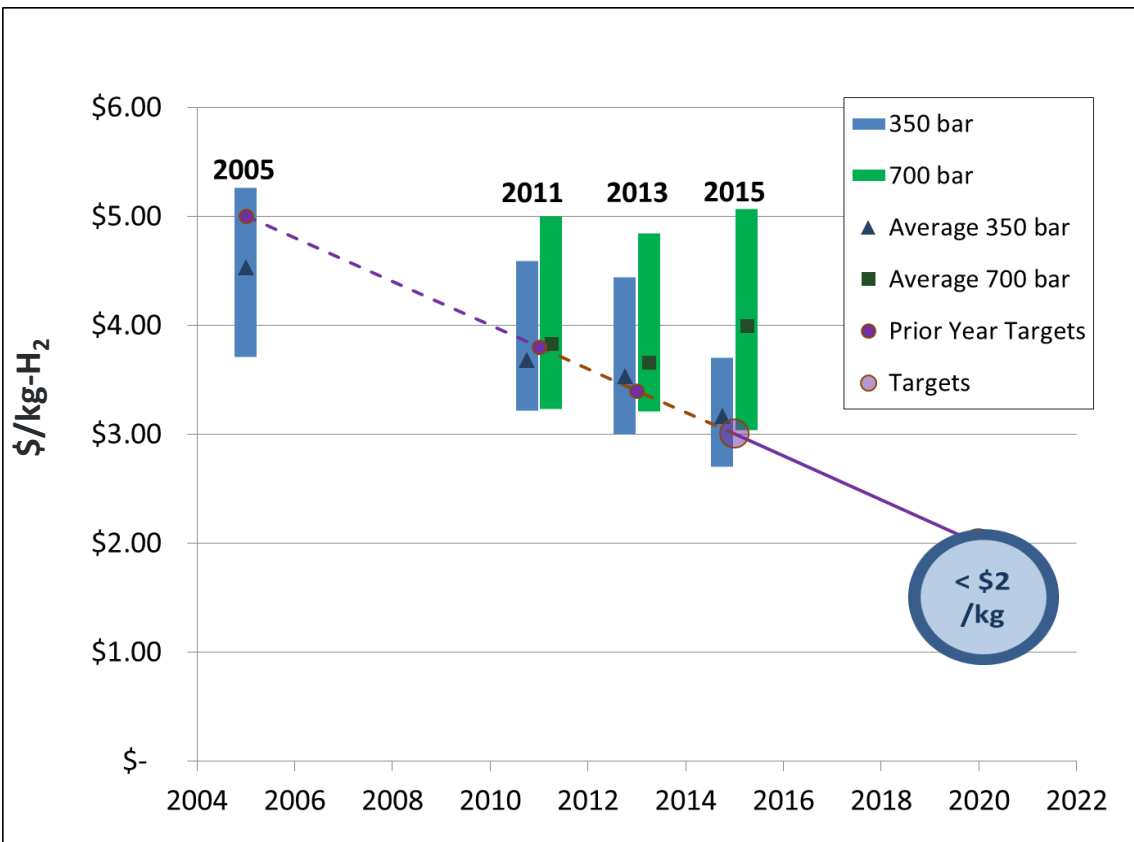
Less than **\$4/gge** by 2020

Less than **\$7/gge** Early Market

*at the pump

Highlights: H₂ Delivery

Cost of Delivering and Dispensing H₂ from Central Production



- Projected to **high volume with economies of scale**
- **Delivery/dispensing** apportionment of the **<\$4/kg P&D target**

World Record

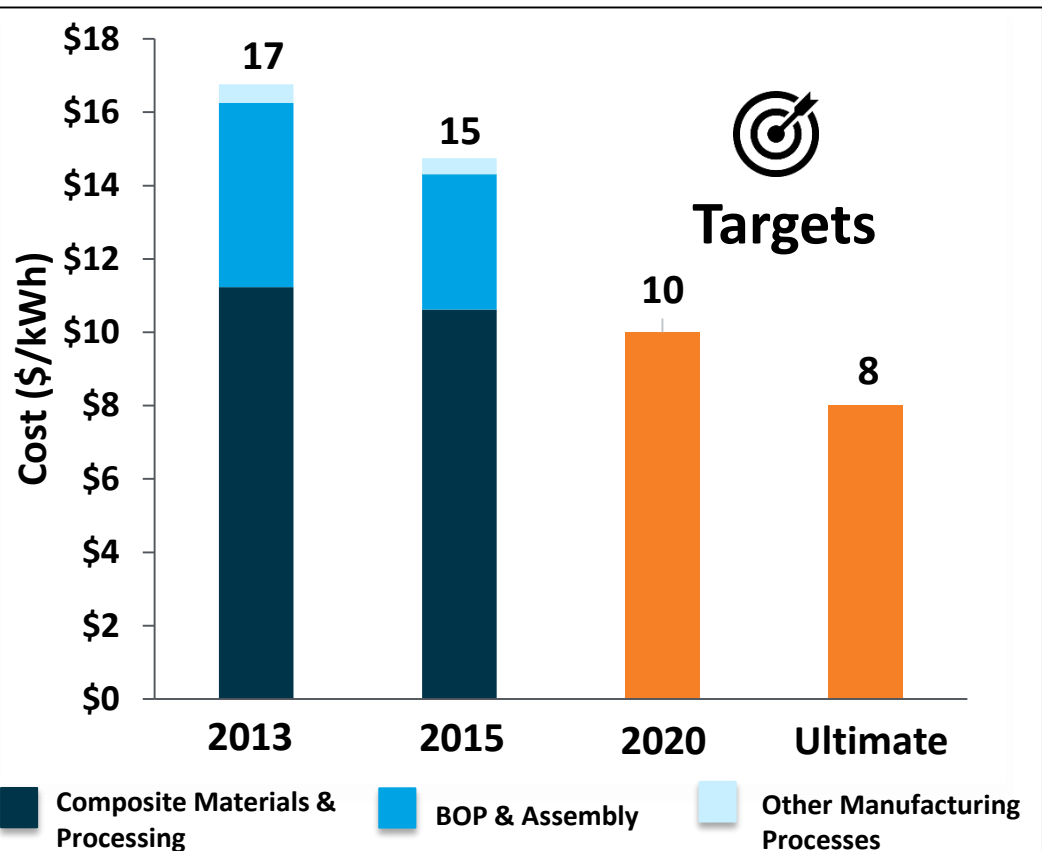
- **First ever liquefaction of a gas from room temperature with magnetocaloric cooling**
- **Record breaking 100°C temperature span**



Source: PNNL, Emerald Energy, Ames Laboratory

Highlights: H₂ Storage

Cost* of High Pressure H₂ Storage System



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

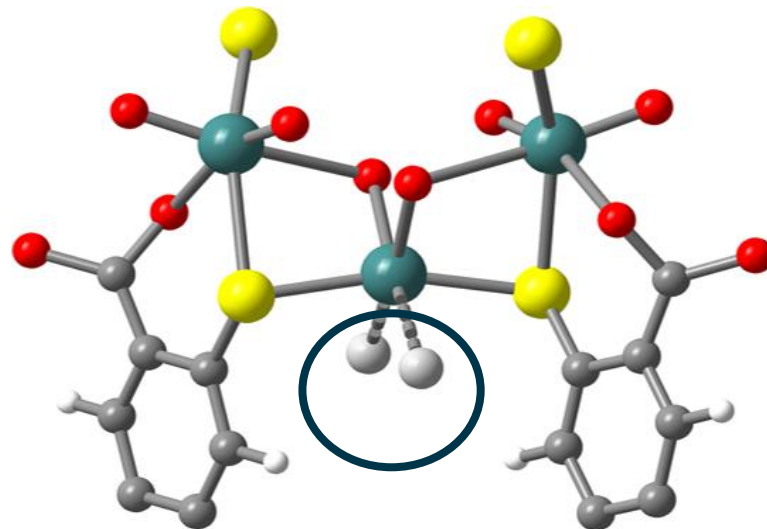
12%

Net Cost Reduction

since 2013 for H₂ storage systems

World's First

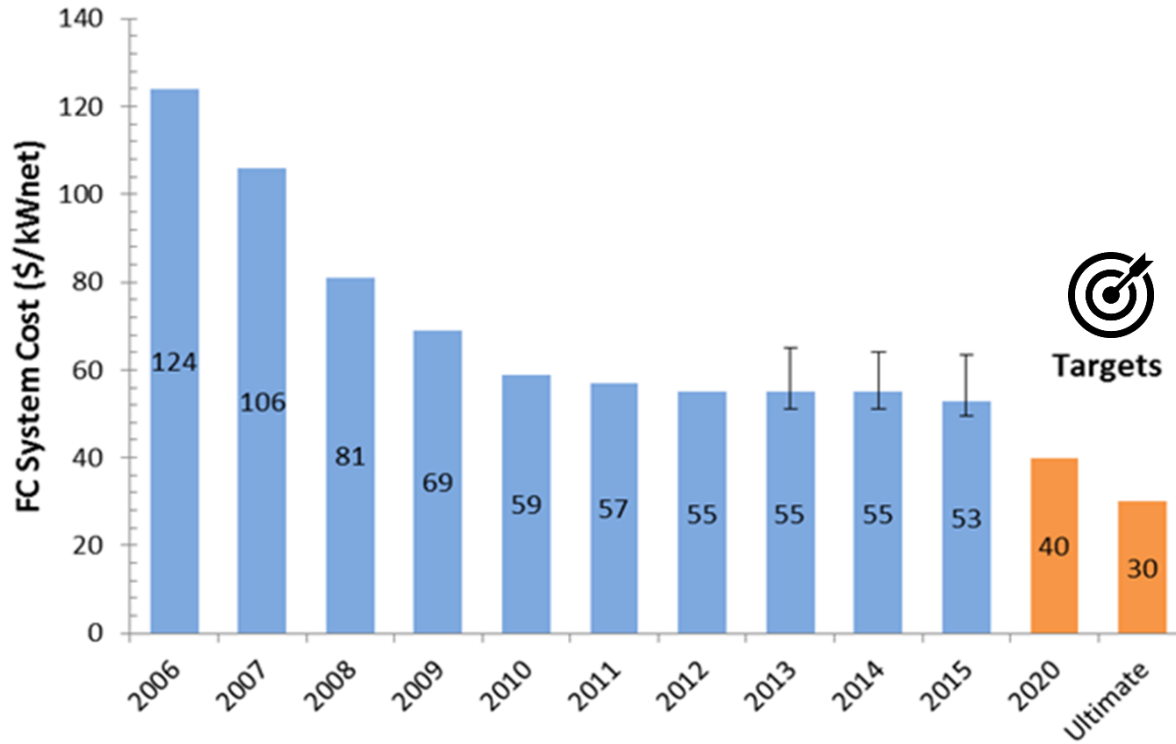
- Two H₂ molecules adsorbed at a single metal site
- Synthetic path to materials with higher densities of adsorbed H₂



Source: Runčevski, T.; Kapelewski, M. T.; Torres-Gavosto, R. M.; Tarver, J. D.; Brown, C. M.; Long, J. R. *Chem. Commun.*, submitted.

Highlights: Fuel Cells

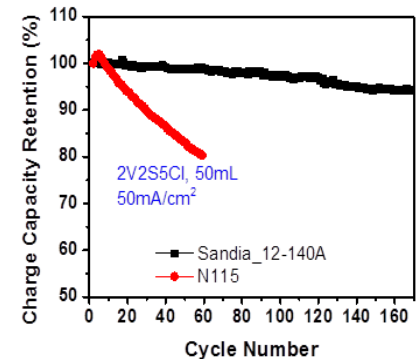
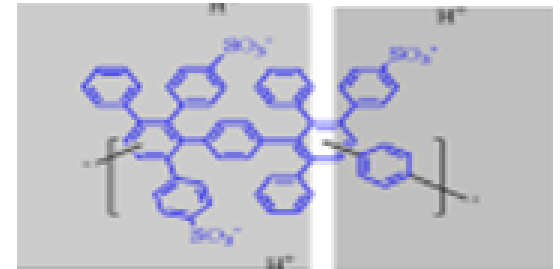
Modeled Cost* of Fuel Cell System Over Time



* 80-kW_{net} PEM fuel cell system projected to high-volume* manufacturing

World Record

- Alkaline exchange Membrane
- Record breaking durability
- Opportunities in flow batteries/electrolysis



Source: SNL

 **8,000 Hrs.**

Ultimate Durability Target Established

Resources

“Toolbox” online:



- HyRAM
- HDSAM
- H2FAST
- H2A
- JOBS and more

Available now at:

<http://energy.gov/eere/fuelcells/hydrogen-analysis-toolbox>



H2Tools.org

HYDROGEN FUEL CELL NEXUS
Hydrogen and Fuel Cell Supply Chain Database

COMPANY TYPES | PRODUCTS | MATCHMAKER | EDUCATION | RESOURCES

Fuel Cell | **Vehicle**

Available products in the menu:
Catalyst
Compressor/Expander
Electrodes
Electrolyzer
Gauges
High Pressure Plumbing
Hydrogen Pump/Ejector
MEAs
Power Electronics
Reactant Management
Sensors
Testing

Vehicle components: catalyst, membrane electrode assembly (MEA), Dispensing, Storage, MEA, Compression, Generation, vessels & vessel liners, compressor expander, battery, power electronics.

www.HFCnexus.com

Coming in September/October 2016: Supply Chain Exchange and Partnership Development Regional Forum- North Canton, OH

Organized by Ohio Fuel Cell Coalition (OFCC) and Partners

Supplier engagement & collaboration & information readily and publicly accessible



Supporting veterans and their families in 3 areas:



Wellness



Employment



Education

**Strong Commitment by the
H₂ and Fuel Cells Community**

**Air Liquide and PDC
committed to hiring
veterans for 10% of
their workforce**



**What can we learn
from early gasoline
infrastructure?**

Many diverse options

Cans, barrels, home models, mobile refuelers



Source: M. Melaina 2008.

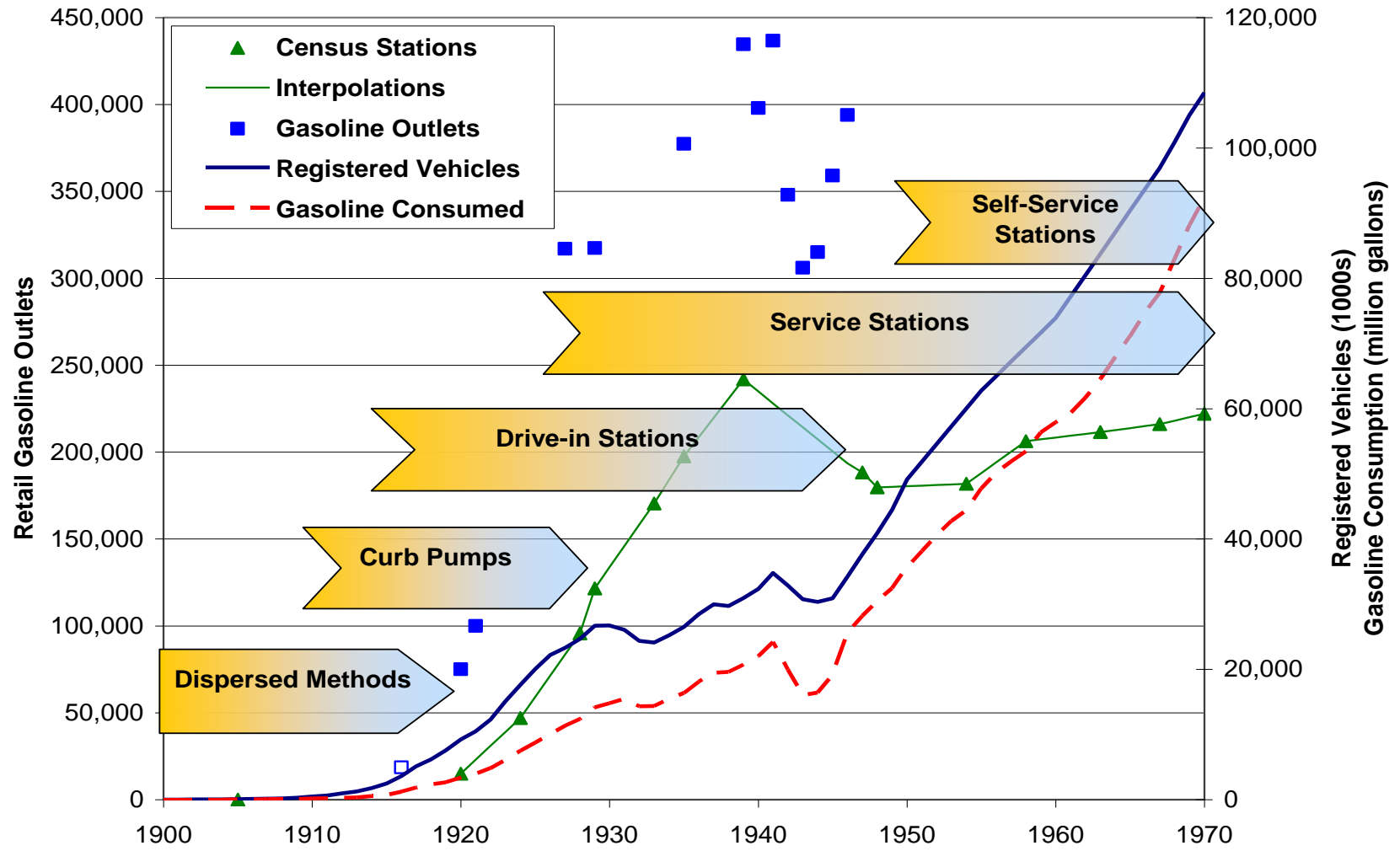


Source: Vieyra, 1979



Source: Milkues, 1978

Refueling Methods Evolved Over Time

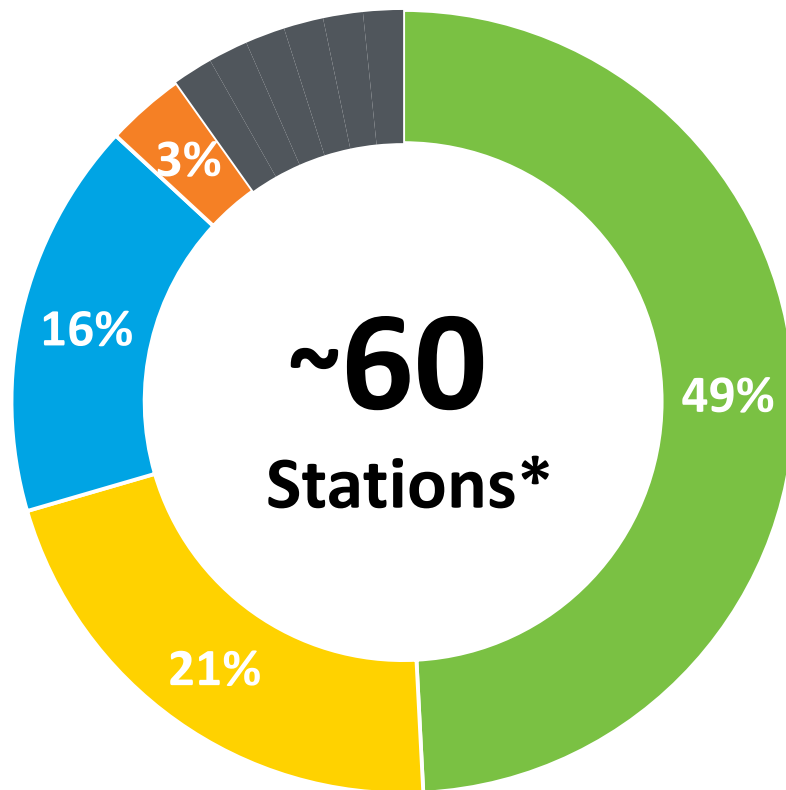


Source: Turn of the Century Refueling: A Review of Innovations in Early Gasoline Refueling Methods and Analogies for Hydrogen (Melaina 2007)

History shows phased introduction of different refueling methods

CA: ~ 20 stations now, up to 100 planned

Northeast: 12 stations planned



Type of Station

Delivered Compressed SMR

On-Site Electrolysis

Delivered Liquid SMR

On-Site SMR

Other

Delivered Pipeline

Delivered Liquid By-Product

Delivered Compressed By-Product

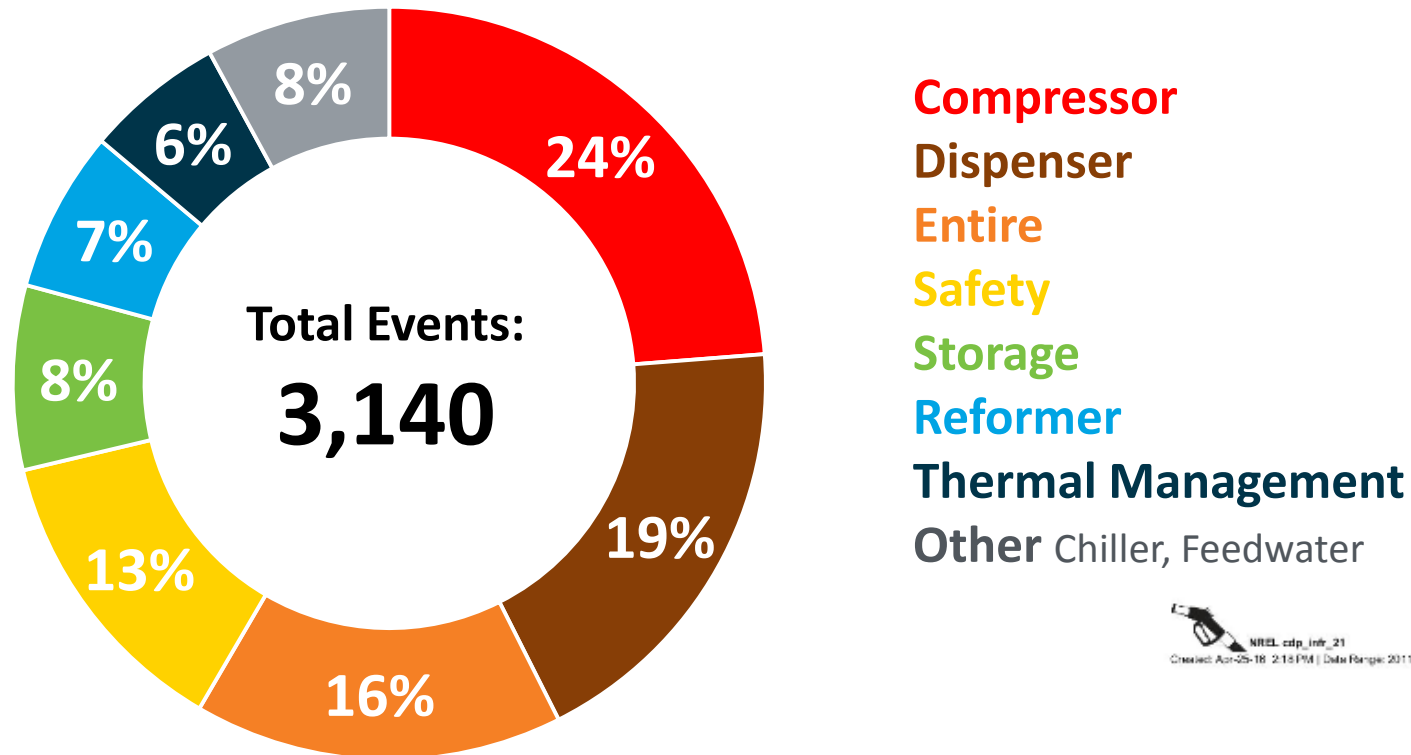
On-Site Tri-Gen

Mobile Fueler

Trailers

*Includes current (21), future (38) and retired (2) stations

Example: Sources of H₂ Infrastructure Maintenance



Most maintenance related to **compressors** and **dispensers**

Contamination is a key issue: See Database www.nrel.gov/hydrogen/system_contaminants_data/
To participate: techval@nrel.gov

Providing insights to guide H₂ infrastructure activities and to maximize impact



\$1M Competition: On-site H₂ fueling

Finalist Team Announced!
More at hydrogenprize.org



© Ivys Inc., All Rights Reserved 2016

Innovative packaging concepts
Electrolysis 350 and 700 bar



© Ivys Inc., All Rights Reserved 2016

Email your Feedback
info@teamsimplefuel.com

DOE H₂ Infrastructure Strategy

KEY CHALLENGES

1 Station Cost

2 Station Reliability

3 Station Rollout

DOE ACTIVITIES

- ✓ Components R&D
- ✓ Systems R&D

- ✓ Contaminant Detection
- ✓ Sensors Testing

- ✓ Safety Awareness
- ✓ Codes and Standards Harmonization
- ✓ Training & Education

EXAMPLES



- HySTEP
- Reference Station Design
- Contaminant Report

SHOWCASE STATION
(HyTEST)

TOOLS
(HyRAM- Hydrogen Risk
Assessment Models)

DOE efforts support public-private partnership:

H₂USA

Hydrogen & Fuel Cells Budget

| Key Activity | FY 15 | FY 16 | FY17 |
|-----------------------------------|-------------------|----------------|---------------------|
| | (\$ in thousands) | | |
| | Approp. | Approp. | Request |
| Fuel Cell R&D | 33,000 | 35,000 | 35,000 |
| Hydrogen Fuel R&D ¹ | 35,200 | 41,050 | 44,500 |
| Manufacturing R&D | 3,000 | 3,000 | 3,000 |
| Systems Analysis | 3,000 | 3,000 | 3,000 |
| Technology Validation | 11,000 | 7,000 | 7,000 |
| Safety, Codes and Standards | 7,000 | 7,000 | 10,000 |
| Market Transformation | 3,000 | 3,000 | 3,000 |
| Technology Acceleration | 0 | 0 | 13,000 ² |
| NREL Site-wide Facilities Support | 1,800 | 1,900 | N/A |
| Total | 97,000 | 100,950 | 105,500 |

| Office | FY 2016* |
|---------------------|----------|
| EERE | \$101.0M |
| Basic Science | \$18.5M |
| Fossil Energy, SOFC | \$30.0M |

FY 2016 DOE Total: ~\$150M

*Estimated for BES funding (based on FY15)



New in FY17 Request

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

²Combines Manufacturing R&D, Technology Validation, Market Transformation.

Sustained, stable funding requests and appropriations

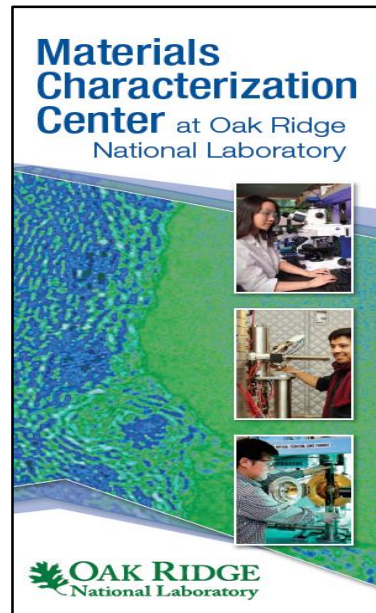
Leveraging National Labs

Lab Impact Initiative

- Tech to Market
- Small Business Vouchers
- Lab Corps

Example:

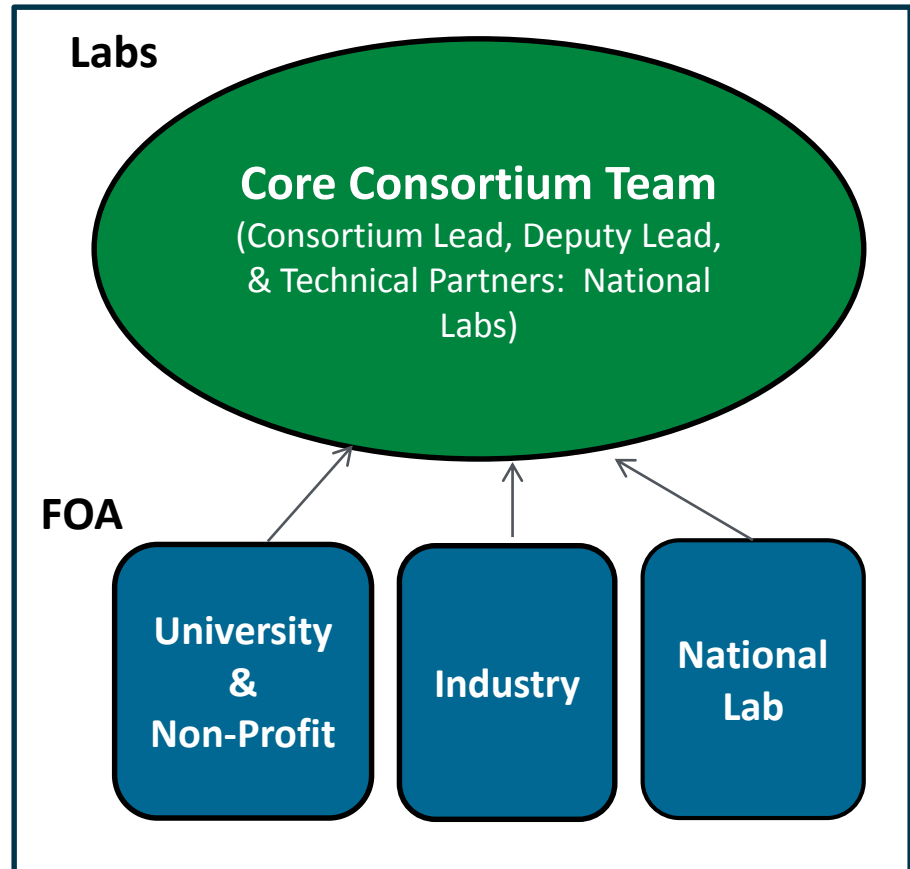
FCTO will provide
50% cost share for
up to 10 partners
through 'streamlined'
CRADA
(up to \$50K total per project)



Contact Karren More (morekl1@ornl.gov)

Consortium Approach

Multi-lab core capabilities with
steady influx of new partners



3 Consortia Launched:

Supporting the Energy Materials Network



Energy Materials Network
U.S. Department of Energy



PGM-Free Catalysts for Fuel Cells



Advanced Research for
Hydrogen Storage Materials

Advancing fuel cell performance and durability through six areas:



FCPAD
FUEL CELL PERFORMANCE
AND DURABILITY

Visit www.fcpad.org

1. Electrocatalysts and Supports
2. Electrode Layer
3. Ionomers, GDL, Bipolar Plates
4. Modelling and Validations
5. "Operando" Evaluation
6. Component Characterization



Energy Materials Network

U.S. Department of Energy

Will be led by NREL with SNL and LBNL on core team: Multiple partners to be added in FY17

Focus: Materials for Renewable H₂ Production including:

**Advanced
Electrolysis**

Photoelectrochemical

**Solar
Thermochemical**

What does lava flowing into water & STCH* production have in common?



Lava in water: oxidize molten rock to give hydrogen



Solar concentrated power

Photo Credit : iStock

Two-step thermochemical water-splitting cycle ➡ Hydrogen

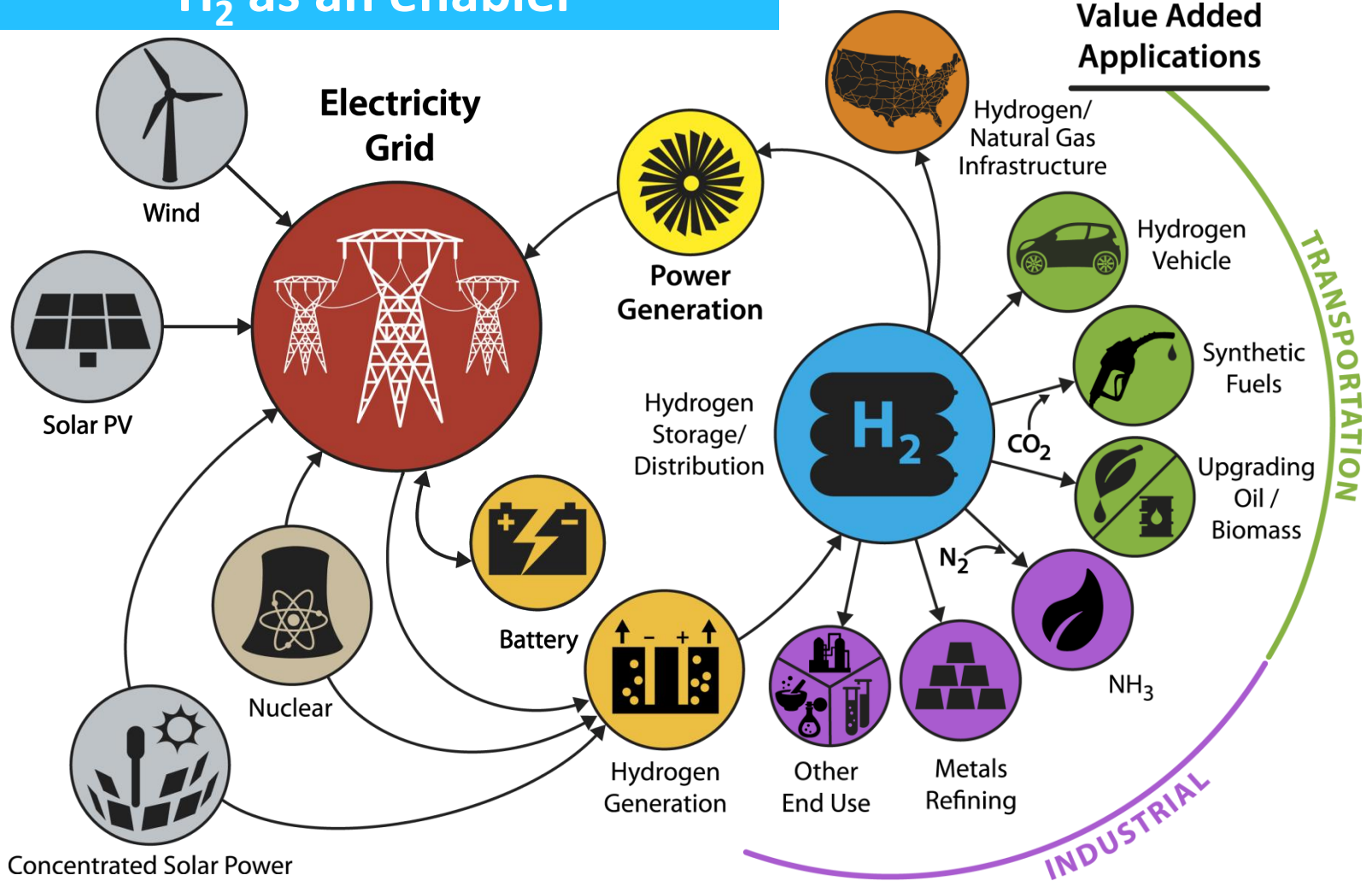
* Solar Thermochemical Hydrogen production

Source: McDaniel Anthony (SNL)

Harnesses the same physics occurring with lava flowing into water to produce H₂

H₂@Scale: Vision for the Future

H₂ as an enabler



Looking for your online feedback
Visit display by registration desk

<https://www.surveymonkey.com/r/h2atscale>



*Illustrative example, not comprehensive
Source: NREL; Lab Big Idea Summit

H₂ @ Scale Potential:

Reduction by Sector

75%
Grid

25%
Transportation

25%
Industrial

A CLEANER FUTURE

50% fewer GHG emissions
than today by 2050

MORE

Jobs
Security
Resiliency



Collaborations and Partnerships

R&D

Demonstration & Deployment

Accelerated Commercialization



- Pre-Competitive R&D
- USCAR, energy companies, EPRI and utilities



- Implementing Agreements
- 25 countries



- State Partnerships and Collaborations



- International Government Coordination
- 18 countries and European Commission



- Public-Private Partnership
- >45 partners
- FCHEA (trade association)

Hydrogen and Fuel Cells Technical Advisory Committee (HTAC)

Industry, academia and state & federal stakeholders working together

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

Sunita.Satyapal@ee.doe.gov

hydrogenandfuelcells.energy.gov