1970s

Labs, industry and gov’t set the foundation for DOE fuel cell programs in the mid 1970s.

Lab researchers taught scientists around the world how to make fuel cells. GM relocated their fuel cell group to Los Alamos.
Recent Emphasis through EPACT 2005

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”

Additional goals for infrastructure by 2020
Fuel Cell Technologies Office

Fuel Cells Market Overview

Fuel Cell Systems Shipped Worldwide by Application


- Consistent ~30% annual growth since 2010
- Global Market Potential in 10-20 years*
  - $14B – $31B/yr for stationary power
  - $11B/yr for portable power
  - $18B – $97B/yr for transportation

Fuel Cell Electric Vehicles (FCEVs) are here – more to come

Cost Status and Targets

**Fuel Cell System**
- $280/kW
- $60/kW (100K/yr)
- $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

- **2020 Targets**
- **High-Volume Projection**
- **Low-Volume Estimate**

*Based on Electrolysis  **Based on NG SMR

*For illustration purposes only, not drawn to scale
# Hydrogen & Fuel Cells Budget

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 15 ($ in thousands)</th>
<th>FY 16 ($ in thousands)</th>
<th>FY17 Request ($ in thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell R&amp;D</td>
<td>33,000</td>
<td>35,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Hydrogen Fuel R&amp;D¹</td>
<td>35,200</td>
<td>41,050</td>
<td>44,500</td>
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<tr>
<td>Manufacturing R&amp;D</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Systems Analysis</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Technology Validation</td>
<td>11,000</td>
<td>7,000</td>
<td>7,000</td>
</tr>
<tr>
<td>Safety, Codes and Standards</td>
<td>7,000</td>
<td>7,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Market Transformation</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Technology Acceleration</td>
<td>0</td>
<td>0</td>
<td>13,000²</td>
</tr>
<tr>
<td>NREL Site-wide Facilities Support</td>
<td>1,800</td>
<td>1,900</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>97,000</strong></td>
<td><strong>100,950</strong></td>
<td><strong>105,500</strong></td>
</tr>
</tbody>
</table>

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
H₂@Scale: A potential opportunity

H₂ as an enabler

Today: 10M tons H₂ produced
>1600 mi pipeline
~ 50 stations (~20 public)

*Illustrative example, not comprehensive
Source: NREL; Lab Big Idea Summit
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

www.hydrogenprize.org

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Fuel Cell Technologies Office Activities By State
Prime and Subcontract Recipients

Source: FY 2015 Annual Progress Report- Project Listings by State
(https://www.hydrogen.energy.gov/pdfs/progress15/xv_project_listing_by_state_2015.pdf)
**Impact: H₂ and Fuel Cells**

**Innovation**

Cumulative Number of Patents due to DOE funds

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

**Commercialization**

Cumulative Number of Commercial Technologies Entering the Market

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

**Economy and Environment**

**U.S. Job Potential**

- 360K to 675K jobs in fuel cells and hydrogen
- Job gains across 41 industries

*2008 DOE Employment Study currently being updated

**GHG Emission Reduction**

- CO₂: 50% - 90% per vehicle
- More than

**Examples of Commercial Technologies**

- Catalysts
- Fuel Cell System Components
- Tanks
- Electrolyzers

**Impact of DOE Investment on Industry**

<table>
<thead>
<tr>
<th>Revenues</th>
<th>Additional Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 7X the DOE Investment</td>
<td>More than 5X the DOE Investment</td>
</tr>
</tbody>
</table>

*for selected companies
Thank You

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

hydrogenandfuelcells.energy.gov
Back Up
FCEVs Reduce Greenhouse Gas Emissions

Compared to 2012 gasoline vehicle

>50% with H₂ from Distributed Natural Gas*

>80% with H₂ from Renewables* (Wind)

>90% with H₂ from Renewables** (Wind)

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

Source: [http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf](http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf)

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

Substantial GHG reductions with H₂ produced from renewables
Well-to-Wheels Analysis: GHG Emissions and Petroleum Use

Electric Drive With Low Carbon Fuels - Pathway with lowest GHG emissions and petroleum use

Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf
**REFUELING/RECHARGING TIME**

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Rate (miles/min)</th>
<th>Long-Trip % Charging Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>150</td>
<td>1-2%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>100</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>EV Supercharger</td>
<td>6</td>
<td>15%</td>
</tr>
</tbody>
</table>

- Fuel cell vehicles have similar functionality to current Internal Combustion Engines
- Battery charging rates (mile/min) limited to about an order of magnitude less than \( \text{H}_2 \) refueling rates

Assumptions: Gasoline & Hydrogen Electric: 350 mile range, Battery Electric: 250 mile range

Source: General Motors, with permission April 2016
DOE Activities Span from R&D to Deployment

**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

*280/kW low volume

**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

**Deployment**

With DOE Funding (Cost Share Deployments)

~18,000 units

>11X additional purchases

~1,600 units

Bu: Back Up Power

Bu Power

Lift Trucks

W/O DOE Funding (Additional Purchases)

FCEV: Fuel Cell Electric Vehicle

APU: Auxiliary Power Units
Early Market Strategies Increase Volume

Early Markets enable:

- Fuel cell cost reduction
- Robust supply base
- Emerging infrastructure
- Customer acceptance

Early Markets Applications Recently Deployed in the U.S.

- Fuel Cell Tow Trucks
- Fuel Cell Bus Fleets
- Forklifts
- Backup Power