DOE Regional Clean Energy App. Centers

Promoting clean energy technology and practices and identifying and implementing regional clean energy projects
Stationary Fuel Cells

- 1 kW - 3+MW
  - Many different applications/niches
- Installed Cost
  - $4,500 to $30,000/kW
  - Incentive Programs in Many States
- Emissions
  - Very Low
- O&M Costs
  - Warranty Issue Now
- Efficiency 35-60%
  - Fuel to Electricity (up to 90%+ overall)
- Quiet Operation
- Design Life 5+ Years*
  - Stack Replacements are Significant O&M Cost
  - Data Scarcity on Actual Degradation Rates
- Baseload or Load Following Depending on Cell Type

Stationary Fuel Cells: Operation

Basic Process: Fuel Cell

- “Continuous Battery”
- Fuel And Oxidant (Air) Supplied to Separate Chambers - Never Needs Charging
- Ionic Transport Through Electrolyte
- Reverse Electrolysis
Stationary Fuel Cells: Operation

Basic Process: Fuel Cell
Stationary Fuel Cells: Operation

Basic Process: Fuel Cell

Solid Oxide Fuel Cell

Fuel

H₂ + CO

CO + H₂O → H₂ + CO₂

H₂O + CO₂

Heat

H₂ (permeable anode)

2H₂ + 2O²⁻ → 4e⁻ + 2H₂O

O₂ + 4e⁻ → 2O²⁻

Depleted O₂

Heat

Air (oxidant)

O₂
Stationary Fuel Cells: Operation

Basic Process: Fuel Cell

- Fuel Cell Stack
- Fuel Processing
- Electric Power Conversion
- Balance Of Plant
Stationary Fuel Cells: Types

- Various *types* of Fuel Cell technology
- Named to reflect electrolyte material

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>PAFC</th>
<th>MCFC</th>
<th>SOFC</th>
<th>PEMFC</th>
<th>AFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature</td>
<td>H₃PO₄</td>
<td>Molten Carbonate Salt</td>
<td>Ceramic (YSZ)</td>
<td>Sulfonic-acid Polymer (Nafion™)</td>
<td>KOH/H₂O</td>
</tr>
<tr>
<td>~ 200°C</td>
<td>~ 650°C</td>
<td>800-1000°C</td>
<td>~ 80°C</td>
<td>60-80°C</td>
<td></td>
</tr>
<tr>
<td>Fuels</td>
<td>H₂/Reformate</td>
<td>H₂/CO/Reformate</td>
<td>H₂/CO/CH₄/Reformate</td>
<td>H₂/Reformate</td>
<td>H₂</td>
</tr>
<tr>
<td>Reforming</td>
<td>External</td>
<td>External/Internal</td>
<td>External/Internal</td>
<td>External</td>
<td></td>
</tr>
<tr>
<td>Oxidant</td>
<td>O₂/Air</td>
<td>CO₂/O₂/Air</td>
<td>O₂/Air</td>
<td>O₂/Air</td>
<td>O₂/Air</td>
</tr>
<tr>
<td>Electrical Efficiency (LHV)</td>
<td>40 - 47%</td>
<td>45 - 55%</td>
<td>50 - 60%</td>
<td>40 - 60%</td>
<td>50 - 60%</td>
</tr>
</tbody>
</table>
Stationary Fuel Cells: Types

- Depleted fuel and product gases out
- Depleted oxidant & product gases out

SOFC
- H₂
- H₂O
- O₂
- O

PAFC and PEMFC
- H₂
- H₂O
- H₂O
- O₂

MCFC
- H₂
- CO₂
- CO₃
- CO₂

AFC
- H₂
- H₂O
- (OH)
- O₂

Fuel in
- Oxidant in

Anode
- Electrolyte (ion conductor)
- Cathode
DG Comparison: Emissions

(Pounds of emissions per 1000 kWh NOx, CO, SOx, Hydrocarbon, Particulates)

Source: www.fuelcells.org
DG Comparison: Emissions

For NOx, compare with new pulverized coal plant target of about 0.61 lb/MWh.

Average current emissions are reported at 10x higher or around 6 lb/MWh NOx, according to U.S. EPA.
DG Comparison: Emissions

UTC Fuel Cell Annual CO₂ Emissions

(Pounds of carbon dioxide emissions)

4,500,000 4,044,000
3,600,000 1,597,000
2,700,000
1,800,000
900,000

Average U.S. fossil fueled plant  Fuel cell

Source: United Technologies Corp.
Stationary Fuel Cells: Economics

- Installed Capital Costs Are High
- For 200kW - 3MW Systems, $5,000/kW to $7,000/kW is Typical for Installed Cost
- ICF for DOE Recent Estimates:
  - PAFC 200-400kW: $6,300 / $7,000 (installed)
  - MCFC 300kW: $5,600 / $6,200 (installed)
  - MCFC 1500kW: $5,300 / $5,800 (installed)
- Buy-Down Programs and Other Incentives in Some States
Stationary Fuel Cells: Economics

- **O&M Costs**
  - Systems are not maintenance free and periodic stack replacements are required
    - Costs of $0.03-0.04/kWh are current estimates for O&M including stack replacements every 4-5 years

- **Availability and economics**
  - Availability can be significant factor in overall economics
    - ~95% availability is typical and achievable
    - Significant economic impact for down time in peak periods
      - Demand charges can be as high as $20-30/kW/month, and even 15 minutes of down time can have severe impact on monthly utility savings in some cases
    - Ownership and vested interest on part of customer can impact system reliability
General DG Economics

“Spark Spread”

T. Rosfjord, United Technologies Research Center
Policies for DG/CHP in CA

- Rule 21 Process for Interconnection
  - Streamlined process for utility interconnection that has reduced interconnection times since 2001

- CA PUC Self-Generation Incentive Program
  - Capital cost buy-down incentives for system installation:
    - $2,500/kW for stationary fuel cells
    - $4,500/kW for stationary fuel cells (renewable fuel)
  - Systems up to 3 MW qualify, with 100% incentive for first MW, 50% for second MW, and 25% for third MW

- New SGIP Program Plan Will Be Announced Soon
  - Technologies to be incentivized on performance basis
  - GHG Emission reductions and financial considerations will be key factors in determining incentive levels
Sierra Nevada Brewing Company Project

- 1 MW of molten carbonate fuel cells at Sierra Nevada Brewery in Chico, California
- Online in 2005
- $7 million project with approx. 5 year payback time (includes incentives)
- Brewery waste goes into aerobic digester to produce a hydrogen-rich gas
- Displacing about 25-40% of natural gas fuel input with digester gas
Santa Rita Jail Project

- 1 MW of molten carbonate fuel cells at Santa Rita jail in Dublin, CA
- Online in 2006
- $6.1 million project with approx. $2.4 million in incentives ($1.4 million SGIP and $1 million DoD)
- Long simple payback period of 13-14 years
- Heat recovery boosts overall efficiency to 70+%