Hydrogen and Fuel Cell Activities

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Fuel Cell Technologies Program
Market Transformation Manager
Stationary Fuel Cell Applications

Variety of stationary fuel cell applications highlight positive market potential.

Assured Power

First National Bank of Omaha
Omaha, Nebraska

On-Line Critical Power

Verizon
Garden City, New York

Indoor Green Power / Cogeneration

Renewable Fuel (ADG)

Wastewater treatment plants
New York, New York

Off-Grid Power

Central Park Police Station,
New York, New York

4 Times Square
New York, New York
Data Centers Are A Good Fit

Multiple Uses for FC Energy Streams

- **Power**
  - Lighting
  - Air conditioning
- **Thermal Energy**
  - Adsorption A/C
    - Supplements electric chillers
      - Thermal reduces electricity consumption
      - Reduces grid CO₂ generation
    - Space and water heating
    - Desiccant dehumidification
Fuel cells emit about 75 – 90% less NOx and about 75 – 80% less particulate matter (PM) than other CHP technologies, on a life-cycle basis. In addition, similar to other CHP technologies, fuel cells can provide more than 50% reduction in CO2 emissions, when compared with the national grid.
Fuel cells use an efficient electrochemical process to generate electricity and heat, with low or zero emissions, offering benefits in a wide range of applications.

Types of Fuel Cells

- **Polymer Electrolyte Membrane (PEMFC)**
  - **Pros**: Low-temperature operation, quick start, and high power density
  - **Cons**: Expensive catalysts
  - **Applications**: Stationary generation, specialty vehicles, transportation, portable power

- **Phosphoric Acid Fuel Cell (PAFC)**
  - **Pros**: Low-temperature operation and high efficiency
  - **Cons**: Low current and power density
  - **Applications**: Distributed generation

- **Alkaline Fuel Cell (AFC)**
  - **Pros**: Low temperature operation and high efficiency
  - **Cons**: Expensive impurity removal
  - **Applications**: Military and space

- **Solid Oxide Fuel Cell (SOFC)**
  - **Pros**: High efficiency, multiple fuel feedstocks, usable waste heat, and inexpensive catalysts
  - **Cons**: Slow start-up and corrosion issues
  - **Applications**: Auxiliary Power Units (APUs) and distributed generation

- **Molten Carbonate Fuel Cell (MCFC)**
  - **Pros**: High efficiency, multiple fuel feedstocks, and usable waste heat
  - **Cons**: Slow start-up and corrosion issues
  - **Applications**: Electric utility
Total Megawatts Shipped Worldwide for Stationary Fuel Cells*

Source: 2011 Pike Research  Preliminary Analysis
Fuel Cells vs. Combustion

Fuel cells are not heat engines, so their efficiency can exceed the Carnot efficiency.

Conventional engines and turbines convert chemical energy into thermal energy prior to conversion to electrical energy. The efficiency of converting thermal energy to electrical energy is bounded by the Carnot efficiency.

Fuel cells convert chemical energy directly into electrical energy, bypassing inefficiencies associated with thermal energy conversion. The available energy is equal to the Gibbs free energy.

Source: EPA, Catalog of CHP Technologies, December 2008

Adapted from Larminie and Dicks, Fuel Cell Systems Explained, 2000
Analysis efforts are underway, to provide information on potential costs and benefits of a variety of stationary fuel cell applications.

Example: Cost of Electricity from Commercial-Scale Stationary Fuel Cell

**Performance Parameters**
- System Electric Efficiency = 45% (LHV Basis)
- System Total Efficiency = 77% (LHV Basis)
- System Size = 1,400 kW
- System Life = 20 years
- Capital cost = $3.5 million
- Installed cost = $5.3 million

**Financial Assumptions**
- Startup year = 2010
- Financing = 54% equity
- Interest rate = 7%
- Financing period = 20 years
- After-tax Real IRR = 5%
- Inflation rate = 1.9%
- Total tax rates = 38.9%
- Depreciation schedule = 7 years (MACRS)
- Payback period = 11 years
- Stack replacement cost distributed annually

**Operation Assumptions**
- System utilization factor = 95%
- Restacking cost = 30% of installed cap. cost
- Heat value = cost of displaced natural gas from 80% efficient device

**Source:** NREL Fuel Cell Power Model

Example for MCFC 1.4 MW
Assessing the Potential for Micro CHP

Inexpensive Natural Gas

<table>
<thead>
<tr>
<th>Natural Gas Cost ($/kWh)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WYOMING</td>
<td>$ 0.029</td>
</tr>
<tr>
<td>ALASKA</td>
<td>$ 0.030</td>
</tr>
<tr>
<td>UTAH</td>
<td>$ 0.032</td>
</tr>
<tr>
<td>COLORADO</td>
<td>$ 0.035</td>
</tr>
<tr>
<td>MONTANA</td>
<td>$ 0.038</td>
</tr>
<tr>
<td>NORTH DAKOTA</td>
<td>$ 0.039</td>
</tr>
<tr>
<td>IDAHO</td>
<td>$ 0.040</td>
</tr>
<tr>
<td>SOUTH DAKOTA</td>
<td>$ 0.040</td>
</tr>
<tr>
<td>NEW MEXICO</td>
<td>$ 0.042</td>
</tr>
<tr>
<td>CALIFORNIA</td>
<td>$ 0.042</td>
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</table>

Expensive Electricity

<table>
<thead>
<tr>
<th>Electricity Cost ($/kWh)</th>
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<tbody>
<tr>
<td>HAWAII</td>
<td>$ 0.235</td>
</tr>
<tr>
<td>CONNECTICUT</td>
<td>$ 0.194</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>$ 0.181</td>
</tr>
<tr>
<td>MASSACHUSETTS</td>
<td>$ 0.165</td>
</tr>
<tr>
<td>NEW JERSEY</td>
<td>$ 0.159</td>
</tr>
<tr>
<td>ALASKA</td>
<td>$ 0.153</td>
</tr>
<tr>
<td>MAINE</td>
<td>$ 0.151</td>
</tr>
<tr>
<td>NEW HAMPSHIRE</td>
<td>$ 0.150</td>
</tr>
<tr>
<td>CALIFORNIA</td>
<td>$ 0.146</td>
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<tr>
<td>VERMONT</td>
<td>$ 0.146</td>
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</table>

Energy Price Ratio

<table>
<thead>
<tr>
<th>Energy Price Ratio</th>
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</thead>
<tbody>
<tr>
<td>ALASKA</td>
<td>5.03</td>
</tr>
<tr>
<td>CALIFORNIA</td>
<td>3.47</td>
</tr>
<tr>
<td>CONNECTICUT</td>
<td>3.33</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>3.23</td>
</tr>
<tr>
<td>NEW JERSEY</td>
<td>3.03</td>
</tr>
<tr>
<td>MASSACHUSETTS</td>
<td>2.88</td>
</tr>
<tr>
<td>WYOMING</td>
<td>2.80</td>
</tr>
<tr>
<td>COLORADO</td>
<td>2.75</td>
</tr>
<tr>
<td>UTAH</td>
<td>2.70</td>
</tr>
<tr>
<td>TEXAS</td>
<td>2.68</td>
</tr>
</tbody>
</table>

Energy Price Ratio:

- Price of electricity
- Price of natural gas

Inexpensive Natural Gas
- WYOMING
- ALASKA
- UTAH
- COLORADO
- MONTANA
- NORTH DAKOTA
- IDAHO
- SOUTH DAKOTA
- NEW MEXICO
- CALIFORNIA

Expensive Electricity
- HAWAII
- CONNECTICUT
- NEW YORK
- MASSACHUSETTS
- NEW JERSEY
- ALASKA
- MAINE
- NEW HAMPSHIRE
- CALIFORNIA
- VERMONT

Natural Gas Prices

Electricity Prices

Natural gas Price
- Residential ($/kWh)

- $0.0425 to $0.0438 (6)
- $0.0392 to $0.0425 (6)
- $0.0358 to $0.0392 (6)
- $0.0329 to $0.0358 (6)
- $0.0313 to $0.0329 (6)
- $0.0313 to $0.0329 (7)
- $0.0285 to $0.0313 (7)
- $0.0285 to $0.0298 (7)
- $0.015 to $0.0298 (7)
CERL Emergency Backup Deployments

- Objectives, Goals, and Background of Joint Efforts
  - Bundle emergency backup power needs across multiple DOD and NASA sites to realize price reductions on a per site basis to demonstrate the advantages of fuel cells over incumbent technologies, which include:
    - Longer continuous run-time and greater durability than batteries (fuel cells will last 15 years or more, depending on actual use)
    - Require less maintenance than batteries or generators
    - Monitored remotely
    - Nearly 25% reduction in lifecycle costs for a 5-kW, 52-hour backup-power system**
  - Project funded by DOE and managed by Army CERL.

- Results to Date
  - Project awarded, installations will roll out over the next 12 months across 9 sites and installing over 40 units producing over 220kW of power,

- Next Steps
  - Collect operation data to facilitate future bundled deployments.

9 Sites Chosen:
- U.S. Army Aberdeen Proving Ground, MD
- U.S. Army Fort Bragg, NC
- U.S. Army Fort Hood, TX
- U.S. Army National Guard, OH
- U.S. Army Picatinny Arsenal, NJ
- NASA Ames Research Center, CA
- USMC AGGC 29 Palms, CA (2 Buildings)
- U.S. Military Academy West Point, NY
- U.S. Air Force Cheyenne Mountain Air Station
Micro CHP

MicroCHP costs are becoming competitive with grid power and ROIs are estimated at under 5 yrs. Deployments will target areas where a business case can be made with pay back periods which meet industry needs.

• Next Steps
  – Review proposals and make awards
  – Gather material performance data.
  – “Real world” evaluation operations and testing of equipment.

Project Details
✓ Up to 50 units
✓ 5 kW units
✓ Prove business case for MicroCHP applications
Micro-CHP Targets

Targets developed with input from stakeholders and the research community cost and durability are the major challenges.

Table 3.4.5 Technical Targets: 1–10 kW<sub>e</sub> Residential Combined Heat and Power and Distributed Generation Fuel Cell Systems Operating on Natural Gas

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>2011 Status</th>
<th>2015 Targets</th>
<th>2020 Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical efficiency at rated power&lt;sup&gt;b&lt;/sup&gt;</td>
<td>34-40%</td>
<td>42.5%</td>
<td>&gt;45%&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>CHP energy efficiency&lt;sup&gt;d&lt;/sup&gt;</td>
<td>80-90%</td>
<td>87.5%</td>
<td>90%</td>
</tr>
<tr>
<td>Equipment cost&lt;sup&gt;e&lt;/sup&gt;, 2-kW&lt;sub&gt;avg&lt;/sub&gt;f system</td>
<td>NA</td>
<td>$1,200/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>$1,000/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
</tr>
<tr>
<td>Equipment cost&lt;sup&gt;e&lt;/sup&gt;, 5-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
<td>$2,300-4,000/kW&lt;sub&gt;g&lt;/sub&gt;</td>
<td>$1,700/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>$1,500/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
</tr>
<tr>
<td>Equipment cost&lt;sup&gt;e&lt;/sup&gt;, 10-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
<td>NA</td>
<td>$1,900/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>$1,700/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
</tr>
<tr>
<td>Transient response (10 - 90% rated power)</td>
<td>5 min</td>
<td>3 min</td>
<td>2 min</td>
</tr>
<tr>
<td>Start-up time from 20°C ambient temperature</td>
<td>&lt;30 min</td>
<td>30 min</td>
<td>20 min</td>
</tr>
<tr>
<td>Degradation with cycling&lt;sup&gt;h&lt;/sup&gt;</td>
<td>&lt;2%/1000 h</td>
<td>0.5%/1000 h</td>
<td>0.3%/1000 h</td>
</tr>
<tr>
<td>Operating lifetime&lt;sup&gt;i&lt;/sup&gt;</td>
<td>12,000 h</td>
<td>40,000 h</td>
<td>60,000 h</td>
</tr>
<tr>
<td>System availability&lt;sup&gt;j&lt;/sup&gt;</td>
<td>97%</td>
<td>98%</td>
<td>99%</td>
</tr>
</tbody>
</table>

2010 Independent Assessment of CHP Fuel Cell Status & Targets

- Confident that by 2015, LT-PEM & HT-PEM can achieve 40,000 hr
- 45% electrical efficiency (2020 target) for 1-10kW systems is feasible for HT-PEM, LT-PEM depends on improved catalysts & higher operating temps
- SOFT systems are likely to achieve DOE targets for electrical and CHP efficiencies. 90% CHP efficiency is likely to be attainable by SOFC systems.
- Confident that by 2020, LT-PEM & HT-PEM can achieve $450-$750/kW, while SOFC can achieve $1000-2000/kW
Background: Biogas as an Early Source of Renewable Hydrogen

- The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen for FCEVs.
- Hydrogen can be produced from this renewable resource using existing steam-methane-reforming technology.

**SOURCE:** Wastewater Treatment, could provide enough H\textsubscript{2} to refuel \textbf{100,000 vehicles per day}.

- 500,000 MT per year of methane is available from wastewater treatment plants in the U.S.
- \textasciitilde50\% of this resource could provide \textasciitilde\textbf{340,000 kg/day} of hydrogen.

**SOURCE:** Landfills, could provide enough H\textsubscript{2} to refuel \textbf{2–3 million vehicles/day}.

- 12.4 million MT per year of methane is available from landfills in the U.S.
- \textasciitilde50\% of this resource could provide \textasciitilde\textbf{8 million kg/day} of hydrogen.
Waste To Energy Example

Los Alamitos JFTB

Urban wood waste is an abundant feedstock around the US

Resource potential for Los Alamitos
- 300 tons/day
- 19,200 kW

Urban Wood Compost
25 ton/day

Gasifier & Cleanup

Fuel Cells
1,600 kW

Urban wood waste is an abundant feedstock around the US
Overview of Combined Heat-Power

Excess power generated by the fuel cell is fed to the grid.
Cost Goals for Fuel Cell R&D – Stationary Fuel Cell Cost-Reduction

Stationary Fuel Cell Cost-Reduction Pathways

- **2010 Cost Status**: $0.21/kWh
- **Fuel Flexibility & Gas Cleanup**: $17/kWh
- **Stack R&D**: $10/kWh
- **Manuf R&D and Volume**: $15/kWh
- **2020 Interim Target**: $0.09/kWh

- **Natural Gas-Only**: $0.08/kWh
- **Biogas Capable**: $0.09/kWh
## Federal Policies Promoting Fuel Cells

<table>
<thead>
<tr>
<th>Grants for Energy Property in Lieu of Tax Credits*</th>
<th>Grant instead of claiming the Investment Tax Credit or Production Tax Credit. Only entities that pay taxes are eligible.</th>
<th>Construction must begin by expiration date, 12/31/2011.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment Tax Credit</td>
<td>30% tax credit for qualified fuel cell property or $3,000/kW of the fuel cell nameplate capacity. 10% credit for CHP-system property.</td>
<td>Equipment must be installed by Dec. 31, 2016.</td>
</tr>
<tr>
<td>Alternative Fuel Infrastructure Tax Credit</td>
<td>30% of expenditures.</td>
<td>Expires 2/31/2014.</td>
</tr>
</tbody>
</table>

*Applies to fuel cell and CHP technologies

**Fuel Cell Motor Vehicle Tax Credit:** $4,000 for LDV, $10,000-$40,000 range for heavier vehicles. Expires 12/31/2014.

**Hydrogen Fuel Excise Tax Credit:** $0.50/gallon. Hydrogen must be sold or used as a fuel to operate a motor vehicle. Expires 9/30/2014.

**Alternative Fuel Infrastructure Tax Credit:** $1,000 cap for residential use.

**Residential Renewable Energy Credit:** Fuel Cell maximum - $500/0.5kW. Fuel cells must have electricity-only generation efficiency greater than 50% and 0.5kW minimum. Expires 12/31/2016.
CA’s Self-Generation Incentive Program (SGIP) extends the current program for three year to 2014. SGIP provides a total of $249M of support for CHP, wind energy, waste heat recovery, and energy storage projects in CA, with in-state manufacturers getting a 20% additional incentive credit.

- CHP is eligible for $0.50/W in capital cost incentives.
- Stationary fuel cells will receive $2.25/W.
- Energy storage projects receive $2.00/W.
- Biogas fueled projects received $2.00/W bonus.

Connecticut offers 100% tax exemption for Class I renewable energy systems. An exemption claim must be filed before November 1 of each applicable year.

Since 2007, South Carolina offers a 100% sales tax exemption on equipment used to produce or research hydrogen fuel cells.

Ohio’s Qualified Energy Property Tax Exemption, passed in 2010 allows for 100% property tax exemption for fuel cell systems <250kW as well as those systems >250kW, though payment in lieu of tax is required.
This document is intended to provide federal agencies with initial guidance on how to procure energy from fuel cell combined heat and power (CHP) technology. This document is based on best practices and the experience of agency personnel and laboratory and industry collaborators.

Provides clear guidance on CHP technology – its benefits, ideal usage, and financing options.

Clear efficiency benefits with CHP

Decision tree to help assess feasibility of CHP systems for each unique situation.
FC Power Model Hourly Energy Analysis Module

- Feed and Utility Prices
- Physical Property Data
- Financial Inputs
- Hourly Solar Wind Profiles
- Electricity Heat Hydrogen Demand Profiles
- Cost of Energy Output
- Cost of Purchased Electricity & Heat
- Credit for “Avoided” Electricity & Heat Purchase
- Greenhouse Gas Emissions

H2A model inputs
- H2A database

Energy analysis done for 8,760 h of one year

User inputs
Example of ITC Benefit to a Fuel Cell Project

Example Cost Comparison for a 300 kW Fuel Cell Combined Heat and Power System in California: Fuel Cell Purchase vs. a Ten-Year Fuel Cell Service Contract

<table>
<thead>
<tr>
<th>Tax Status of Owner</th>
<th>Tax-exempt</th>
<th>Taxpayer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installed Cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchased Price</td>
<td>$1,500,000</td>
<td>$1,500,000</td>
</tr>
<tr>
<td>Installation Expenses</td>
<td>584,000</td>
<td>584,000</td>
</tr>
<tr>
<td>Sales Tax (California)</td>
<td>0</td>
<td>105,000</td>
</tr>
<tr>
<td>Third-Party Financing Expenses</td>
<td>0</td>
<td>60,000</td>
</tr>
<tr>
<td><strong>Installation Cost</strong></td>
<td>$2,084,000</td>
<td>$2,249,000</td>
</tr>
<tr>
<td>State Grant (California location and eligibility)</td>
<td>(750,000)</td>
<td>(750,000)</td>
</tr>
<tr>
<td>Federal ITC(^4)</td>
<td>0</td>
<td>(675,000)</td>
</tr>
<tr>
<td>ITC Financing and Transaction Expenses(^5)</td>
<td>0</td>
<td>200,000</td>
</tr>
<tr>
<td><strong>Net Installation Cost</strong></td>
<td>$1,334,000</td>
<td>$1,024,000</td>
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<tr>
<td><strong>Net Installation cost impact to energy user</strong></td>
<td>$1,334,000</td>
<td>$0*</td>
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<table>
<thead>
<tr>
<th><strong>Annual Energy Operating and Maintenance (O&amp;M) Costs</strong></th>
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<tbody>
<tr>
<td>Annual Maintenance Cost</td>
<td>$150,000</td>
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<tr>
<td>Annual Fuel Consumption</td>
<td>175,000</td>
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<tr>
<td>Annual Energy Savings</td>
<td>(289,000)</td>
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<tr>
<td>Third-Party Financing Costs(^7)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Net Annual Energy O&amp;M Costs</strong></td>
<td>$36,000</td>
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<tr>
<td><strong>Cumulative O&amp;M cost impact to energy user (10 years)</strong></td>
<td>$360,000</td>
</tr>
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</table>

**TOTAL COST IMPACT TO ENERGY USER**
- Tax-exempt: $1,694,000
- Taxpayer: $1,530,000

**TOTAL COST IMPACT TO ENERGY USER, Present Value\(^8\)**
- Tax-exempt: $1,525,000
- Taxpayer: $1,126,000

**COST SAVINGS TO ENERGY USER, Present Value**
- Tax-exempt: $0
- Taxpayer: $399,000

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*http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fuel_cell_financing_fact_sheet.pdf*
Education & Outreach

Collaborations with universities, governments, and industry help to educate the public about H$_2$ and fuel cells.
Thank you

For more information, please contact

Peter.Devlin@ee.doe.gov

hydrogenandfuelcells.energy.gov