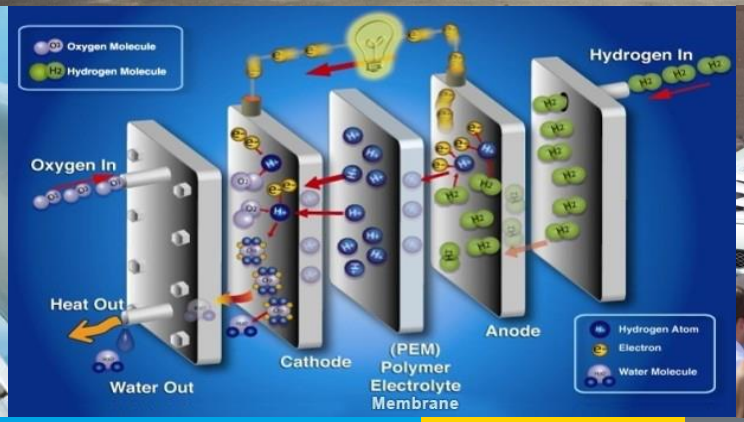
U.S. Department of Energy Hydrogen and Fuel Cells Program

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

Plenary at Glance

- **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

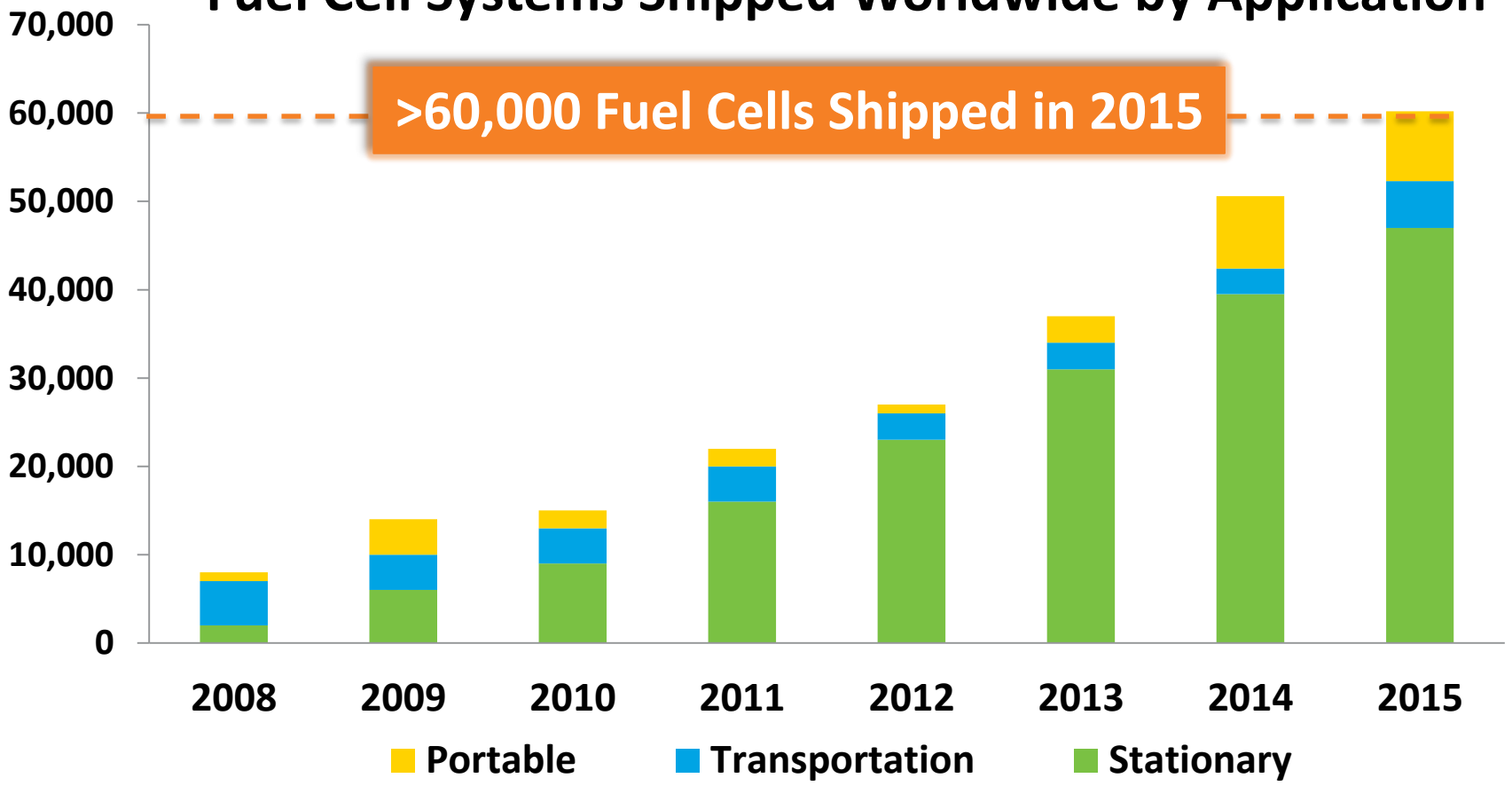
Honda FCV

Commercial FCEVs are here **today!**

FCEV: Fuel Cell Electric Vehicle

Market Growth in Fuel Cell Sales

Fuel Cell Systems Shipped Worldwide by Application



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

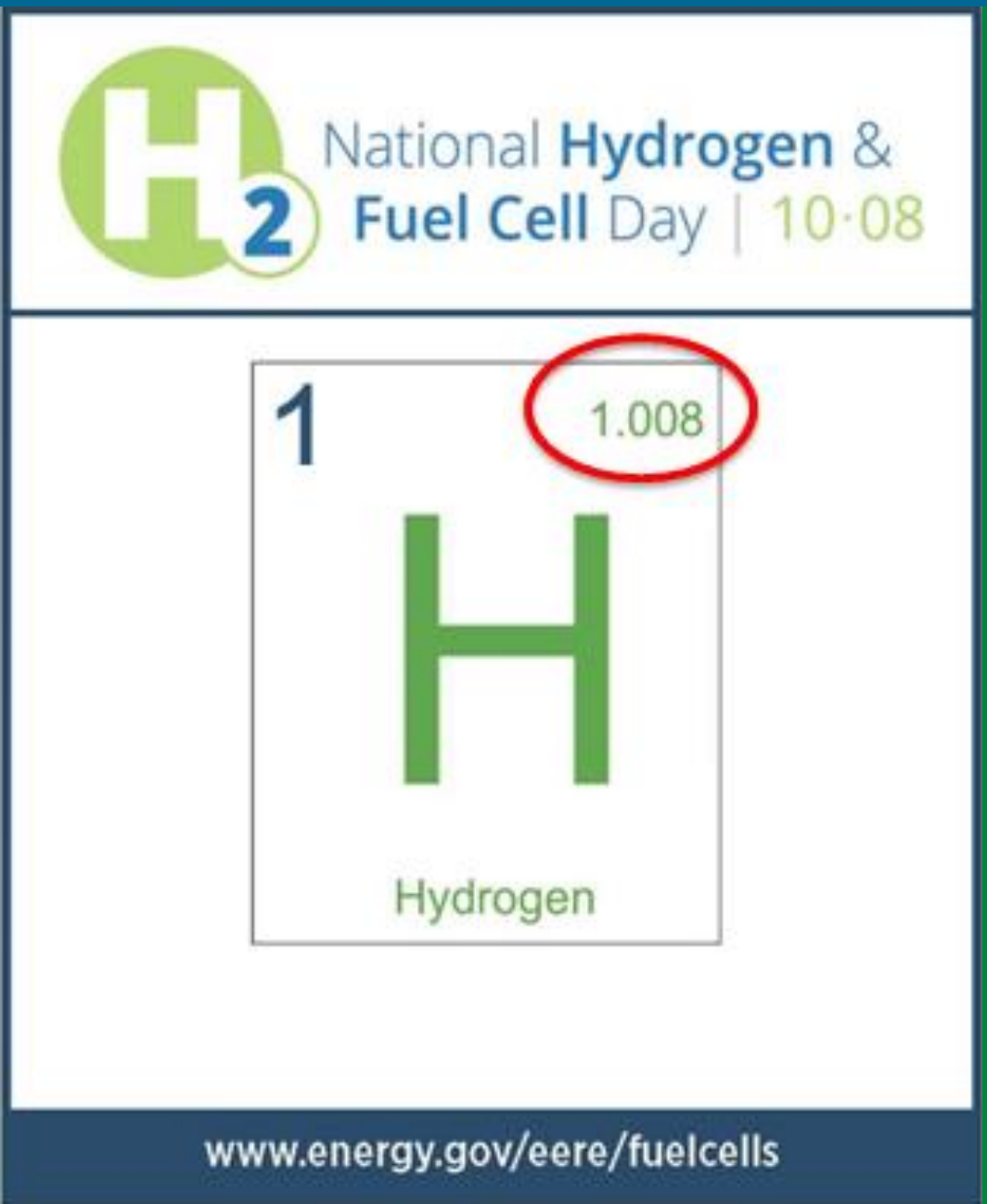
Source: Navigant Research (2008-2013) & E4tech (2014-2015)

Consistent ~30% annual growth since 2010

Fuel Cells: Big Leaps in the Last Year

Fuel cell powered lights at the Superbowl

Fuel Cells: Big Leaps in the Last Year



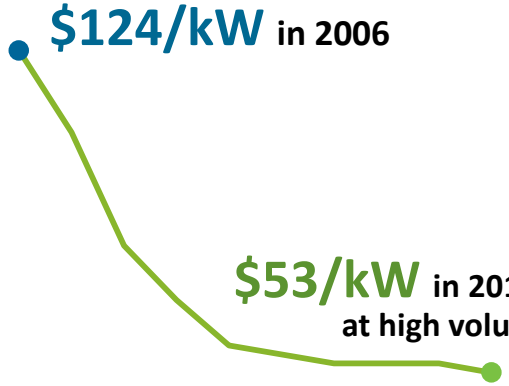
The First Ever National Hydrogen & Fuel Cell Day
(Held on its very own atomic-weight-day)

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



*$280/kW low volume

2. Demonstration

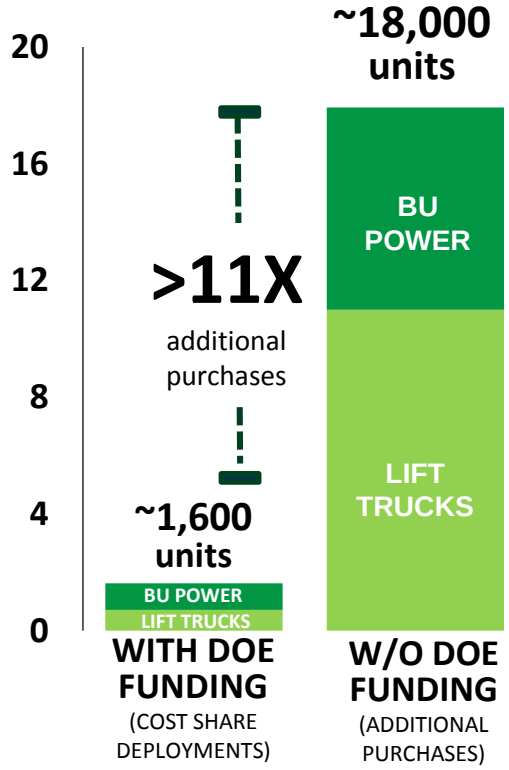
Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

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

World's first tri-gen station

FCEV: Fuel Cell Electric Vehicle

3. Deployment



BU: Back Up Power

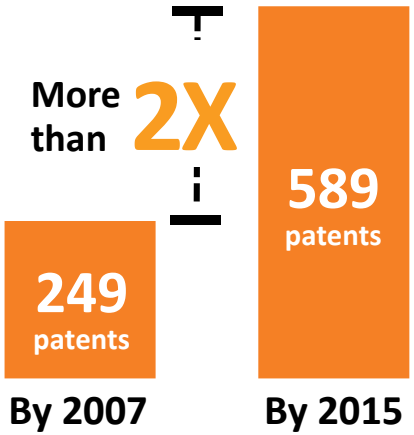
Savings from Active Project Management & Downselects

More than **$40M** last 7 yrs

DOE Impact- H_2 and Fuel Cells

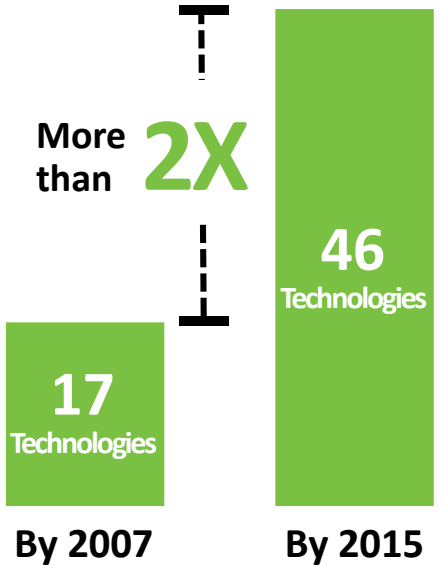
Innovation

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

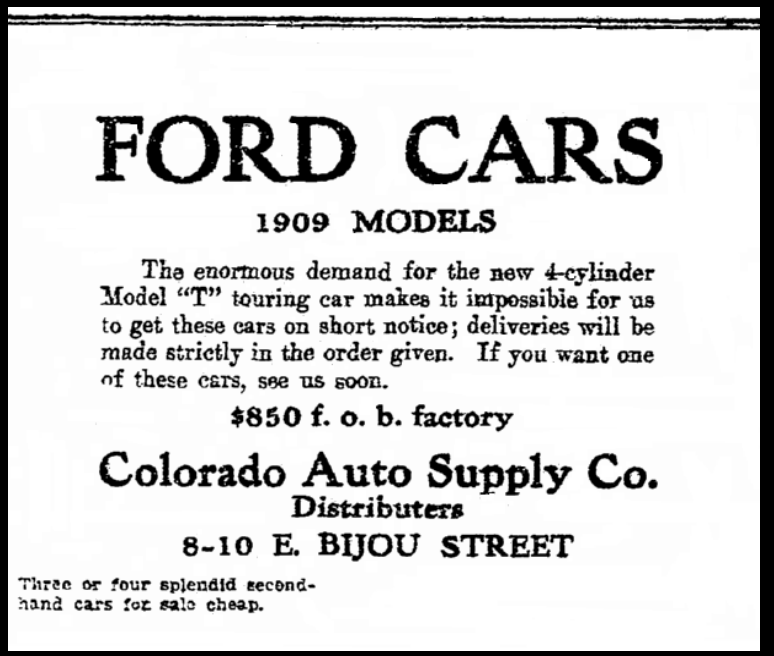
Impact of DOE Investment on Industry

Revenues	Additional Investment
More than **7X** the DOE 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

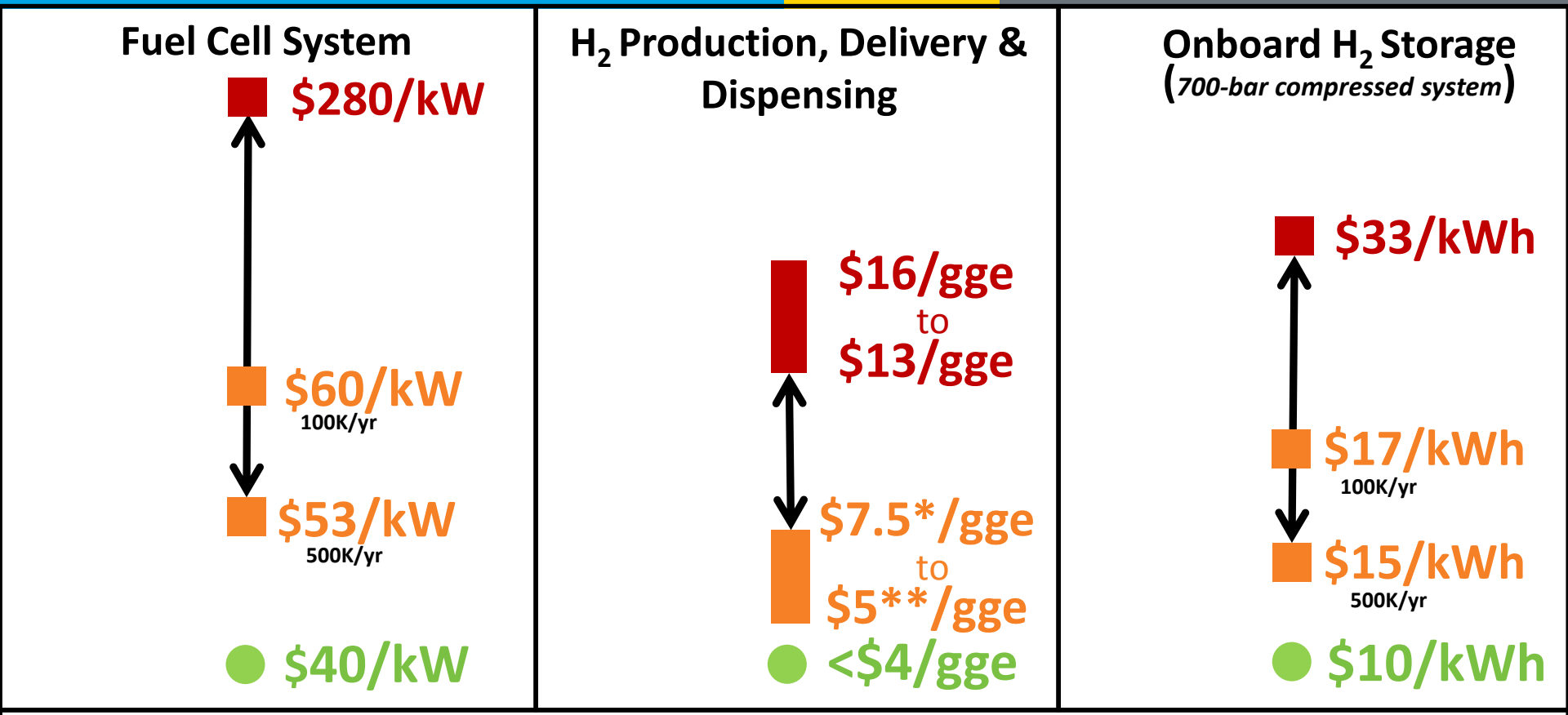
The enormous demand for the new 4-cylinder Model "T" touring car makes it impossible for us to get these cars on short notice; deliveries will be made strictly in the order given. If you want one of these cars, see us soon.

$850 f. o. b. factory

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

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

DOE Cost Targets and Status



Key Challenges- Examples

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

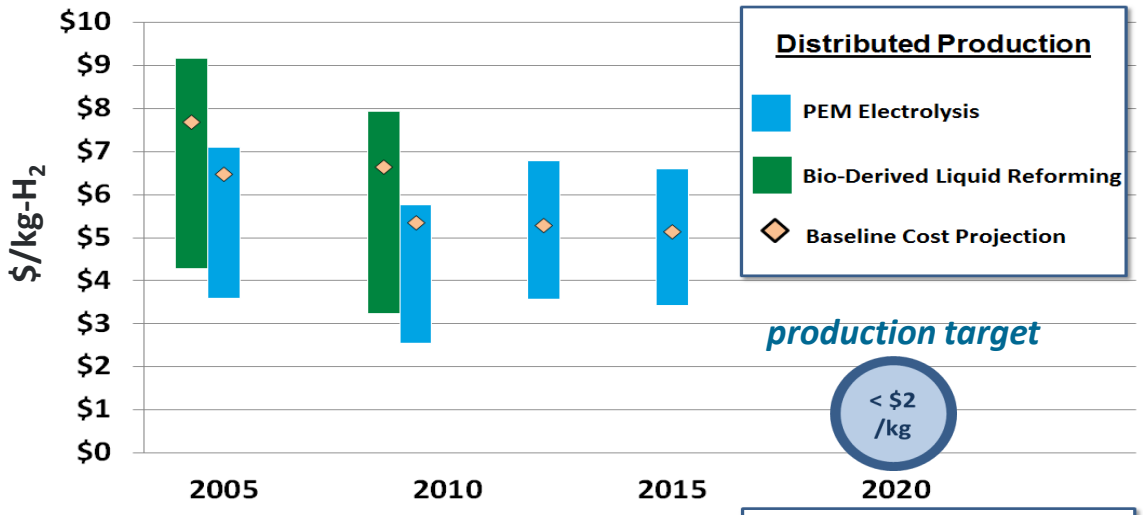
- Efficiency and Reliability
- Feedstock and Capital Costs
- Compression, Storage and Dispensing (CSD) Costs

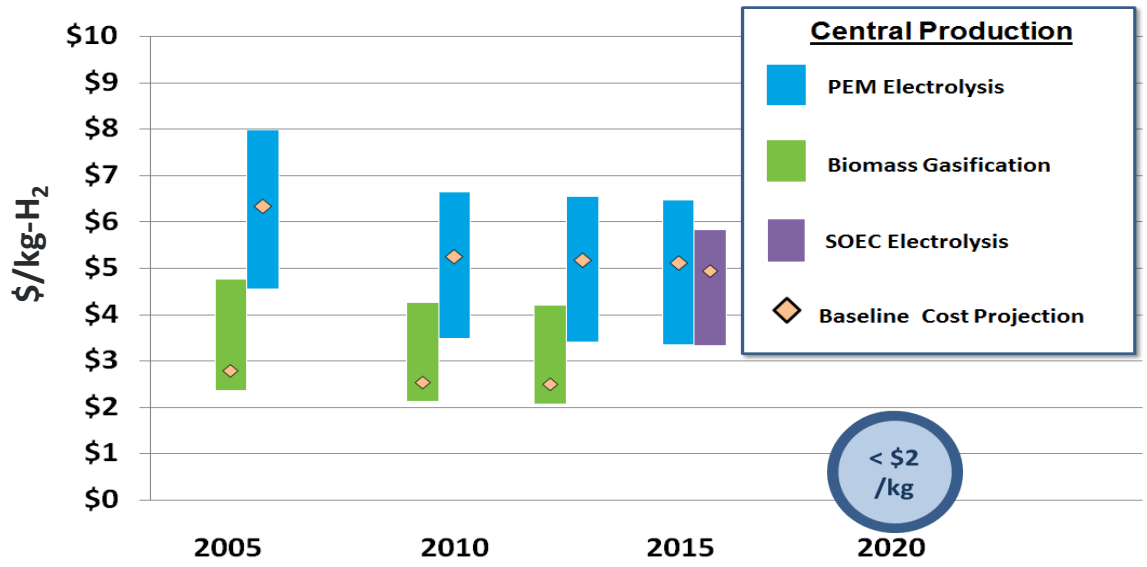
- Carbon fiber precursors and conversion
- Composite/resin materials
- BOP and assembly costs

*Based on Electrolysis **Based on NG SMR

Highlights: Renewable H_2 Production

Cost* Renewable H_2 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

H_2 Cost* Targets

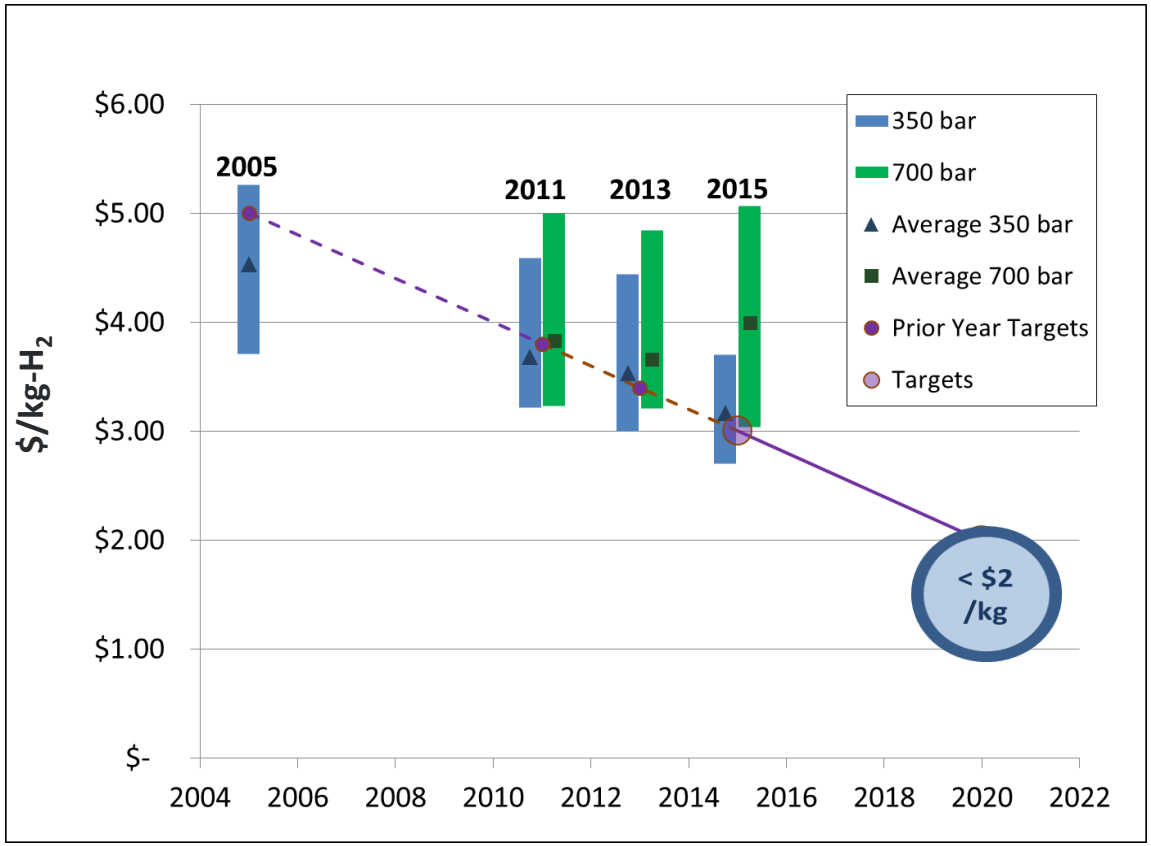
Less than **$4/gge** by 2020

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

*at the pump

Highlights: H_2 Delivery

Cost of Delivering and Dispensing H_2 from Central Production



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

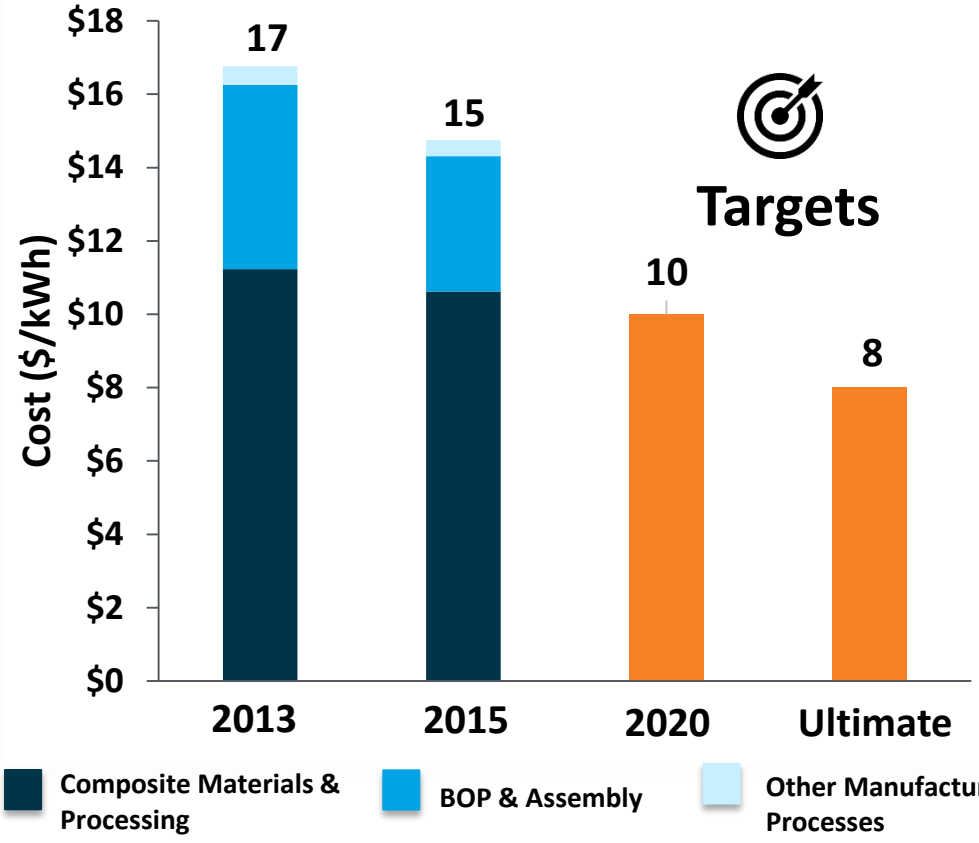
World Record

- **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: H_2 Storage

Cost* of High Pressure H_2 Storage System

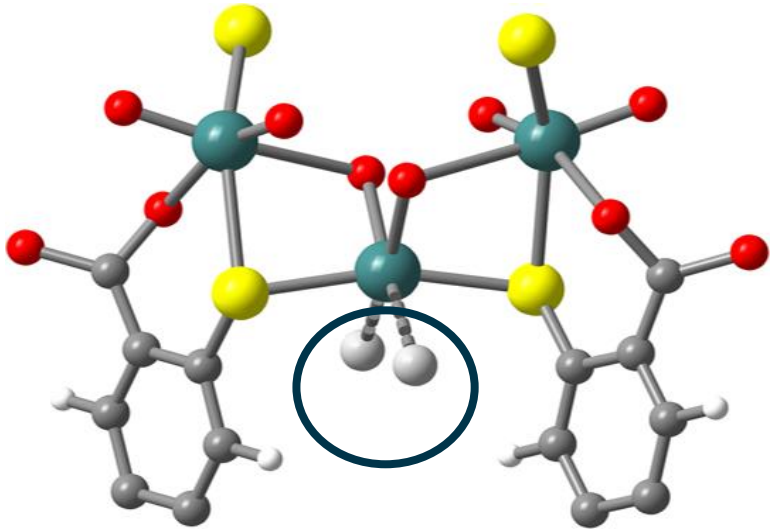


*Assumes high volume (500K/yr.), 2007$, 700-bar type IV single tank system. Based on program record 15013

12% **Net Cost Reduction** since 2013 for H_2 storage systems

World's First

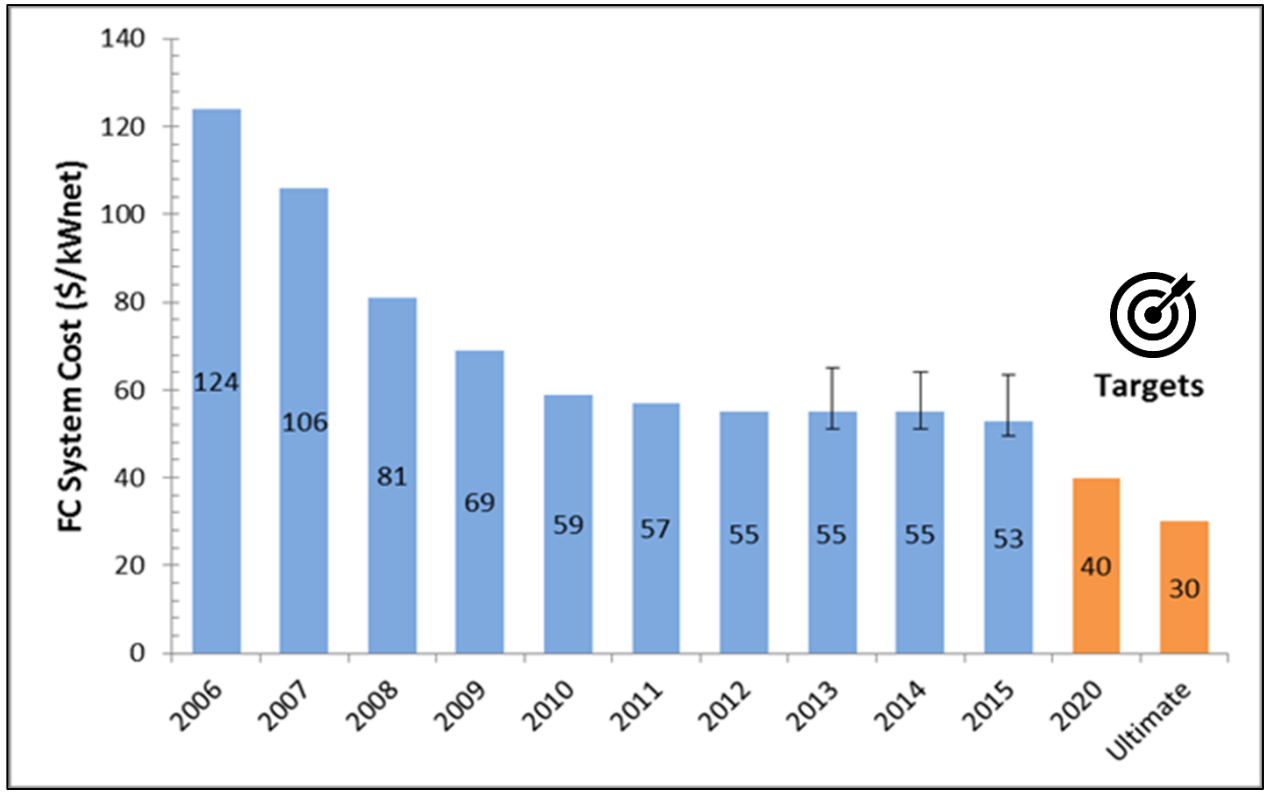
- **Two H_2 molecules adsorbed** at a **single metal site**
- Synthetic path to materials with **higher densities** of adsorbed H_2



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



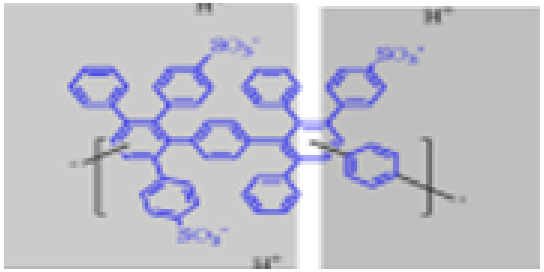
* 80-kW_{net} PEM fuel cell system projected to high-volume* manufacturing

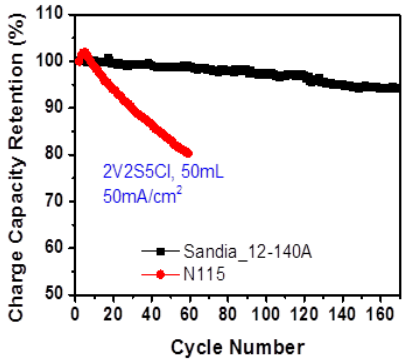
8,000 Hrs.

Ultimate Durability Target Established

World Record

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





Source: SNL

Tools, Models and Databases Online

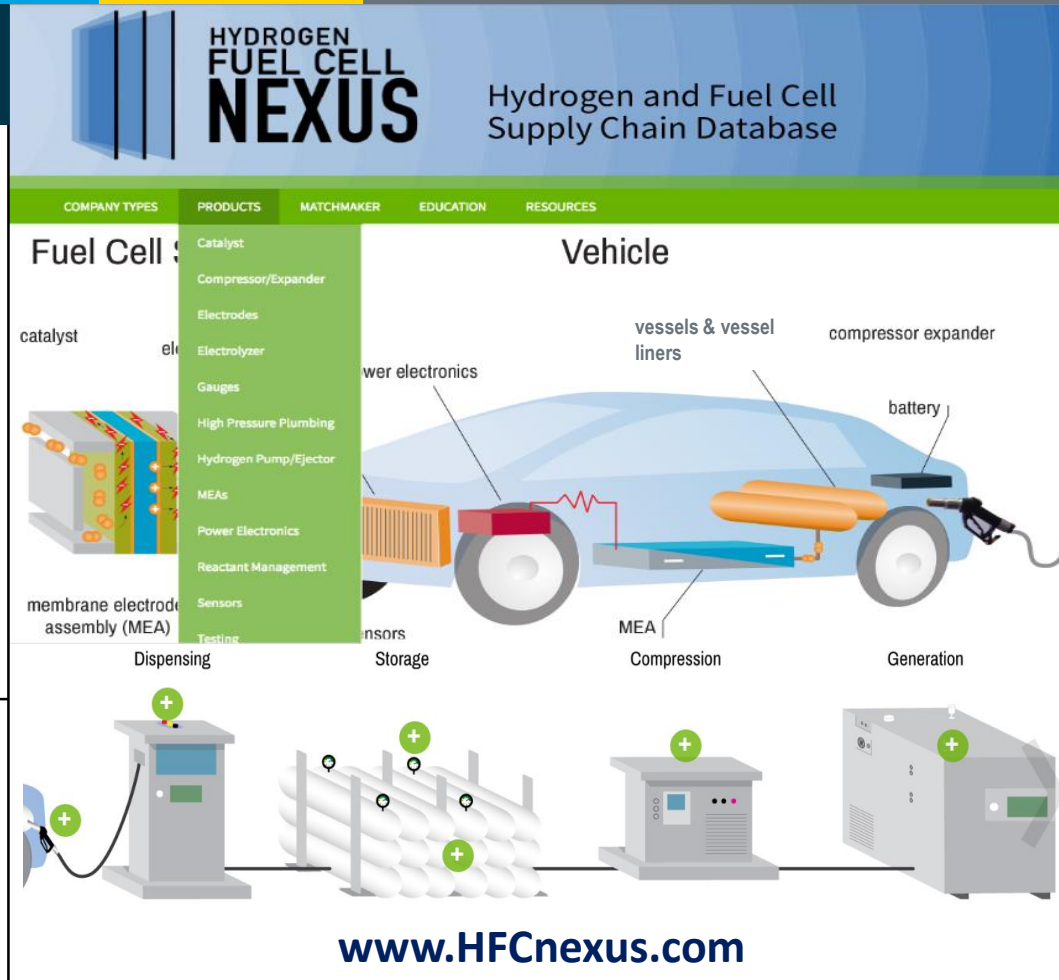
Resources

"Toolbox" online:

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

Available now at:
http://energy.gov/eere/fuelcells/hydrogen-analysis-toolbox

H2Tools.org



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

First Lady's and Dr. Jill Biden's Initiative: Joining Forces

Supporting veterans and their families in 3 areas:

Wellness

Employment

Education

Strong Commitment by the H_2 and Fuel Cells Community

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

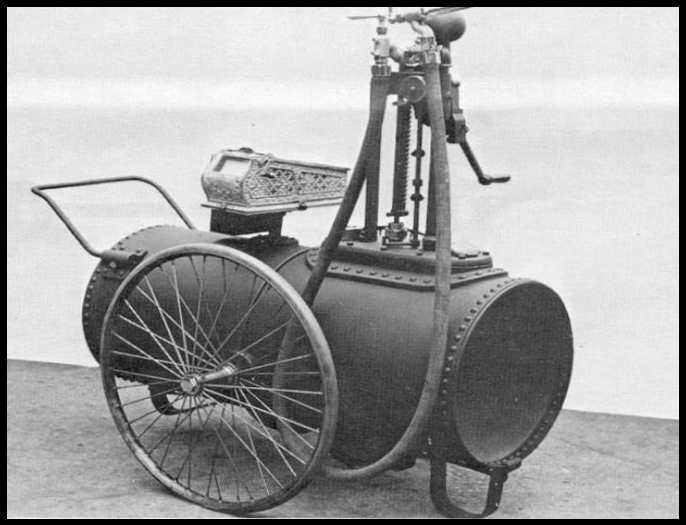
What can we learn from early gasoline infrastructure?

Many diverse options

Cans, barrels, home models, mobile refuelers

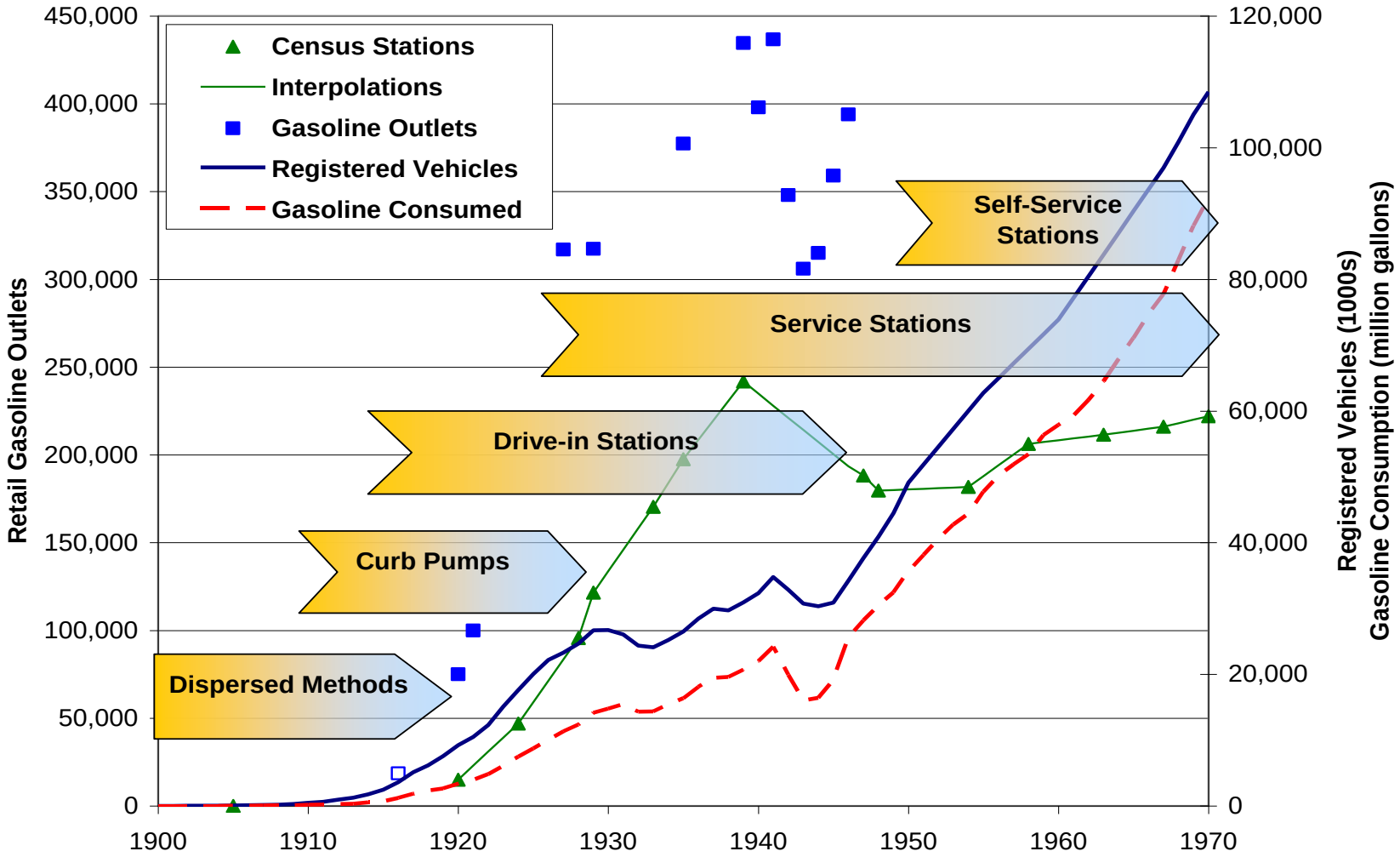
Source: M. Melaina 2008.

Source: Vieyra, 1979



Source: Milkues, 1978

Refueling Methods Evolved Over Time



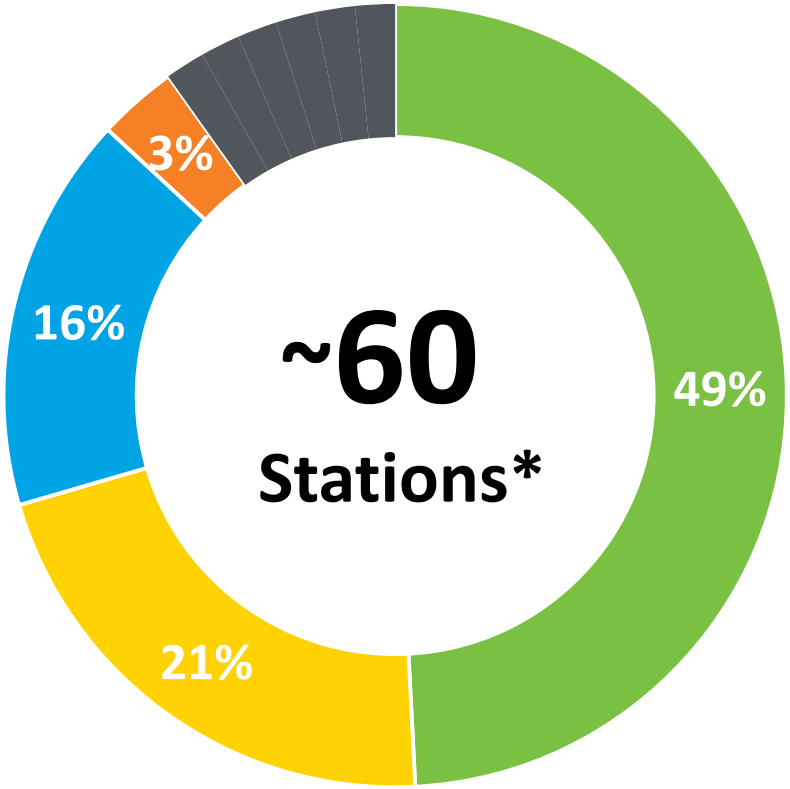
Source: Turn of the Century Refueling: A Review of Innovations in Early Gasoline Refueling Methods and Analogies for Hydrogen (Melaina 2007)

History shows phased introduction of different refueling methods

A Variety of H_2 Stations Demonstrated To Date

CA: ~ 20 stations now, up to 100 planned

Northeast: 12 stations planned



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

Type of Station

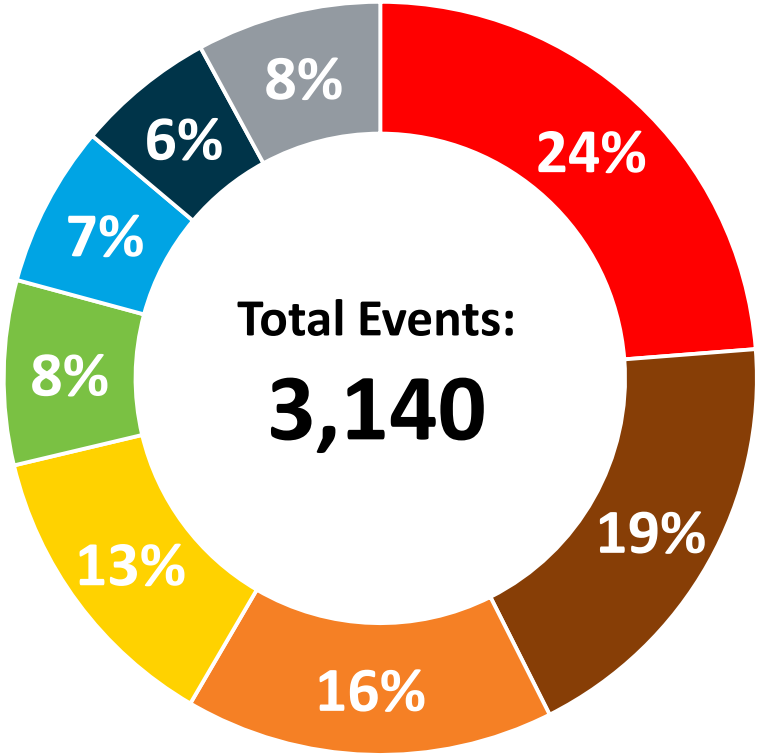
- Delivered Compressed SMR
- On-Site Electrolysis
- Delivered Liquid SMR
- On-Site SMR
- Other
  - Delivered Pipeline
  - Delivered Liquid By-Product
  - Delivered Compressed By-Product
  - On-Site Tri-Gen
  - Mobile Fueler
  - Trailers

NREL cdp_infr_11
Created: Mar-30-16 11:06 AM | Data Range: 2008Q3-2015Q4

SMR= Steam methane reforming

Real World Operation Data- H_2 Infrastructure

Example: **Sources of H_2 Infrastructure Maintenance**



Compressor
Dispenser
Entire
Safety
Storage
Reformer
Thermal Management
Other Chiller, Feedwater

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 H_2 infrastructure activities and to maximize impact

Complementing Retail Stations: H_2 Refuel H-Prize

H2refuel
U.S. Department of Energy

$1M Competition: On-site H_2 fueling

Finalist Team Announced!
More at hydrogenprize.org

simple.fuel.™

Innovative packaging concepts
Electrolysis 350 and 700 bar

Email your Feedback
info@teamsimplefuel.com

DOE H_2 Infrastructure Strategy

KEY CHALLENGES	DOE ACTIVITIES	EXAMPLES
1 Station Cost	✓ Components R&D ✓ Systems R&D	H2FIRST ▪ HySTEP ▪ Reference Station Design ▪ Contaminant Report
2 Station Reliability	✓ Contaminant Detection ✓ Sensors Testing	**SHOWCASE STATION** (HyTEST)
3 Station Rollout	✓ Safety Awareness ✓ Codes and Standards Harmonization ✓ Training & Education	**TOOLS** (HyRAM- Hydrogen Risk Assessment Models)

DOE efforts support public-private partnership: H_2 USA

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

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

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

Sustained, stable funding requests and appropriations

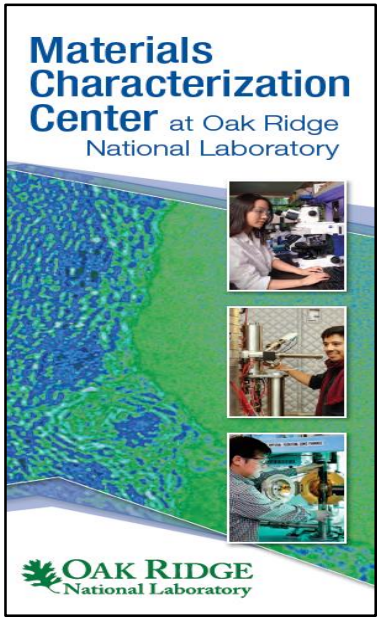
Leveraging National Labs

Lab Impact Initiative

- Tech to Market
- Small Business Vouchers
- Lab Corps

Example:

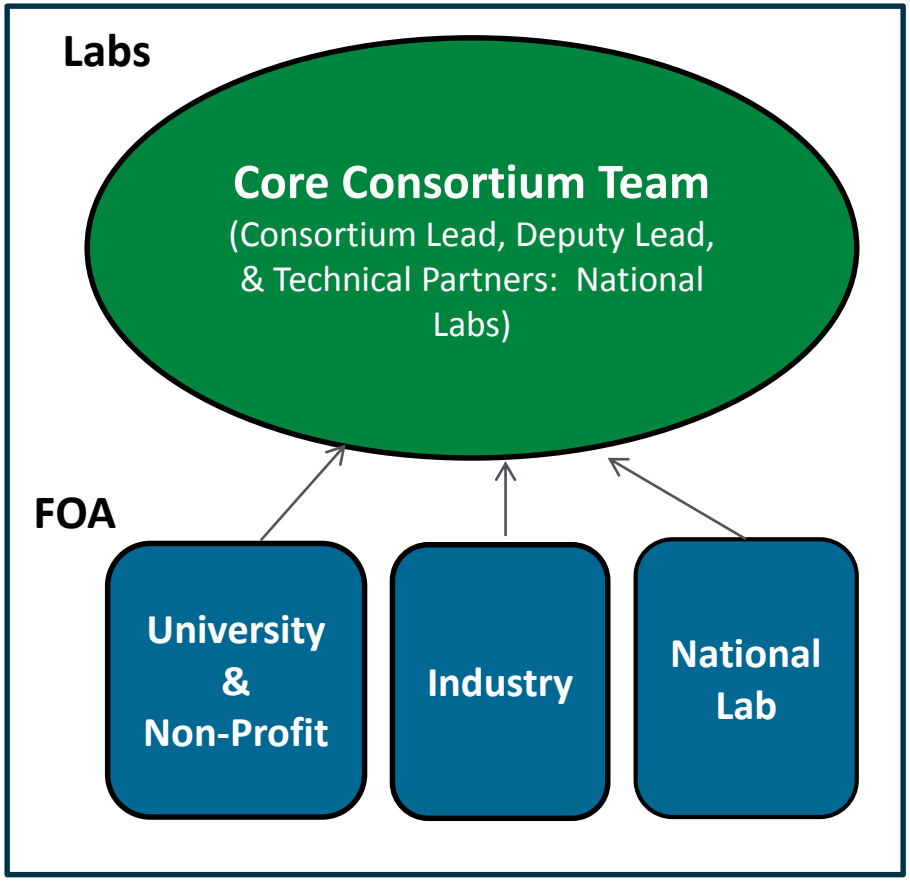
FCTO will provide 50% cost share for up to 10 partners through 'streamlined' CRADA
(up to $50K total per project)



Contact Karren More (morekl1@ornl.gov)

Consortium Approach

Multi-lab core capabilities with steady influx of new partners



New Consortia to Address Key Challenges

3 Consortia Launched:

Supporting the Energy Materials Network

Energy Materials Network
U.S. Department of Energy

ElectroCat
Electrocatalysis Consortium

PGM-Free Catalysts for Fuel Cells

HyMARC

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

Future: Renewable Hydrogen Consortium

Supporting

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

Focus: **Materials for Renewable H_2 Production** including:

Advanced Electrolysis	**Photoelectrochemical**	**Solar Thermochemical**

Future Focus: Renewable Hydrogen Production

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

Photo Credit : iStock

Two-step thermochemical water-splitting cycle ➡ Hydrogen

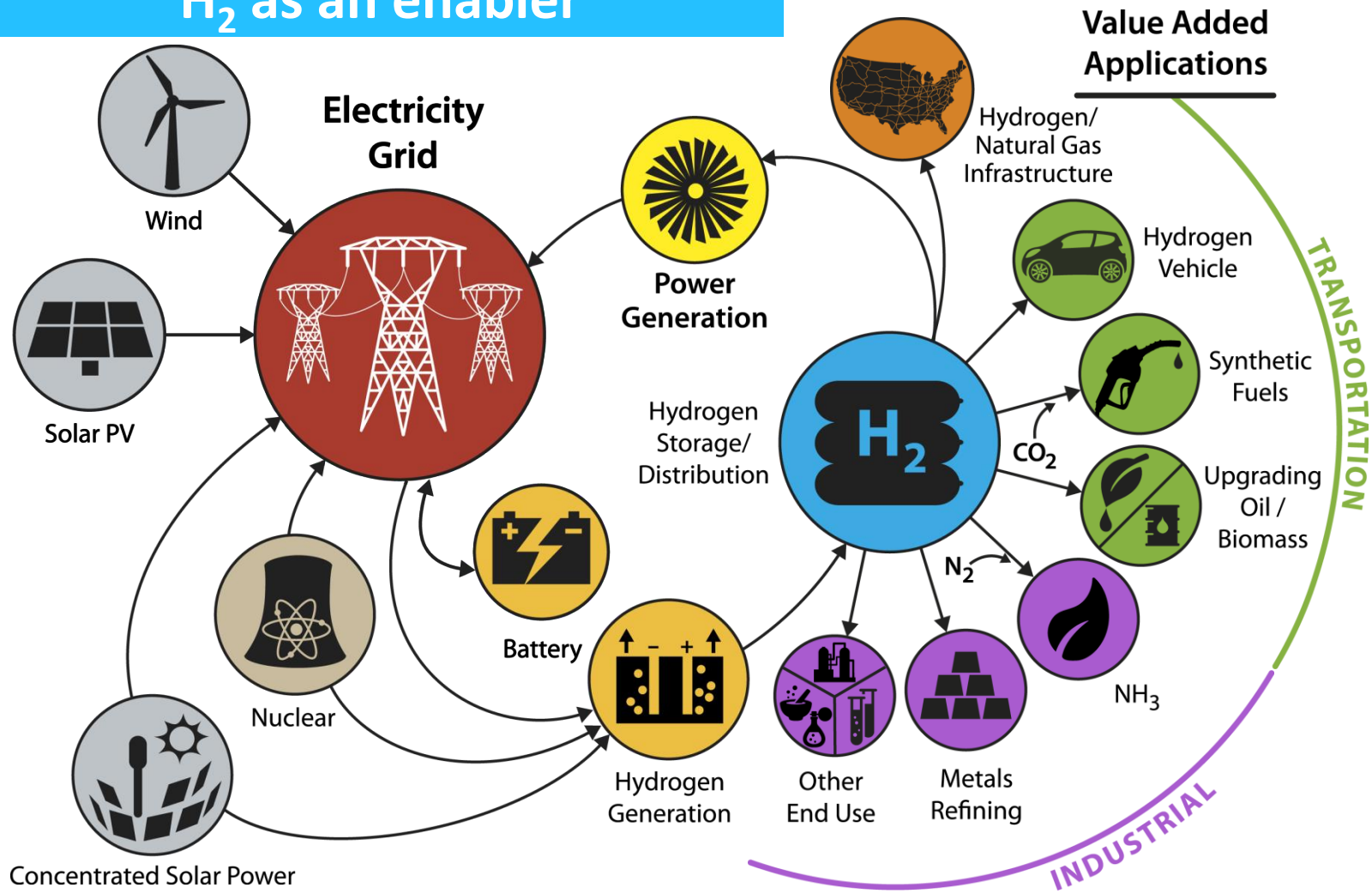
* Solar Thermochemical Hydrogen production

Source: McDaniel Anthony (SNL)

Harnesses the same physics occurring with lava flowing into water to produce H_2

H_2@Scale: Vision for the Future

H_2 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

H_2 @ Scale Potential:

A CLEANER FUTURE

50% fewer GHG emissions than today by 2050

Reduction by Sector

75%
Grid

25%
Transportation

25%
Industrial

MORE

Jobs
Security
Resiliency

Collaborations and Partnerships

R&D → Demonstration & Deployment → Accelerated Commercialization

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

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

International Energy Agency

- Implementing Agreements
- 25 countries

California Fuel Cell Partnership

Connecticut Hydrogen-Fuel Cell Coalition
Massachusetts Hydrogen Coalition
SC Hydrogen & Fuel Cell Alliance www.SCHydrogen.org
OFCC Ohio Fuel Cell Coalition
H2I Hawai'i Hydrogen Initiative

- State Partnerships and Collaborations

IPHE

- International Government Coordination
- 18 countries and European Commission

H2USA

- 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

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hydrogenandfuelcells.energy.gov