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

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22nd World Hydrogen Energy Conference

Rio de Janeiro, Brazil – June 20, 2018
U.S. energy mix covers wide of energy sources

U.S. energy consumption by energy source, 2016

Total = 97.4 quadrillion British thermal units (Btu)

- Petroleum: 37%
- Natural gas: 29%
- Coal: 15%
- Nuclear electric power: 9%
- Renewable energy: 10%

Total = 10.2 quadrillion Btu

- Biomass: 46%
- Biofuels: 22%
- Wood: 19%
- Hydroelectric: 24%
- Wind: 21%
- Solar: 6%
- Geothermal: 2%

Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, Monthly Energy Review, Table 1.3 and 10.1, April 2017, preliminary data
Hydrogen is one part of an ‘all of the above’ portfolio

H₂ can be produced from diverse domestic sources

- Natural Gas (steam methane reforming current process today)
- Renewable Sources (wind, solar, biomass, hydro, geothermal)
- Nuclear
- Coal (with carbon sequestration)

Many applications rely on or could benefit from H₂

- Fuel Cells
- Engines/Turbines
- Energy Storage
- Petroleum Recovery & Refining
- Methanol Production
- Electronics
- Ammonia Production
- Metal Production & Fabrication
- Cosmetics
- Food Processing

Clean, sustainable, versatile, and efficient energy carrier
4 Key Messages
1. Progress on multiple fronts, increased industry activity and global interest
Upward trend with global fuel cell shipments

Fuel Cell Power Shipped (MW)

- 2014
- 2015
- 2016
- 2017

- Stationary
- Portable
- Transportation

- 650 MW fuel cell power shipped worldwide
- 70,000 fuel cell units shipped worldwide
- Approximately $2 Billion fuel cell revenue

Source: DOE and E4Tech

Electrolyzers: Over 100MW/year estimated global sales

*Courtesy of NOW, E4tech and partners: A collaborative effort to assess electrolyzer market potential
An exciting time for the transportation sector

Commercial fuel cell electric cars are here

Nearly 5,000 sold or leased in the United States

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

As of Dec 2017

Honda Clarity

Hyundai Tucson Fuel Cell SUV

Toyota Mirai
Interest in material handling equipment applications

More than 20,000 forklifts

Over 12 million refuelings
Long-Range, Heavy Duty Applications Emerging

Fuel cell buses in CA surpass 19M passengers

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

Industry demonstrates first heavy duty fuel cell truck in CA
Stationary Power for Multiple Applications

Fuel cells provided backup power during Hurricane Sandy in the U.S. Northeast

Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii

Fuel cells used to power new World Trade Center in NYC

Over 240 MW of fuel cell stationary power installed across more than 40 US states
Multiple H₂ and Fuel Cell Applications in the U.S.

U.S. Snapshot

- **>240MW** Backup Power
- **>20,000** Forklifts
- **>30** Fuel Cell Buses
- **35** H₂ retail stations
- Nearly **5,000** fuel cell cars

States with Growing Interest

Latest News: 200 stations by 2025 in CA

More than **$180M***

The total amount **states have invested** in H₂ infrastructure in the past decade*

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

**HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others with interest**
- Over $27M invested
- 12-25 stations planned in the NE

*Excludes recent announcement from CA to invest $235M in electric vehicles
2. Technical and institutional challenges remain and need to be addressed
U.S. Dept. Of Energy H₂ and Fuel Cells R&D Focus

**Early R&D Focus**

Applied research, development and innovation in hydrogen and fuel cell technologies leading to:

- Energy security
- Energy resiliency
- Strong domestic economy

**Early R&D Areas**

<table>
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<tr>
<th>Fuel Cells</th>
<th>Hydrogen Fuel</th>
<th>Infrastructure R&amp;D</th>
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<td>• PGM- free catalysts</td>
<td>• Production Pathways</td>
<td>• Safety</td>
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<tr>
<td>• Durable MEAs</td>
<td>• Advanced materials for storage</td>
<td>• Manufacturing</td>
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<tr>
<td>• Electrode performance</td>
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<td>• Delivery components</td>
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<td>• Others</td>
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PGM = Platinum group metals
MEA = Membrane Electrode Assembly
## Technology targets in various applications guide R&D

### Light Duty
- **Truck (MD)***
  - **High-Volume Projection:** $320 (200/yr)
  - **Low-Volume Estimate:** $6,100 (100/yr)

### Forklifts (5-kW)
- **High-Volume Projection:** $2,800 (10K/yr)
- **Low-Volume Estimate:** $2,800 (50K/yr)

### Backup Power (5-kW)
- **High-Volume Projection:** $7,400 (100/yr)
- **Low-Volume Estimate:** $7,400 (100/yr)

### Stationary (25-kW)
- **High-Volume Projection:** $3,000 (100/yr)
- **Low-Volume Estimate:** $3,000 (100/yr)

<table>
<thead>
<tr>
<th>($/kW)</th>
<th>Targets</th>
<th>High-Volume Projection</th>
<th>Low-Volume Estimate</th>
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<tbody>
<tr>
<td>Light Duty</td>
<td></td>
<td></td>
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<tr>
<td>Under Development</td>
<td>$230†</td>
<td>$320</td>
<td>$1,900</td>
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<tr>
<td>100K/yr</td>
<td>$45</td>
<td>$100</td>
<td>$2,000</td>
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<tr>
<td>500K/yr</td>
<td>$180*</td>
<td>$100</td>
<td>$1,500</td>
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<tr>
<td>Truck (MD)</td>
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*Based on commercially available FCEVs  †Based on state of the art technology

Note: Graphs not drawn to scale and are for illustration purposes only.
More R&D needed to meet affordability targets

Production, Delivery & Dispensing

$16/kg to $13/kg

$10/kg to $5/kg

<$4/gge

On-board Storage
(700-bar compressed system)

$24/kWh

$17/kWh

$15/kWh

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

DOE Targets
High-Volume Projection
Low-Volume Estimate
The Hydrogen Infrastructure Challenge

• Cost
• Reliability
• Availability
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 H₂ fueling design

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

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

www. hydrogenprize.org
More liquid stations planned in the U.S.

Based on data from NREL
3. H$_2$@Scale concept: value, volume and versatility
How much hydrogen for 1 car?

12,000 miles per year
60 miles per kilogram

= 200 kg or 0.2 tonnes per year

How much hydrogen for many cars?

100 M cars

= 10M cars

20M tons H₂ per year
20 B kg H₂ per year
H₂@Scale Energy System

Conventional Storage

Renewables
Nuclear
Fossil

Electric Grid Infrastructure

Power Generation

Hydrogen Generation

Hydrogen

Hydrogen Vehicle
Synthetic Fuels
Upgrading Oil / Biomass
Ammonia / Fertilizer
Metals Refining
Other End Use

Heating

Gas Infrastructure

Gas

Other
End Use
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.
The Duck Curve 101 - Example

Total Load (demand)

Load (net) on commercial utility grid (duck belly forms)

Solar Production

Midnight
Noon
Evening

Megawatts
The Duck’s belly is getting bigger

Two Concerns:

• **Low Net Load:** flexibility to reduce baseload generation resources is limited

• **High Ramp Rates in Evening:** flexibility of other generation to ramp up is limited

Source U.S. DOE Solar Energy Technologies Office

**Actual 3-hour ramp of 13GW on December 18, 2016**

**Steeper Ramps**

**Deeper Belly**

**Net Load of 8.5GW on May 14, 2017**

Can be addressed by
Lab testing electrolyzers’ value for ancillary services

First Ever Validation of Frequency Regulation with Electrolyzers

Lab testing shows dynamic response within seconds and potential for grid services
H₂@Scale: Enabling renewable energy transport?

Where we find abundant solar and wind energy
...and deliver it or co-locate distributed generation with demand for certain applications

Where energy is consumed
Analysis underway to guide future plans

Cost of long distance electricity transmission is high

Can H₂ or H₂ carriers be an option?
H₂@scale can enable increased renewable penetration

Top Countries for Renewable Electricity Installed

Source: 2016 NREL Renewable Energy Data Book
Labs assess resource availability. Most regions have sufficient resources.

Red: Only regions where projected industrial & transportation demand exceeds supply.
4. Continued collaboration and information sharing are key moving forward.
H₂ Safety Information Sharing Resources Available

H₂Tools.org : A one stop resource for hydrogen safety

- Includes resources on safety best practices, first responder training, and H₂ codes & standards
- Site visit tracking shows a global reach: 50% of visits have been international after launch
- Over 250,000 site visits
- Training resource translated into Japanese. Interest in other languages.

h2tools.org
IPHE: International Partnership for H₂ and Fuel Cells in the Economy

- **Share** information on H₂ and fuel cells, lessons learned, best practices
- **Increase** international collaboration to accelerate progress

- Australia
- Austria
- Brazil
- Canada
- China
- European Commission
- France
- Germany
- Italy
- Japan
- Republic of Korea
- Norway
- Russian Federation
- South Africa
- United Kingdom
- United States

Launched 2003 and includes 18 countries and the European Commission

U.S. elected as Chair
May 2018
Examples of Brazil and U.S. Collaboration on Energy

- **Fossil energy, energy efficiency, nuclear energy and other technical exchanges** (U.S.-Brazil Strategic Energy Dialogue or SED)
- **Natural gas energy storage** (DOE Fossil Energy Office, Energy Information Administration and Brazil’s Energy Planning Authority)
- **Buildings energy efficiency** (DOE Lawrence Berkley National Laboratory and Brazil’s Federal University of Santa Catarina)
Opportunities for outreach and to increase awareness

Celebrate Hydrogen & Fuel Cell Day
October 8 or 10/8
(Held on its very own atomic-weight day)

Information and Training Resources to Increase Awareness

Learn more at: energy.gov/eere/fuelcells

Download for free at:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource
Thank You

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energy.gov/eere/fuelcells