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

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The Versatility of Fuel Cell Technologies

Domestic Energy Sources

Clean, Efficient Energy Conversion

Multiple, Diverse and Versatile Uses

Source: DOE Fuel Cell Technologies Office
U.S. Transportation Sector

Over 90% of transportation sector relies on petroleum

Energy consumption by travel mode

2017

Focus has been on light duty vehicles but interest is growing in other applications

Source: DOE EIA Annual Energy Outlook 2018
The Beginning of the DOE Fuel Cell Program...

1970s

A group from labs, government and industry met at Los Alamos to set the foundation for DOE fuel cell programs.

Lab researchers taught scientists around the world how to fabricate fuel cell electrodes. Group from GM relocated to Los Alamos.
Forty years later for the first time in history....

Commercial fuel cell electric cars are here

Over 3,800 sold or leased in the United States

- No petroleum, no pollution
- Refuels in minutes
- More than 360 mi driving range
- Over 60 mpgge
Progress
Unprecedented Growth in the Fuel Cell Industry

Total power (in MW) shipped by application

Growth in Transportation

- 2014: 100 MW
- 2015: 300 MW
- 2016: 500 MW

Total power (in MW) shipped by fuel cell chemistry

Growth in PEMFC

- 2014: 100 MW
- 2015: 300 MW
- 2016: 500 MW

500 MW fuel cell power shipped worldwide

62,000 fuel cell units shipped worldwide

$1.6 Billion fuel cell revenue

Forklifts and Backup Power Units on the Rise

Over 10 million refuelings

Credit: BMW Manufacturing

Credit: Fuel Cell Energy

More than 7,500 backup power (BU) units

More than 16,000 forklifts

Supported by prior DOE funds

Total: 900 BU units
700 forklifts

Supported by industry

0
5,000
10,000
15,000
20,000
25,000
Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states

Over 235MW in stationary fuel cell power installed

Over 8,000 backup power units deployed or on order

Bus and Long-Range, Heavy Duty Applications Emerging

Fuel cell buses in CA surpass 17M passengers

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

Industry demonstrates first heavy duty fuel cell truck in CA
Fuel Cell Buses in the U.S. - Examples

**California**

Current: 19 Buses
San Francisco Bay Area (13), Thousand Palms (4), Santa Ana (1), Irvine (1).

Planned: Over 30 Buses
Oakland and Santa Ana (21), Thousand Palms (12).

**Michigan**

Current: 1 Bus
Flint

**Massachusetts**

Current: 1 Bus
Boston

**Ohio**

Current: 5 Buses
Canton
Planned: 7 Buses
Canton, Columbus

**Illinois**: Planned: 1 Bus (Champaign-Urbana)

Source: 2017 NREL Bus Report
Hydrogen and Fuel Cell Applications in the U.S.

**U.S. Snapshot**

- >235MW Backup Power
- >16,000 Forklifts
- >25 Fuel Cell Buses
- >30 H₂ retail stations
- More than 3,800 fuel cell cars

**Cumulative State Funding**

- More than $180M*
  - The total amount states have invested in H₂ infrastructure in the past decade*

- Latest News: 200 stations by 2025 in CA

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

- HI, SC, NY, CT, MA and others
  - Over $27M invested
  - 12-25 stations planned in the NE

*Excludes recent announcement from CA to invest $235M in electric vehicles
Challenges and Gaps
DOE Cost Status and Targets for R&D

**Fuel Cell R&D**
- **System**
  - High-Volume Projection: $180/kW^+
  - $50/kW^+ 100K/yr
  - $45/kW^+ 500K/yr
  - $40/kW

**Hydrogen R&D**
- **Production, Delivery & Dispensing**
  - $16/gge^+ to $10/gge
  - $7.5*/gge to $5/**/gge
  - <$4/gge

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

*Based on Electrolysis **Based on NG SMR †Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

Note: Graphs not drawn to scale and are for illustration purposes only.
Data through 2017
Fuel Cell Major Cost Components – Example

Cost contributors depend on manufacturing volumes & scale

Cost by Component – DOE Independent peer-reviewed analysis

High-Volume (500,000/yr)
Challenges: Catalyst and Bipolar Plates

Low-Volume (1,000/yr)
Challenges: Membrane, GDL, Catalyst

Hydrogen Production

Production cost goal: <$2/kg (excludes delivery, storage, dispensing)

Projected Production Cost* by Pathway

- **Fossil Resources** (broad range of projected spot prices)
  - < $2/kg

Production Pathway:
- PEM Electrolysis: 3¢-8¢/kWh electricity
- High-T Electrolysis: 3¢-8¢/kWh electricity
- Biomass Gasification: $40-$120/dry short ton

**Target Production**
- < $2/kg

Early Stage R&D Examples:
- Innovative Reactor Concepts
- Novel Devices and Components
- Materials Development
- PEC, thermochemical methods, advanced electrolysis, biological methods

*Ranges with sensitivities to feedstock price variations
Hydrogen Delivery

Delivery cost goal: <$2/kg** (includes dispensing at the station)

Cost by Component
Tube Trailer Delivery Example

- Compressor 31%
- Storage 14%
- Dispenser 14%
- Electrical 6%
- Pre-Cooling 16%
- Controls/Other 19%

**gge = gallon of gasoline equivalent

Early Stage R&D Examples

Innovative concepts on:
- Gaseous & Liquid Delivery
- Compressors
- Storage
- Dispensers
- Materials Compatibility
- Liquefaction
- Pipeline & joining materials
- Other innovations (e.g. liquid carriers, etc.)
Hydrogen Storage

Storage goal: <$8/kWh, > 300 mile range, no space compromises

Cost* of High Pressure H₂ Storage System

- 2013: $17
- 2015: $15
- 2025: $9
- Ultimate: $8

Early Stage R&D Examples

- Low-cost carbon fiber precursors for high pressure H₂ storage
- Advanced hydrogen storage materials with higher energy densities and favorable thermodynamics

Still need to increase storage density

*Assumes high volume (500K/yr.), 2007$, 700-bar type IV single tank system. Based on program record 15013
Example: Potential Option for Heavy Duty Vehicles

Cryo-compression can offer densities higher than liquid hydrogen

The Hydrogen Infrastructure Challenge

- Cost
- Reliability
- Availability
What can we learn from history?
Fuel was made widely available before the retail stations of today
Gasoline History: Many diverse options
Cans, barrels, home models, mobile refuelers

Source: Milkues, 1978

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

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

Ivys Energy Solutions (MA)
McPhy Energy (MA)
PDC Machines (PA)
Opportunities and Focus Areas “H2@Scale”
H2@Scale Energy System

*Illustrative example, not comprehensive
Source: NREL
H2@Scale Energy System
Electricity Mix Landscape is Changing - Example

Example: Installed Capacity in Texas

Source: ERCOT
Hydrogen Energy Storage is Scalable

One hydrogen cavern could provide ~ 100 GWh energy storage

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.

Image: Hydrogen Council
First Ever Validation of Frequency Regulation with Electrolyzers

Lab testing shows dynamic response within seconds and potential for grid services
Labs assess resource availability. Most regions have sufficient resources. Red: Only regions where projected industrial & transportation demand exceeds supply.
Hydrogen Station Analysis - Example

NREL’s Station Rollout Scenario Analysis in support of H₂USA

Examples of variables considered in scenarios:

☑️ Consumer adoption ☑️ Station Expansion Network

Source: Marc Melaina, et al, NREL

Analysis example:
7,750 H₂ Stations by 2050

Urban markets scenario (20% FCEV market share*)

*Nationwide
Water Consumption Analysis

Life-Cycle Water Consumption: Gallons Water per 100 miles driven

- Gasoline ICEV: E10: 23 gallons
- Diesel ICEV: 8.1 gallons
- Gasoline ICEV: E85: 3.9 gallons
- CNG ICEV: 147 gallons
- BEV210: US Grid Electricity: 26 gallons
- BEV210: Solar Electricity: 1.6 gallons
- FCEV: Dist. Electrolysis (Solar): 9.0 gallons
- FCEV: Dist. NG SMR: 13 gallons
- FCEV: Dist. Electrolysis (US Grid): 65 gallons
- FCEV: Cent. NG SMR: 12 gallons
- FCEV: Cent. NG SMR w/ CCS: 14 gallons
- FCEV: Cent. Electrolysis (Wind): 13 gallons
- FCEV: Cent. Biomass (Gas. H₂): 27 gallons
- FCEV: Cent. Coal w/ CCS: 22 gallons

Source: Program records 17005 (www.hydrogen.energy.gov/pdfs/17005_water_consumption_ldv_fuels.pdf)
Argonne Analysis on Byproduct Hydrogen

More than 4,000 metric tons per day of H\textsubscript{2} byproduct from chlorine and ethylene cracker plants

Existing hydrogen byproduct production capacity could serve

8 Million hydrogen fuel cell cars

Hydrogen Production Capacity
(metric ton per day)
- Ethylene Crackers - Existing
- Ethylene Crackers - Planned
- Chlorine Plants

Source: A. Elgowainy, et al

*average FCEV needs approx. 0.5 kg of hydrogen per day
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
Collaboration Tools: H₂ Safety Information Sharing

H₂Tools.org : A one stop resource for hydrogen safety

- Site visit tracking shows a global reach: 50% of visits have been international after launch
- Over 150,000 site visits
- Training resource translated into Japanese. Interest in other languages.

h2tools.org

- Includes resources on safety best practices, first responder training, and H₂ codes & standards
Recently Announced!

Energy Department Partners with Japanese Counterpart to Accelerate Hydrogen and Fuel Cell Technologies

OCTOBER 10, 2017
Japan-US and Global Collaboration in Action!

2013 Steering Committee Meeting Fukuoka, Japan (left)

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

2015 FC Expo Tokyo, Japan (lower middle)

2017 DOE (lower right)
International Inter-Governmental Partnership

- Enables monitoring of global landscape
- **Sharing** information on H₂ and fuel cells
- **Increases** international collaboration
- **Sharing** lessons learned

Launched 2003 and includes 18 countries and the European Commission
Collaboration Tools: Increasing Awareness

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

First time ever
All Agencies working on hydrogen and fuel cell technologies at Annual Merit Review (AMR)
See www.hydrogen.energy.gov

Save the Date
June 13-15, 2018
DOE AMR
Washington DC

Learn more:
energy.gov/eere/fuelcells

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

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