U.S. Department of Energy Fuel Cell Activities: Progress and Future Directions

Total Energy USA
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Overview
Fuel Cells - An Emerging Global Industry

**U.S. Clean Energy Patents**

- Source: Clean Energy Patent Growth Index
- Fuel Cells lead with over 1000 patents issued in 2011.
- Nearly double the second place holder, solar, which has ~540 patents.

**Clean Energy Patent Growth Index[1]** shows that fuel cell patents lead in the clean energy field with over 950 fuel cell patents issued in 2011.

- Top 10 companies: GM, Honda, Samsung, Toyota, UTC Power, Nissan, Ballard, Plug Power, Panasonic, Delphi Technologies

**Fuel Cell Patents Geographic Distribution 2002-2011**

- United States 46%
- Japan 31%
- Germany 7%
- Korea 7%
- Other 3%

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Worldwide Investment & Interest Are Strong and Growing

Interest in fuel cells and hydrogen is global, with more than $1 billion in public investment in RD&D annually.

Examples of Global Players in addition to the U.S.

- **Japan**: $242 million in FY12, $400 million requested for FY13 (~$1.0 Billion in funding for FY08–FY12);
  - Nearly 30,000 residential fuel cells deployed (40,000 by April 2013)
  - Plans for 2 million FCEVs and 1000 H₂ stations by 2025 (100 stations by 2015)

- **Germany**: >$1.2 Billion in funding (’07 – ’16)
  - plans for 1,000 hydrogen stations
  - >22,000 small fuel cells shipped.

- **European Union**: >$1.2 Billion in funding (’08–’13)

- **South Korea**: ~$590 M (’04–’11); plans to produce 20% of world shipments and create 560,000 jobs in Korea

- **China**: Thousands of small units deployed; 70 FCEVs, buses, 100 FC shuttles at World Expo and Olympics

**Worldwide fuel cell markets continue to grow (>20,000 units shipped in 2011; >35% increase over 2010)**,
As the cost of fuel cells comes down (through technological improvements and economies of scale), they will become competitive in a growing number of markets.

The Market Potential

Independent analyses show global markets could mature over the next 10–20 years, producing revenues of:

- $14 – $31 billion/year for stationary power
- $11 billion/year for portable power
- $18 – $97 billion/year for transportation

Potential Early Markets to Reduce Cost

References: ¹ITA 2010 Outlook, ²MicroCHP, ³Large scale CHP, ⁴Industry estimate based on refrigerated truck and trailer APUs (total number), ⁵http://hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf
The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.

WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS
- Transportation
- Stationary Power
- Auxiliary Power
- Backup Power
- Portable Power

Nearly 300 projects currently funded at companies, national labs, and universities/institutes
Federal RD&D Role

DOE’s Focus is on **High-Risk, High-Impact R&D**

Examples of near-term and long-term R&D

- **High-risk** and **High Impact**

  - **Near Term**
    - High-pressure Tanks
    - Low-cost Pt Catalysts
    - Low-cost Membranes and Membrane Electrode Assemblies
  - **Long Term**
    - Non-Pt Catalysts
    - Materials-based H₂ storage (e.g., spillover)
    - Photobiological & Photoelectrochemical H₂ production
    - Liquid-basd fuel cells

- **Low Risk** and **Less Impact**

  - **Near Term**
    - High-Temperature Membranes
    - Cryo-compressed Tanks
    - Compressors
    - Low-cost Tanks
  - **Long Term**

DOE supports RD&D, for both near-term and long-term impact with emphasis on high-risk, high-impact projects.
Summary: Program Impact

DOE FCT funding has led to 363 patents, 35 commercial technologies and 65 emerging technologies.

Example of Impact: ~$70M in funding for specific projects was tracked – and found to have led to nearly $200M in industry investment and revenues.

DOE FCT funding has enabled:

- > 80% cost reduction in PEM fuel cells since 2002, > 35% since 2008
- Reduction in Pt by a factor of 5 since 2005
- > Double the durability since 2006
- > 80% cost reduction in electrolyzer stacks in the last decade

Leveraging DOE funds: Early market deployments of ~1,400 have led to >5,000 additional purchases by industry with no DOE funding.


FCT Patent Breakdown

<table>
<thead>
<tr>
<th>Category</th>
<th>Total Patents</th>
<th>Licensed</th>
<th>Seeking to License</th>
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</thead>
<tbody>
<tr>
<td>Fuel Cells</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Production &amp; Delivery</td>
<td></td>
<td></td>
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<tr>
<td>Storage</td>
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Backup Power | Lift Trucks

DOE cost-shared deployments led to >3X additional purchases.

~1,400 DOE cost-shared deployments

>5,000 purchases without DOE funding
Projected high-volume cost of fuel cells has been reduced to $47/kW (2012)*

• More than 35% reduction since 2008

• More than 80% reduction since 2002

*Based on projection to high-volume manufacturing (500,000 units/year). The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.
Current Portfolio Addresses High-Impact Areas - PEM Example

Strategic technical analysis guides focus areas and priorities for budget. Need to reduce cost but also increase durability.

Targeted 80 kW PEM fuel cell system cost: $30/kW at 500,000 units/yr

Strategies to Address Challenges – Catalyst Examples
- Lower PGM Content
- Pt Alloys
- Novel Support Structures
- Non-PGM catalysts
Challenges and Strategy: Stationary Applications

Further reduction in capital cost of medium scale distributed generation/CHP (100 kW – 3 MW) need to be pursued to facilitate widespread commercialization.

Technical Parameters (2015)

- Electric Efficiency (LHV): 45.0%
- Combined Effic.(LHV): 87.5%
- Size, MWe: 1
- Operating Life, years: 20
- Equipment, $/kWe: 2,300
- Engineering & Installation, $/kWe: 700
- Fixed O&M, $/MWh: 13
- Variable O&M, $/MWh: 8.0

Funding:

- Natural Gas $7/MMBtu
- Cap Cost $2/MW
- Equity Return 6%
- Stack Life 40,000 hrs

LCOE in Cents/kWh of CHP Electricity

- Nat Gas $11/MMBtu
- Cap Cost $3/MMW
- Equity Return 13%
- Stack Life 80,000 hrs

Sensitivity analysis around 2015 targets assesses impact of fuel cell system cost and durability on commercialization prospects.

- Further reduction of fuel cell system cost required to expedite commercialization.
- Natural gas availability and fuel cell performance (efficiency) gains will enhance the technology’s market attractiveness.
- Development of a cost-effective process for removing fuel contaminants would allow for fuel flexibility.
- Also applicable for tri-gen (H₂ production).
Opportunities for Distributed Generation (DG) and Efficient use of Natural Gas- and Biogas?

Combined Heat & Power (CHP) offers opportunity to recover losses

More than two-thirds of the fuel used to generate power in the U.S. is lost as heat.

Conversion Losses 63.9%

Range of electrical efficiencies for DG technologies

Typical Electrical Efficiency (HHV)

Steamb Turbine  Recip. Engine  Gas Turbine  Micro-Turbine  Fuel Cell

New World Trade Center (Freedom Tower) will use 12 fuel cells totaling 4.8MW

Critical Loads- e.g. banks, supermarkets, hospitals, data centers

Examples of fuel cell deployments using natural gas

Source: EPA, Catalog of CHP Technologies, December 2008

Electrical Efficiency

DOE/NREL is aggregating and analyzing durability results by application that protect proprietary data, providing a benchmark in time of state-of-the-art fuel cell durability. Results include 82 data sets from 10 fuel cell developers.

<table>
<thead>
<tr>
<th>Application</th>
<th>Avg Projected Time to 10% Voltage Drop</th>
<th>Avg Operation Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backup power</td>
<td>2,400</td>
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<tr>
<td>Automotive</td>
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</tr>
<tr>
<td>Prime</td>
<td>11,200</td>
<td>7,000</td>
</tr>
</tbody>
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PEM & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing.

Please send inquires to Fuelcelldatacenter@ee.doe.gov
Future Directions

Continue and strengthen critical R&D

- Hydrogen, fuel cells, manufacturing, safety, codes and standards, etc.

Conduct strategic, selective demonstrations of innovative technologies

Continue to conduct key analysis to guide RD&D and path forward, determine infrastructure needs and opportunities to address them

Leverage activities to maximize impact

- U.S. and global partnerships

Continue and strengthen communication and outreach
Thank You

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New energy data initiative to share the latest energy information and data. Please visit:


hydrogenandfuelcells.energy.gov