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

FC EXPO 2016
Tokyo, Japan
March 2, 2016

Dr. Sunita Satyapal
Director
Fuel Cell Technologies Office
U.S. Department of Energy
“Let that be the common purpose here in Paris. A world that is worthy of our children. A world that is marked not by conflict, but by cooperation; and not by human suffering, but by human progress. A world that’s safer, and more prosperous, and more secure, and more free than the one that we inherited. Let’s get to work.”

- President Barack Obama at the launch of COP21
Reduce GHG emissions by 17% by 2020, 26-28% by 2025 and 83% by 2050 from 2005 baseline

By 2035, generate 80% of electricity from a diverse set of clean energy resources

Double energy productivity by 2030

Reduce net oil imports by half by 2020 from a 2008 baseline

Reduce CO₂ emissions by 3 billion metric tons cumulatively by 2030 through efficiency standards set between 2009 and 2016
Oil Dependency is Dominated by Vehicles

- Transportation is responsible for **66%** of U.S. petroleum usage
- **27%** of GHG emissions
- On-Road vehicles responsible for **85%** of transportation petroleum usage

- **16.0M LDVs** sold in 2014.
- **240 million light-duty vehicles** on the road in the U.S
- **10-15 years** for annual sales penetration
- **10-15 years** to turn over fleet

Poses significant economic, energy and environmental risks to U.S.

Photos courtesy of Spc. Jordan Huettl, U.S. Army; U.S. Environmental Protection Agency; and M. Studinger, NASA

It takes decades of sustained effort to turn over the fleet
“We’ve got to invest in a serious, sustained, all-of-the-above energy strategy that develops every resource available for the 21st century.”

- President Barack Obama

“As part of an all-of-the-above energy approach, fuel cell technologies are paving the way to competitiveness in the global clean energy market and to new jobs and business creation across the country.”

- Secretary Moniz, U.S. Department of Energy
The beginning of the DOE Fuel Cell Program...

1970s

A group of scientists and DOE managers set the foundation for DOE fuel cell programs

Lab researchers taught scientists around the world how to fabricate MEAs
Energy Policy Act of 2005 (Title VIII)

Program goals include:

“To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market”
FCEVs are on U.S. Roads Now!

Available for Commercial Sale
- $57,500 MSRP
- 67 mi/gge
- 312 mi range, ~5 min refuel
- 114 kW stack
- US: 200 2015, 3000 by 2017

Available for Lease
- $499/month lease
- 50 mi/gge
- 265 mi range
- 100 kW stack
- US: 70 thru May ‘15 (237 overall)

Just Announced at Auto Shows
- $60,000 MSRP
- $500/month lease for initial launch
- +300 mi range*
- 100 kW stack
- Initial launch planned for late 2016

*Preliminary range estimate determined by Honda

Additional OEMs planning FCEVs in soon
FCEV Ride-n-Drive at DOE Headquarters

Watch Secretary Moniz driving the Mirai!
http://energy.gov/eere/fuelcells/test-driving-toyota-mirai
Hydrogen and Hydrocarbons

Hydrogen has the highest energy content by mass but low energy density. Hydrogen has a specific energy of ~43 MJ/kg. Increasing specific energy can be achieved by using hydrogen in fuel cells. Similar components in gasoline have a specific energy of ~32 MJ/L.

Hydrocarbons, such as methane (CH₄), have a specific energy of 4.8 MJ/L at 700 bar, which is higher than hydrogen. Methane also has a higher energy density of 8.5 MJ/L (l). Increasing energy density can be achieved by using hydrocarbons in engines. Similar components in gasoline have an energy density of ~32 MJ/L.

Hydrogen has the highest energy content by mass but low energy density.
Hydrogen- An energy carrier feedstock

Source: DOE, NREL, Hydrogen and Fuel Cell Program
FCEVs Reduce Greenhouse Gas Emissions

Well-to-Wheels CO₂ Emissions (in grams per km) for 2035 Vehicles Technologies, except were indicated

>50% from Distributed Natural Gas*

>80% from Renewables** (Wind)

>90% from Renewables* (Wind)

[Graph showing emissions from different sources]

*Compared to 2012 gasoline vehicle
**Compared to 2035 gasoline vehicle

Source: http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

Substantial GHG reductions with H₂ produced from renewables
Market Report Just Published!

In 2014...

>$2B in revenues

>180 MW fuel cells shipped


Fuel Cells—Steady Market Growth

Consistent ~30% annual growth since 2010

Global Market Potential in 10-20 year

$14B – $31B/yr for stationary power

$11B /yr for portable power

$18B – $97B/yr for transportation
Mission

To enable the **widespread commercialization** of hydrogen and fuel cell technologies

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**2020 Targets by Application**

<table>
<thead>
<tr>
<th>Category</th>
<th>2020 Target 1</th>
<th>2020 Target 2</th>
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<tbody>
<tr>
<td>Fuel Cell Cost</td>
<td>$40/kW</td>
<td>$1,000/kW*</td>
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<tr>
<td></td>
<td></td>
<td>$1,500/kW**</td>
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<tr>
<td>Durability</td>
<td>5,000 hrs</td>
<td>80,000 hrs</td>
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<tr>
<td>H₂ Storage Cost (On-Board)</td>
<td>$10/kWh</td>
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<td></td>
<td>1.8 kWh/L, 1.3 kWh/kg</td>
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<tr>
<td>H₂ Cost at Pump</td>
<td>&lt;$4/gge</td>
<td>&lt;$7/gge (early market)</td>
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</table>

*For Natural Gas  
**For Biogas

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Integrated approach to widespread commercialization of H₂ and fuel cells
DOE Activities Span from R&D to Deployment

1. **Research & Development**

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

   **$124/kW** in 2006

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

3. **Deployment**

   >13,500 units

   **>8X** additional purchases

   ~1,600 units

   **WITH DOE FUNDING**
   (COST SHARE DEPLOYMENTS)

   **W/O DOE FUNDING**
   (ADDITIONAL PURCHASES)

   BU: Back Up Power

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

   **$124/kW** in 2006

   **$53/kW** in 2015*

   *$280/kW low volume

   **LIFT TRUCKS**

   **BU POWER**
## Hydrogen & Fuel Cells Budget

<table>
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<th>Key Activity</th>
<th>FY 15</th>
<th>FY 16</th>
<th>FY17</th>
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<tr>
<td></td>
<td>(in thousands)</td>
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<td>Approp.</td>
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<td>Request</td>
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<td>Fuel Cell R&amp;D</td>
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<td>35,000</td>
<td>35,000</td>
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<td>Hydrogen Fuel R&amp;D(^1)</td>
<td>35,200</td>
<td>41,050</td>
<td>44,500</td>
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<td>Manufacturing R&amp;D</td>
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<tr>
<td>Technology Validation</td>
<td>11,000</td>
<td>7,000</td>
<td>7,000</td>
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<tr>
<td>Safety, Codes and Standards</td>
<td>7,000</td>
<td>7,000</td>
<td>10,000</td>
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<tr>
<td>Market Transformation</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
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<tr>
<td>Technology Acceleration</td>
<td>0</td>
<td>0</td>
<td>13,000(^2)</td>
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<tr>
<td>NREL Site-wide Facilities Support</td>
<td>1,800</td>
<td>1,900</td>
<td>N/A</td>
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<tr>
<td><strong>Total</strong></td>
<td>97,000</td>
<td>100,950</td>
<td>105,500</td>
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</table>

### Office FY 2015

- **EERE**: $97.0M
- **Basic Science**: $18.5M
- **Fossil Energy, SOFC**: $30.0M

**FY 2015 DOE Total**: ~$150M

### Number of Recipients funded from 2008-2015

- **Industry**: >110
- **Universities**: >100
- **Laboratories**: 12

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\(^1\)Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

\(^2\)Combines Manufacturing R&D, Technology Validation, Market Transformation.

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*Sustained, stable funding requests and appropriations*
DOE Cost Targets and Status

**Fuel Cell System**
- $280/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

**2020 Targets**
- $53/kW
- $40/kW

**High-Volume Projection**
- $60/kW
- $53/kW
- $40/kW

**Low-Volume Estimate**
- $60/kW
- $40/kW

**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
Techno-Economic Analysis Guides R&D Portfolio

**Fuel Cells**
- Bipolar Plates
- Membranes
- BOP
- MEA
- Frames/Gaskets
- GDLs

Focusing on...
- Low and Non PGM Catalysts,
- Alkaline Membranes

**H₂ Station**
- Storage
- Cooling
- Dispensing
- Other

Focusing on...
- Advanced Compression
- Alternate Approaches

**H₂ Storage**
- BOP/Assembly
- Other processing
- Resin

Focusing on...
- Low Cost Carbon Fiber (CF)
- Long term Materials Approaches
Fuel Cell Progress and Status

2020 Goals: 65% peak efficiency, $40/kW, 5000 hour durability

2015 Status: 60% peak efficiency, $53/kW, 3900 hour durability

Significant progress but fuel cell cost reduction is leveling off. Further R&D is needed to overcome challenges - durability and cost.
**H₂ Production Pathways Cost Status**

**Current Technology**
- Natural Gas (D/C)
- Electrolysis (D)

**Near to Mid-Term:**
- Electrolysis - Wind and Solar Powered (D/C)
- Bio-derived Liquids (D/C)
- Fermentation (D/C)

**Long-Term (not shown):**
- Central Renewable H₂
  - Solar-based water splitting
  - Photolytic Bio-hydrogen

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_Distributed Production_
- **PEM Electrolysis**
  - Feedstock variability $0.03-$0.08 per MMBTU
- **Natural Gas Reforming**
  - Feedstock variability $4-$10 per MMBTU
- **Bio-Derived Liquid Reforming**
  - Feedstock variability $1-$3 per gallon

**Baseline Cost Projection**
- $10/	ext{kg-H₂}$
- $8/	ext{kg-H₂}$
- $6/	ext{kg-H₂}$
- $4/	ext{kg-H₂}$
- $2/	ext{kg-H₂}$
- $0/	ext{kg-H₂}$

2020 target: Production < $2/	ext{kg}$

_Distributed Production_
- **PEM Electrolysis**
  - Feedstock variability $0.03-$0.08 per kWh
- **Biomass Gasification**
  - Feedstock variability $40-$120 per dry short ton
- **Natural Gas Reforming**
  - Feedstock variability $4-$10 per MMBTU

**Baseline Cost Projection**
- $10/	ext{kg-H₂}$
- $8/	ext{kg-H₂}$
- $6/	ext{kg-H₂}$
- $4/	ext{kg-H₂}$
- $2/	ext{kg-H₂}$
- $0/	ext{kg-H₂}$

2020 target: Production < $2/	ext{kg}$

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*H₂ from NG can be competitive today - renewables is a longer-term focus*
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
# Lab Consortia Approach

## Activities

### Consortia Core
- **Fuel Cells: FC-PAD** (Fuel Cell Performance and Durability)
- **Storage: HyMARC** (Hydrogen Storage Materials Advanced Research Consortium)
- **ElectroCat (planned)**
- **Renewable H2 Production (planned)**

### Projects added through FOAs
- Companies, universities, labs
- 2-4 yrs/project
- May include seedling projects

*Subject to appropriations*

## Strategy and Structure

### Multi-Lab team with Lab Call to competitively select core team

**Lab Call**

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

**FOA**

- University & Non-Profit
- Industry
- National Lab

### Potential Future Collaborations

Relevant Offices and other Agencies (e.g. Office of Science, Advanced Manufacturing Office, etc.)
Materials Based Storage Database Analytics

21,548 page views

10,937 total visits from 124 countries

Top 3 Countries visiting:
• United States
• United Kingdom
• India

78% New Visitors
22% Return Visitors

Pages per Visit: 1.97
Average Time on Site: 2:12

Visit: hydrogenmaterialssearch.govtools.us

*Data courtesy of Google Analytics for data through June, 2015
What can we learn from history?
Henry Ford and his first car, the Quadricycle, built in 1896
Many diverse options, makes and models

Source: M. Melaina et al
Options for accessibility to fuel

Source: M. Melaina et al
Mobile refuelers bring fuel to you

Source: M. Melaina et al
Examples of Gasoline Refueling Methods

History shows phased introduction of different refueling methods
H₂ Production: Current Status

~10 million* metric tons of H₂ mostly from:

- Steam methane reforming of natural gas (SMR)

H₂ consumption market share by application

- Petroleum Recovery & Refining: 46.30%
- Ammonia Production: 44.50%
- Methanol Production: 3.70%
- Metal Production & Fabrication: 1.50%
- Electronics: 1.00%
- Food Industry: 2.00%


Near-term strategy for cost-competitive hydrogen fuel

- H₂ from Natural Gas through SMR
- At-scale production
- <$2/gge produced ($4.50/gge delivered)

Centralized H₂ production facilities

Early adoption of H₂ and fuel cell technologies can leverage production and delivery infrastructure associated with low cost NG reforming
Post-2018 FCEV deployment is anticipated to accelerate more rapidly than previously projected.
Rapid innovation is critical.
Collaboration is critical.
Public-private, regional and global partnerships.
H₂USA: Public-Private Partnership

**Mission**

To address hurdles to establishing hydrogen fueling infrastructure, enabling the large scale adoption of fuel cell electric vehicles

**Structure**

4 Working Groups coordinated by the Operations Steering Committee

**H₂USA’s Working Groups**

- Hydrogen Fueling Station
- Locations Roadmap
- Financing Infrastructure
- Market Support & Acceleration

More than 45 partners - Visit www.H2USA.org

~ 45 Partners in 2015

**Partners**

Visit www.H2USA.org
H₂ Infrastructure Status

H₂ Delivery Infrastructure

- **Current:** 1,600 miles of H₂ pipeline

H₂ Station Options

- **H₂ from central site:**
  - >$1-2 M for stations*
  - ~$7-$16/gge for H₂

- **Distributed production:**
  - Natural gas
  - Electrolysis

H₂ Stations in the U.S.

- **Current:** ~50 total (~10 public)
- **State Plans:**
  - CA- 100 stations, ~$100M planned through 2023
  - Northeast States & Hawaii
  - 8 State MOU- 3.3M ZEVs by 2025

*~100-300 kg/day (range of cost)

H₂ delivery options present opportunities for expanding H₂ infrastructure
California - H₂ Station Status

**How Many?**

<table>
<thead>
<tr>
<th>Status</th>
<th>Count</th>
</tr>
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<tbody>
<tr>
<td>Seeking new Site</td>
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<tr>
<td>Finishing Permit Apps</td>
<td>6</td>
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<tr>
<td>In Permitting</td>
<td>3</td>
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<tr>
<td>Planning Approval</td>
<td>4</td>
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<tr>
<td>Approved to Build</td>
<td>3</td>
</tr>
<tr>
<td>Under Construction</td>
<td>8</td>
</tr>
<tr>
<td>Fully Constructed</td>
<td>6</td>
</tr>
<tr>
<td>Open - Non-Retail</td>
<td>12</td>
</tr>
<tr>
<td>Open - Retail</td>
<td>52</td>
</tr>
</tbody>
</table>

**Where?**

- **Open – Non-Retail:** Burbank, Torrance#, Emeryville*, Harbor City*, Newport Beach*, OCSD**#

- **Open – Retail:** West Sac, Diamond Bar, LA Santa Monica Blvd#, UCI, Coalinga, San Juan Capistrano#, Long Beach, South SF, San Jose, La Canada Flintridge, Costa Mesa, Santa Monica

*As of February 25, 2016 (Data from CARB). # Stations in need of extension or upgrade

* Currently Torrance (H70 only), Santa Monica, San Juan Capistrano, and OCSD are offline (01/15/16 CaFCP SOSS)
Hydrogen Fueling Infrastructure Research Station Technology

Leveraging Expertise of National Labs

In support of

H₂USA and tasked to deliver:

Reference Station Design
✓ Report Delivered with Detailed Station Designs and Cost Estimates

Fuel Contaminant Detection
✓ Market Survey and Gap Analysis Complete

HyStEP (H₂ Station Equipment Performance Device)
✓ Design Complete
✓ Testing Complete

DOE’s H₂FIRST project supports H2USA goals to address infrastructure

Outstanding Partnership Award

By the Federal Laboratory Consortium (FLC) for efforts toward deployment of hydrogen fueling infrastructure
H₂Tools: One-stop for H₂ safety knowledge

- Includes resources on safety best practices, first responder training, and H₂ codes & standards
- Tracked downloads from Europe and Japan
- Resource translated in Japanese
- 50% of visits are international!

Enabling dissemination of safety information around the world
### International Partnership

**IPHE is an Inter-Governmental Partnership to**

- **Advance policies** supportive of H₂ and fuel cells
- **Increase** international **collaboration**
- **Share information** and lessons learned

### Recent and Upcoming IPHE Events

- 24th IPHE Steering Committee Dec 2015, in Grenoble France
- **New:** May 20th- IPHE Workshop in California USA

### 18 members working together to advance hydrogen and fuel cell technologies

<table>
<thead>
<tr>
<th>Australia</th>
<th>France</th>
<th>Republic of Korea</th>
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<td>Austria</td>
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<td>Europe</td>
<td>Japan</td>
<td>United States</td>
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Visit [www.iphe.net](http://www.iphe.net) for more information
Japan- US Collaboration in Action!

20th Steering Committee Meeting
City of Fukuoka, Japan (left)

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

2015 FC Expo
Tokyo, Japan (lower right)
Outreach and Communication Efforts

- **Publications- ~100/yr**
  - Monthly Newsletter
  - Success Stories
  - News Alerts, Blogs

- **Educated:**
  - >12,000 teachers
  - >35,000 code officials & first responders

- **Investor Days**

- **Congressional Caucus Events**

- **Annual Merit Review**
  June 2015- >1,800 attendees

- **Ride-n-Drives**

*Increasing public awareness and understanding about fuel cells and H₂*
2015: Big year for Hydrogen and Fuel Cells

The U.S. joined celebrating the 1st ever Hydrogen and Fuel Cells Day

www.energy.gov/eere/fuelcells
Going Forward

• R&D and accelerate Tech to Market (Lab impact)
  • Key Focus: Renewable H₂
  • Consortia, high throughput materials, safety, fuel cells, H₂

• Strategic, selective demonstrations

• Key analyses to guide RD&D and path forward
  • Life cycle cost; infrastructure, economic & environmental analyses, sustainable pathways, etc.

• Leverage activities to maximize impact
  • U.S. and global partnerships, H₂USA, States

Save the date: Annual Merit Review (AMR)
June 6-10, 2016- Washington DC
“It is literally true that you can succeed best and quickest by helping others to succeed”

Napoleon Hill
Thank You

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