Plenary at Glance

• History
• Progress
• Future

Active in social media?
Share your thoughts using:

#H2AMR
#H2IQ
Fuel Cells: Big Leaps in the Last Year

Commercial FCEVs are here today!

Hyundai Tucson Fuel Cell SUV

Toyota Mirai

Honda FCV

FCEV: Fuel Cell Electric Vehicle
Market Growth in Fuel Cell Sales

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

Consistent ~30% annual growth since 2010

Fuel Cell Technologies Office

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)

www.energy.gov/eere/fuelcells
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

2. Demonstration
   - Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APU, buses, mobile lighting, refuse trucks
   - >220 FCEVs, >30 stations, >6M miles traveled
   - World’s first tri-gen station

3. Deployment
   - ~18,000 units
   - >11X additional purchases
   - ~1,600 units

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

Savings from Active Project Management & Downselects

More than $40M last 7 yrs
DOE Impact- H₂ and Fuel Cells

Innovation

Cumulative Number of Patents

- More than 2X
- 249 patents: By 2007
- 589 patents: By 2015

Commercialization

Cumulative Number of Commercial Technologies Entering the Market

- More than 2X
- 17 Technologies: By 2007
- 46 Technologies: By 2015

Jobs

From DOE-supported Commercial Technologies:

- 450 jobs: average per year
- 1,400 jobs: created or sustained

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

ARRA: American Recovery and Reinvestment Act
What can we learn from history?
Henry Ford and his first car, the Quadricycle, built in 1896
**DOE Cost Targets and Status**

**Fuel Cell System**
- High-Volume Projection: $280/kW
- Low-Volume Estimate: $60/kW 100K/yr
- 2020 Targets: $53/kW 500K/yr
- $40/kW

**H₂ Production, Delivery & Dispensing**
- $16/gge to $13/gge
- $7.5*/gge to $5**/gge
- $<4/gge

**Onboard H₂ Storage**
- 700-bar compressed system
- $33/kWh
- $17/kWh 100K/yr
- $15/kWh 500K/yr
- $10/kWh

**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

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*Based on Electrolysis  **Based on NG SMR*
Highlights: Renewable H₂ Production

Cost* Renewable H₂ Production Pathways

World Record

Solar-to-hydrogen Efficiency

16.4%

Benchmarked under outdoor sunlight at NREL

H₂ Cost* Targets

Less than $4/gge by 2020

Less than $7/gge Early Market

*high volume cost projections. See DOE Record for details.
Highlights: H₂ Delivery

Cost of Delivering and Dispensing H₂ from Central Production

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

Projected to **high volume with economies of scale**

**Delivery/dispensing** apportionment of the <$4/kg P&D target

Source: PNNL, Emerald Energy, Ames Laboratory
Highlights: H₂ Storage

Cost* of High Pressure H₂ Storage System

- **Targets**
  - 2013: $17
  - 2015: $15
  - 2020: $10
  - Ultimate: $8

Net Cost Reduction

- **12%** since 2013 for H₂ storage systems

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

World’s First

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

Highlights: Fuel Cells

Modeled Cost* of Fuel Cell System Over Time

World Record

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

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

8,000 Hrs. Ultimate Durability Target Established

Source: SNL
Fuel Cell Technologies Office

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

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

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

Supporting veterans and their families in 3 areas:
- Wellness
- Employment
- Education

Photo credit: philly.com
What can we learn from early gasoline infrastructure?
Many diverse options
Cans, barrels, home models, mobile refuelers
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 H₂ Stations Demonstrated To Date

CA: ~20 stations now, up to 100 planned
Northeast: 12 stations planned

~60 Stations*

- 49%
- 21%
- 16%
- 3%

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

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

SMR= Steam methane reforming
Example: **Sources of H₂ Infrastructure Maintenance**

- **Total Events:** 3,140
- **Compressor:** 24%
- **Dispenser:** 19%
- **Entire:** 16%
- **Safety:** 13%
- **Storage:** 8%
- **Reformer:** 7%
- **Thermal Management:** 6%
- **Other (Chiller, Feedwater):** 8%

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

Contamination is a key issue: See Database [www.nrel.gov/hydrogen/system_contaminants_data/](http://www.nrel.gov/hydrogen/system_contaminants_data/)

To participate: techval@nrel.gov

Providing insights to guide H₂ infrastructure activities and to maximize impact
Complementing Retail Stations: H₂ Refuel H-Prize

$1M Competition: On-site H₂ fueling

Finalist Team Announced!
More at hydrogenprize.org

Innovative packaging concepts
Electrolysis 350 and 700 bar

Email your Feedback
info@teamsimplefuel.com

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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:
# Hydrogen & Fuel Cells Budget

## Key Activity

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 15 ($ in thousands)</th>
<th>FY 16 ($ in thousands)</th>
<th>FY 17 ($ in thousands)</th>
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<tbody>
<tr>
<td>Fuel Cell R&amp;D</td>
<td>33,000</td>
<td>35,000</td>
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<tr>
<td>Hydrogen Fuel R&amp;D(^1)</td>
<td>35,200</td>
<td>41,050</td>
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<td>Manufacturing R&amp;D</td>
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<td>Technology Validation</td>
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<td>Safety, Codes and Standards</td>
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<td>Market Transformation</td>
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<td>Technology Acceleration</td>
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<td>13,000(^2)</td>
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<td>NREL Site-wide Facilities Support</td>
<td>1,800</td>
<td>1,900</td>
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<td><strong>Total</strong></td>
<td><strong>97,000</strong></td>
<td><strong>100,950</strong></td>
<td><strong>105,500</strong></td>
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### Office FY 2016*

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<th>Office</th>
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<tr>
<td>EERE</td>
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<tr>
<td>Basic Science</td>
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<tr>
<td>Fossil Energy, SOFC</td>
<td>$30.0M</td>
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### FY 2016 DOE Total: $~150M

\(^1\)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

Core Consortium Team
(Consortium Lead, Deputy Lead, & Technical Partners: National Labs)

Labs

FOA

University & Non-Profit

Industry

National Lab
New Consortia to Address Key Challenges

3 Consortia Launched:

Supporting the Energy Materials Network

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:

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

Visit www.fcpad.org
Future: Renewable Hydrogen Consortium

Focus: Materials for Renewable H₂ Production including:

- Advanced Electrolysis
- Photoelectrochemical
- Solar Thermochemical

Will be led by NREL with SNL and LBNL on core team: Multiple partners to be added in FY17
Future Focus: Renewable Hydrogen Production

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

Two-step thermochemical water-splitting cycle → Hydrogen

* Solar Thermochemical Hydrogen production

Harnesses the same physics occurring with lava flowing into water to produce $H_2$
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
H₂ @ 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

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

Demonstration & Deployment

- Implementing Agreements
- 25 countries

- State Partnerships and Collaborations

Accelerated Commercialization

- 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

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