Expanding the Use of Biogas with Fuel Cell Technologies

Biogas with Fuel Cells Workshop
National Renewable Energy Laboratory
Golden, Colorado

6/11/2012

Sunita Satyapal
U.S. Department of Energy
Fuel Cell Technologies Program
Program Manager
U.S. Energy Consumption

U.S. Primary Energy Consumption by Source and Sector

- **Renewable Energy**: 8%
- **Nuclear Energy**: 9%
- **Coal**: 21%
- **Natural Gas**: 25%
- **Petroleum**: 37%

**Electric Power**: 8%

**Industrial**: 9%

**Residential & Commercial**: 9%

**Transportation**: 9%

**Total U.S. Energy**: 98 Quadrillion Btu/yr

Source: Energy Information Administration, *Annual Energy Review 2010*, Table 1.3

**Fuel Cells can apply to diverse sectors**

**Share of Energy Consumed by Major Sectors of the Economy, 2010**

- **Electric Power**: 29%
- **Residential**: 16%
- **Commercial**: 13%
- **Transportation**: 20%
- **Industrial**: 22%

- Nearly double the second place holder, solar, which has ~540 patents.

Fuel Cells: Benefits & Market Potential

The Role of Fuel Cells

- **Diverse Energy Sources & Fuels**
  - Conventional Fuels: Natural Gas, Propane, Diesel, Other Hydrocarbons
  - Biomass/Biogas: Methane, Methanol
  - Renewable Resources: Wind, Solar, Biomas
  - Nuclear
  - Natural Gas
  - Coal (with carbon sequestration)

- **Clean, Efficient Energy Conversion**
  - Fuel Cells: Alkaline, Direct Methanol, Molten Carbonate, Polymer Electrolyte Membrane (PEM), Phosphoric Acid, Solid Oxide

- **Diverse Applications**
  - Stationary Power: Primary Power & Combined-Heat-and-Power (residential, commercial, industrial), Backup Power
  - Transportation: Trucks, Trains, Aircraft, Ships, Specialty Vehicles (e.g., forklifts), Buses, Automobiles
  - Auxiliary Power: Consumer Electronics, Battery Chargers, Soldier Power
  - Portable Power: Consumer Electronics

- **Energy Storage for Renewable Electricity**
  - Intermittent Renewables (solar, wind, ocean) → H₂ → Fuel Cells or Turbines → Grid/Distributed Power or Fuel

Key Benefits

- **Very High Efficiency**
  - up to 60% (electrical)
  - up to 70% (electrical, hybrid fuel cell / turbine)
  - up to 85% (with CHP)

- **Reduced CO₂ Emissions**
  - 35–50%+ reductions for CHP systems (>80% with biogas)
  - 55–90% reductions for light-duty vehicles

- **Reduced Oil Use**
  - >95% reduction for FCEVs (vs. today’s gasoline ICEVs)
  - >80% reduction for FCEVs (vs. advanced PHEVs)

- **Reduced Air Pollution**
  - up to 90% reduction in criteria pollutants for CHP systems

- **Fuel Flexibility**
  - Clean fuels — including biogas, methanol, H₂
  - Hydrogen — can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity
  - Conventional fuels — including natural gas, propane, diesel

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eere.energy.gov
Worldwide Commitment to H2 and Fuel Cells

The world’s leading automakers have committed to develop FCEVs. Germany and Japan have announced plans to expand the hydrogen infrastructure.

Major Auto Manufacturers’ Activities and Plans for FCEVs

Toyota
- 2010-2013: U.S. demo fleet of 100 vehicles
- 2015: Target for large-scale commercialization
- “FCHV-adv” can achieve 431-mile range and 68 mpgge

Honda
- Clarity FCX named “World Green Car of the Year”; EPA certified 72mpgge; leasing up to 200 vehicles
- 2015: Target for large-scale commercialization

Daimler
- Small-series production of FCEVs began in 2009
- Plans for tens of thousands of FCEVs per year in 2015 – 2017 and hundreds of thousands a few years after
- In partnership with Linde to develop fueling stations
- Recently moved up commercialization plans to 2014

General Motors
- 115 vehicles in demonstration fleet
- 2012: Technology readiness goal for FC powertrain
- 2015: Target for commercialization

Hyundai-Kia
- 2012-2013: 2000 FCEVs/year
- 2015: 10,000 FCEVs/year
- “Borrego” FCEV has achieved >340-mile range.

Volkswagen
- Expanded demo fleet to 24 FCEVs in CA
- Recently reconfirmed commitment to FCEVs

SAIC (China)
- Partnering with GM to build 10 fuel cell vehicles in 2010

Ford
- Alan Mulally, CEO, sees 2015 as the date that fuel cell cars will go on sale

BMW
- BMW and GM plan to collaborate on the development of fuel cell technology

H₂Mobility - evaluate the commercialization of H₂ infrastructure and FCEVs
- Public-private partnership between NOW and industry stakeholders including: Daimler, Linde, OMV, Shell, Total, Vattenfall, EnBW, Air Liquide, Air Products

UKH₂Mobility will evaluate anticipated FCEV roll-out in 2014/2015
- 13 industry partners including: Air Liquide, Air Products, Daimler, Hyundai, ITM Power, Johnson Matthew, Nissan, Scottish & Southern Energy, Tata Motors, The BOC Group, Toyota, Vauxhall Motors

13 companies and Ministry of Transport announce plan to commercialize FCEVs by 2015
- 100 refueling stations in 4 metropolitan areas and connecting highways planned, 1,000 station in 2020, and 5,000 stations in 2030.

Example: Seoul plans for ~48% of its renewable energy to come from fuel cells

Anticipated Renewable Energy Generation in Seoul, Korea by 2030

Based on publicly available information during 2011
The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.

Nearly 300 projects currently funded at companies, national labs, and universities/institutes

More than $1B DOE funds spent from FY 2007 to FY 2011
Federal Role in Fuel Cells: RD&D to Deployments

DOE R&D

- Reduces cost and improves performance

Examples:

Transportation Fuel Cell System Cost
- projected to high-volume (500,000 units per year)

Status: $49/kW (high vol)

Target: $30/kW

ā Reduced cost of fuel cells 30% since 2008, 80% since 2001

ā Reduced cost of electrolyzer stacks 60% since 2007

DOE Demonstrations & Technology Validation

- Validate advanced technologies under real-world conditions
- Feedback guides R&D

Examples—validated:

- 59% efficiency
- 254 mile range (independently validated 430-mile range)
- 75,000-mi durability

Program also includes enabling activities such as codes & standards, analysis, and education.

Deployments

- Market Transformation
- DOE Recovery Act Projects
- Government Early Adoption (DoD, FAA, California, etc.)
  - IDIQ*
  - Tax Credits: 1603, 48C

Recovery Act & Market Transformation Deployments

- 1,000 fuel cell deployments in ~ 2 years
- 1 million hours of operation

*IDIQ = indefinite duration/indefinite quality
Early market deployments of approximately 1,400 fuel cells have led to more than 5,000 additional purchases by industry—with no further DOE funding.

Early Market Deployment Summary

Backup Power Units

>1,300 purchases without DOE investment*

~730 total DOE cost-shared deployments

Leveraging DOE funds:

DOE deployments led to almost 2X additional purchases by industry.

Lift Truck Deployments

>3,500 purchases without DOE investment*

~700 total DOE cost-shared deployments

Leveraging DOE funds:

DOE deployments led to >5X additional purchases by industry.

*industry purchases include units on order
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%

Coal 51.1%
Natural Gas 16.9%
Petroleum 0.2%
Other Gases 0.4%
Nuclear Electric Power 19.0%
Renewable Energy 10.1%

Range of electrical efficiencies for DG technologies

Electrical Efficiency

Steam
Recip. Engine
Gas Turbine
Micro-Turbine
Fuel Cell

Typical Electrical Efficiency (HHV)

Source: EPA, Catalog of CHP Technologies, December 2008

Examples of fuel cell deployments using natural gas

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

Supermarkets one of several in the food industry interested

New World Trade Center (Freedom Tower) will use 12 fuel cells totaling 4.8MW
Further reduction in capital cost of medium scale DG/CHP (100kW-3 MW) need to be pursued to facilitate widespread commercialization.

Challenges and Strategy: Stationary Applications

- 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 trigen (H₂ production).

Technical Parameters (2015)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Electric Efficiency (LHV)</td>
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<tr>
<td>Combined Effic.(LHV)</td>
<td>87.5%</td>
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<td>Size, MWe</td>
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<tr>
<td>Operating Life, years</td>
<td>20</td>
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<tr>
<td>Equipment, $/kWe</td>
<td>2,300</td>
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<tr>
<td>Engineering &amp; Installation, $/kWe</td>
<td>700</td>
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<tr>
<td>Fixed O&amp;M, $/MWh</td>
<td>13</td>
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<tr>
<td>Variable O&amp;M, $/MWh</td>
<td>8.0</td>
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</tbody>
</table>
Hydrogen Production - Strategies

Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of $2-$4/gge $H_2$ by 2020

HTAC Subcommittee: $H_2$ Production Expert Panel
Review underway to provide recommendations to DOE
The revised hydrogen threshold cost is a key driver in the assessment of Hydrogen Production and Delivery R&D priorities.

Projected High-Volume Cost of Hydrogen Production¹ (Delivered²) — Status

**Distributed Production (near term)**

- Electrolysis
  
  *Feedstock variability: $0.03 - $0.08 per kWh*

- Bio-Derived Liquids
  
  *Feedstock variability: $1.00 - $3.00 per gallon ethanol*

- Natural Gas Reforming
  
  *Feedstock variability: $4.00 - $10.00 per MMBtu*

**Central Production (longer term)**

- Electrolysis
  
  *Feedstock variability: $0.03 - $0.08 per kWh*

- Biomass Gasification
  
  *Feedstock variability: $40 - $120 per dry short ton*

Notes:

[1] Cost ranges for each pathway are shown in 2007$ based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates.

[2] Costs include total cost of production and delivery (dispensed, untaxed). Forecourt compression, storage and dispensing added an additional $1.82 for distributed technologies, $2.61 was added as the price of delivery to central technologies. All delivery costs were based on the Hydrogen Pathways Technical Report (NREL, 2009).
Two Main Options for Low-cost Early Infrastructure

1. Hydrogen delivered from central site
   - Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge (e.g., high-pressure tube trailers, with pathway to $5/gge at 400–500 kg/day- comparable to ~$2.10/gallon gasoline untaxed)

2. Distributed production (e.g. natural gas, electrolysis)

Other options

1. Co-produce H₂, heat and power (tri-gen) with natural gas or biogas
2. Hydrogen from waste (industrial, wastewater, landfills)
Overview of Combined Heat-Power

Electricity

Natural Gas

Fuel Cell

Excess power generated by the fuel cell is fed to the grid

Heat / Cooling

Coproductive of H₂

Combined heat, hydrogen and power (CHHP) or Trigeneration

Adapted from NREL
Tri-Generation of Heat, Hydrogen, and Power

Potential Opportunity
Does a synergy exist between stationary and transportation sectors?

Demonstrated world’s first Tri-generation station (54% efficiency – H₂ and power)
- Anaerobic digestion of municipal wastewater-

Gas or Biogas

Fuel Cleanup

Electricity

FuelCell Energy

H₂ is produced at anode

Is tri-generation a viable option for H₂ production and synergy with biogas?
- Co-produce H₂, power, and heat for multiple applications?
- More efficient use of natural gas?
- Use a renewable resource in anaerobic digester gas?
- Use off-gas from other waste material processing (e.g., gasifiers)?
- Establish an early market infrastructure?

Fountain Valley, CA
~ 250 kW of electricity
~ 100 kg/day H₂
U.S. Greenhouse Gas and Methane Emissions

Landfills and Wastewater Treatment contribute ~30% of Methane Emissions in the U.S.

U.S. Methane Emissions by Source, 2009
(million metric tons carbon dioxide equivalent)

- Energy, 303 (41%)
- Landfills, 180 (25%)
- Agriculture, 216 (30%)
- Industrial Processes, 4 (1%)
- Industrial Wastewater Treatment, 18 (2%)
- Domestic Wastewater Treatment, 10 (1%)
- Energy Related Carbon Dioxide, 5359 (82%)
- Methane, 731 (11%)
- Nitrous Oxide, 220 (3%)
- Other Carbon Dioxide, 87 (1%)
- High-GWP Gases, 178, (3%)

2009 total = 6575

Fuel cells operating on bio-methane or hydrogen derived from bio-methane can mitigate energy and environmental issues and provide an opportunity for their commercialization. Other drivers are: need for fuel diversity/flexibility, evolving policies for renewables, and related incentives.

Opportunities for Biogas Applications

<table>
<thead>
<tr>
<th>Source</th>
<th>Production &amp; Cleanup</th>
<th>Distribution &amp; Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Waste</td>
<td>Anaerobic Digester</td>
<td>Power Grid</td>
</tr>
<tr>
<td>Landfills</td>
<td></td>
<td>Electricity</td>
</tr>
<tr>
<td>Food Processing Waste</td>
<td>Biogas</td>
<td>Heat</td>
</tr>
<tr>
<td>Water Treat. Plant</td>
<td>Clean-Up System</td>
<td>Hydrogen</td>
</tr>
</tbody>
</table>

Source: National Renewable Energy Laboratory
Biogas as an Early Source of Renewable Hydrogen and Power

- The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen generation for hydrogen fuel cell vehicles (FCEVs) and power generation from stationary fuel cells.
- Hydrogen can be produced from this renewable resource using existing steam-methane-reforming technology.

U.S. biogas resource has capacity to produce ~5 GW of power at 50% electrical efficiency.

**SOURCE: Wastewater Treatment**, could provide enough $\text{H}_2$ to refuel ~600,000 vehicles/day.

- 500,000 MT per year of methane is available from wastewater treatment plants in the U.S.
- ~50% of this resource could provide ~340,000 kg/day of hydrogen.

**SOURCE: Landfills**, could provide enough $\text{H}_2$ to refuel ~13 million vehicles/day.

- 12.4 million MT per year of methane is available from landfills in the U.S.
- ~50% of this resource could provide ~8 million kg/day of hydrogen.
Example:
Landfills offer ~1.6 M tons/yr of biomethane.

Only ~50% of the landfill biomethane is used
Potential Resources Near DOD Sites
Validate fuel cell powered material handling equipment low-cost hydrogen from land fill gas including performance, operation and maintenance, durability, and reliability under real-world operating conditions.

Phase 1: Feasibility Study
Completed 26 October 2011

Phase 2: LFG-to-Hydrogen Conversion
8 months nominal; target completion date: July 2012
Critical milestones:
Land, interconnect, start up and test equipment
Monitor hydrogen purity for at least 2 months

Phase 3: Side-by-Side Trial (to be funded)
6 months from satisfactory completion of monitoring portion of Phase 2
Target completion date: January 2013
Critical milestones:
Operate test group of MHE to attain 25,000 run hours
Continue monitoring hydrogen purity of LFG-sourced hydro

Project Lead: SCRA
Project Partners:
- BMW
- Gas Technology Institute
- Ameresco, Inc.
Examples of Fuel Cell CHP Industry Deployments

The Food Industry and Waste Treatment are emerging markets for stationary fuel cells

Waste Treatment Deployments:
Nine Sites Include

- Orange County Sanitation District (CA, 300 kW)
  - 1-300 kW fuel cell
  - Operates on biogas from wastewater treatment plant
  - Produces >100 kg/day of fuel cell grade hydrogen (99.9999% purity)

- Tulare (CA, 1 MW)
  - 4-300 kW fuel cells
  - Generates ~50% of waste water treatment plant’s electrical demand
  - Waste heat used for generating steam and boiling beer

Completed Food Producer Deployments:

- Gills Onions (CA, 600 kW)
  - 2-300kW fuel cells
  - Generates power for facility @ 47% electrical efficiency
  - Processes ~32 scfm of biogas per fuel cell

- Sierra Nevada Brewery (CA, 1 MW)
  - Generates ~100% of brewery’s electrical demand
  - Waste heat used for generating steam and boiling beer

Source: Gills Onions
22 eere.energy.gov
Recently Released States Reports

Northeast Hydrogen Fuel Cell Industry Status and Direction

Report by Joel M. Rinebold, Alexander C. Barton, and Adam J. Brzozwski
Connecticut Center for Advanced Technology, Inc.

Highlights potential for fuel cell industry in northeast US detailing relevant information on products and markets, employment, and system efficiency and cost.

1.85 GW opportunity identified.


State by state plans identifying fuel cell opportunities and potential implementation strategies (drafts in process)
## Northeast Hydrogen Fuel Cell Cluster

**Targets: Breakdown Example for 300 kW Stationary**

### Category Breakdown

<table>
<thead>
<tr>
<th>Category</th>
<th>Total Sites</th>
<th>Potential Sites</th>
<th>MWs</th>
<th>MW-hrs per year</th>
<th>MW at 90% Capacity Factor</th>
<th>Aggregate Annual Thermal Output</th>
<th>CO2 emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Education</strong></td>
<td>18,335</td>
<td>2,190</td>
<td>210.9</td>
<td>1,662,735.6</td>
<td>189.81</td>
<td>4,478,301.22</td>
<td>434,286.20</td>
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<tr>
<td><strong>Food Sales</strong></td>
<td>51,300</td>
<td>1,201</td>
<td>360.3</td>
<td>2,840,605.2</td>
<td>324.27</td>
<td>7,650,696.67</td>
<td>642,698.16</td>
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<tr>
<td><strong>Food Services</strong></td>
<td>64,600</td>
<td>387</td>
<td>116.1</td>
<td>915,332.4</td>
<td>104.49</td>
<td>2,465,295.26</td>
<td>219,715.25</td>
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<td><strong>Inpatient Healthcare</strong></td>
<td>3,994</td>
<td>422</td>
<td>126.6</td>
<td>998,114.4</td>
<td>113.94</td>
<td>2,688,254.78</td>
<td>232,631.61</td>
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<td><strong>Lodging</strong></td>
<td>8,033</td>
<td>884</td>
<td>265.2</td>
<td>2,090,836.8</td>
<td>238.68</td>
<td>5,631,320.45</td>
<td>484,156.44</td>
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<td><strong>Public Order &amp; Safety</strong></td>
<td>3,310</td>
<td>313</td>
<td>93.9</td>
<td>740,307.6</td>
<td>84.51</td>
<td>1,993,895.14</td>
<td>179,454.82</td>
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<td><strong>Energy Intensive Industries</strong></td>
<td>4,758</td>
<td>429</td>
<td>128.7</td>
<td>1,014,670.8</td>
<td>115.83</td>
<td>2,732,846.69</td>
<td>223,655.68</td>
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<td><strong>Government Operated Buildings</strong></td>
<td>1,255</td>
<td>90</td>
<td>27.0</td>
<td>212,868.0</td>
<td>24.30</td>
<td>573,324.48</td>
<td>49,990.87</td>
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<tr>
<td><strong>Wireless Telecommunication Towers</strong>*</td>
<td>3,960</td>
<td>397</td>
<td>-</td>
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<td><strong>WWTPs</strong></td>
<td>578</td>
<td>16</td>
<td>4.8</td>
<td>37,843.2</td>
<td>4.32</td>
<td>101,924.35</td>
<td>8,417.75</td>
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<td><strong>Landfills</strong></td>
<td>213</td>
<td>14</td>
<td>4.2</td>
<td>33,112.8</td>
<td>3.78</td>
<td>89,183.81</td>
<td>7,327.39</td>
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<td><strong>Airports (w/ AASF)</strong></td>
<td>842</td>
<td>50 (20)</td>
<td>16.2</td>
<td>127,720.8</td>
<td>14.58</td>
<td>343,994.69</td>
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<td><strong>Military</strong></td>
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<td>33,112.8</td>
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<td><strong>Ports</strong></td>
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<td>19</td>
<td>5.7</td>
<td>44,938.8</td>
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<td>121,035.17</td>
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<td><strong>Total</strong></td>
<td><strong>161,312</strong></td>
<td><strong>6,426</strong></td>
<td><strong>1,363.8</strong></td>
<td><strong>10,752,199.2</strong></td>
<td><strong>1,227.42</strong></td>
<td><strong>28,959,256.51</strong></td>
<td><strong>2,064,422.25</strong></td>
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* No Base Load
## Northeast Hydrogen Fuel Cell Cluster

### Policies and Incentives

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<tr>
<th>Energy Policy</th>
<th>ME</th>
<th>NH</th>
<th>VT</th>
<th>MA</th>
<th>RI</th>
<th>CT</th>
<th>NY</th>
<th>NJ</th>
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<tr>
<td>Mandatory Renewable Portfolio Standard (RPS)</td>
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<tr>
<td>Fuel Cell Eligibility</td>
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<tr>
<td>Interconnection Standards (Includes Fuel Cells)</td>
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<td>Net Metering (Includes Fuel Cells)</td>
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<td>Public Benefits Fund (Includes Fuel Cells)</td>
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<tr>
<td>Renewable Greenhouse Gas Initiative (RGGI) Member</td>
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### State Incentives for Fuel Cells

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<tr>
<th>Performance-Based</th>
<th>ME</th>
<th>NH</th>
<th>VT</th>
<th>MA</th>
<th>RI</th>
<th>CT</th>
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<td>State Grant Program</td>
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<td>State Loan Program</td>
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<td>State Rebate Program</td>
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<tr>
<td>Property Tax Incentive (Commercial)</td>
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<tr>
<td>Sales Tax Incentive</td>
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<tr>
<td>Industry Recruitment/ Support</td>
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<tr>
<td>Property-Assessed Clean Energy (PACE) Financing</td>
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The Connecticut Center for Advance Technology, Inc.

www.dsireusa.org

www.ccat.us

eere.energy.gov
Hydrogen Requirements for Carbon Feedstocks also Adds to Demand

Hydrogen requirements for processing of carbon feedstocks to produce liquids fuels

Production of pyrolysis oil from corn stover
- Annual corn stover production is ~400 million tons and represents ~40% of the biomass resource in the U.S.\(^1\)
- Thermal conversion of ~2000 metric tons/d of corn stover yields ~3,500 bbls/day of pyrolysis oil.\(^2\)
- Upgrading and stabilization of pyrolysis oil to naphtha and diesel products requires ~49,000 kg/d (~18 million kg/yr.) of hydrogen.
- Thermal conversion of the corn stover biomass to upgraded pyrolysis oil would require ~9-10 million metric tons/yr.

Notes:

\(^2\)Source for the hydrogen demand was an NREL study Techno-Economic Analysis of Biomass Fast Pyrolysis to Transportation Fuels by Mark M. Wright, Justinus A. Satrio, and Robert C. Brown Iowa State University Daren E. Daugaard ConocoPhillips David D. Hsu NREL
Key Questions - Examples

- What RD&D is needed by government and industry to enable more biogas use for fuel cell?
  - What are the key challenges?
  - What are the next steps to address them?
  - What are the priorities?

- What are the best near term applications (now to 2015)?

- What are the best mid-term applications (2016 -2020)?

- Other Questions:
  - How will biogas be integrated with the NG infrastructure? Can tri-gen/other options be used to produce H₂ for biomass processes?
  - What other issues do we need to address?
Thank You

Sunita Satyapal
sunita.satyapal@ee.doe.gov
www.hydrogen.energy.gov
Supplemental Material
**FY12 Appropriations:** “The Committee recognizes the progress and achievements of the Fuel Cell Technologies program. The program has met or exceeded all benchmarks, and has made significant progress in decreasing costs and increasing efficiency and durability of fuel cell and hydrogen energy systems.”

### EERE FCT Funding ($ in thousands)

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 2011 Allocation</th>
<th>FY 2012 Appropriation</th>
<th>FY 2013 Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Systems R&amp;D</td>
<td>41,916</td>
<td>44,812</td>
<td>38,000</td>
</tr>
<tr>
<td>Hydrogen Fuel R&amp;D</td>
<td>32,122</td>
<td>34,812</td>
<td>27,000</td>
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<tr>
<td>Technology Validation</td>
<td>8,988</td>
<td>9,000</td>
<td>5,000</td>
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<tr>
<td>Market Transformation</td>
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<td>3,000</td>
<td>0*</td>
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<tr>
<td>Safety, Codes &amp; Standards</td>
<td>6,901</td>
<td>7,000</td>
<td>5,000</td>
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<tr>
<td>Education</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Systems Analysis</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Manufacturing R&amp;D</td>
<td>2,920</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$95,847</strong></td>
<td><strong>$103,624</strong></td>
<td><strong>$80,000</strong>*</td>
</tr>
</tbody>
</table>

*In FY 2013, the Program plans to leverage activities in other EERE Programs (e.g., Advanced Manufacturing and Vehicle Technologies in key areas), subject to appropriations.*

**Future Directions**

**Continue critical R&D**

Hydrogen, fuel cells, 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**

**Leverage activities to maximize impact**

FY 2013 House Mark: $82M  Senate Mark: $104 M
The bulk of total sulfur species in the digester gas is mainly H$_2$S

- H$_2$S show variability in the order of 10 to 1000 ppm
- DMS, Mercaptans can vary from ppb to few ppm
- Iron salts used in the water treatment process sequesters sulfide
- Impacts Reformer/Fuel cell catalyst/Electrolyte. Sulfur impurities need to be reduced to levels of ~0.1-1 ppm

Hydrogen Sulfide (H$_2$S) Content of Digester Gas

Source: Argonne National Laboratory

Low H$_2$S content due to iron salt used in the waste water treatment process, i.e. for sludge thickening, phosphate precipitation
Land Fill Gas contains a wide spectrum of sulfur compounds creating a challenge for impurity cleanup.

Concentration of organic sulfur is higher in landfill gas in particular Dimethyl Sulfide (DMS).

Source: Argonne National Laboratory
Digester gas contains predominately cyclic (D4,D5) organosilicon (siloxanes) species

- Cyclic compounds (D4 & D5) are dominant in WWTP gas
- Concentration of linear compounds and TMS are usually low
- ADG temperature affects speciation and concentration of siloxane compounds
- Solid silica deposits on surfaces. Tolerance level often require “below detection limit”

Source: Argonne National Laboratory
Landfill gas contains a variety of halocarbons and at much higher concentrations than Digester Gas.

- Concentration of halogens are generally much lower in WWTP than LFG gas
- Chlorine is the dominant halogen species
- Forms corrosive gases, combustion or reforming
- Affects long-term performance of fuel cell

**Legend:**
- ADG – Anaerobic Digestion Gas
- LFG – Land Fill Gas

Source: Argonne National Laboratory
What are the tolerance limits for the Fuel Cells?

• **Sulfur**
  - Corrosive, affects catalyst and electrolyte
  - Rapid initial followed by slower voltage decay. Effect may be recoverable
  - Tolerance limits 0.5-5 ppm
  - More severe effect with CH₄/CO rich fuels to Fuel Cell and anode recirculation

• **Siloxanes**
  - Thermally decompose forming glassy layers
  - Fouls surfaces (HEx, sensors, catalysts)
  - Few studies on the effects on FC’s, but tolerance limits may be practically zero

• **Halogens**
  - Corrosive, affects electrolyte
  - Long term degradation effect
  - Tolerance limits, 0.1-1 ppm

Source: Argonne National Laboratory
Stationary Fuel Cells – Cost Analysis

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

MCFC 1.4 MW
Application-driven targets for commercial viability in terms of cost and performance recently revised and updated

**Example of system level targets:**

<table>
<thead>
<tr>
<th>Technical Targets: 1–10 kW&lt;sub&gt;e&lt;/sub&gt; Residential Combined Heat and Power and Distributed Generation Fuel Cell Systems Operating on Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>Electrical efficiency at rated power</td>
</tr>
<tr>
<td>CHP energy efficiency</td>
</tr>
<tr>
<td>Equipment cost, 2-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
</tr>
<tr>
<td>Equipment cost, 5-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
</tr>
<tr>
<td>Equipment cost, 10-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
</tr>
<tr>
<td>Transient response (10 - 90% rated power)</td>
</tr>
<tr>
<td>Start-up time from 20°C ambient temperature</td>
</tr>
<tr>
<td>Degradation with cycling</td>
</tr>
<tr>
<td>Operating lifetime</td>
</tr>
<tr>
<td>System availability</td>
</tr>
</tbody>
</table>

Targets revised for the complete portfolio guiding R&D for transportation, stationary, and portable applications.

Revised targets in recently released MYRDD Plan
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html
Waste To Energy Example
Los Alamitos Joint Forces Training Base (JFTB)

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 Compost 25 ton/day
Gasifier & Cleanup
Fuel Cells

1,600 kW

National Renewable Energy Laboratory
Innovation for Our Energy Future
Examples of DOE Funded Fuel Cell Deployments

U.S. Fuel Cell Deployments Using DOE Market Transformation and Recovery Act Funding

Primarily forklifts and back-up power units
Tactical WTE Efforts & Demos*

• Defense Advanced Research Projects Agency (DARPA) and Army Research Lab (ARL)
  – Basic research and fundamental technology development (MISER, etc)

• Natick Soldier RDEC (NSRDEC)
  – Combination of SBIR and mission funded projects for Waste to Energy Converter (WEC) since 2000
    Contractors include Community Power Corp (CPC), Infosicite, General Atomics, and Green Liquid and Gas Technologies
  – Targeting PM Force Provider for technology transition / deployment
  – Mobile Encampment Waste to Electrical Power System (MEWEPS) project with CPC, second field demonstration scheduled at Ft. Irwin, CA in Feb 2011

• Edgewood Chemical / Biological Center (ECBC)
  – Tactical Garbage to Energy Refinery (TGER) AIDE project with DLS, Purdue University, and CPC, field demonstration executed in theater

• Communications-Electronics RDEC (CERDEC)
  – Biofuel / Tactical Quiet Generator Hybrid Waste to Energy project with CPC, contract on-going

Other Potential Opportunities
• Fort Stewart 94,000 lbs/hr steam Wood Chip Plant (off line).
• Aberdeen Proving Ground - Offsite plant supplies approx 70,000 lbs/hr (peak) and approx 452,000 Mlbs total 350 psi steam/year.
• The Eielson Air Force Base system processed over 560 tons of paper products in the base’s central heat and power plant which provided 7.82 mmBtu of energy (program currently suspended because the pellet plant is inoperable).
• Hill Air Force Base, which generated 2.1 MW of electricity from landfill gas and has plans to expand to 3.2 MW.
• Dyess Air Force Base which is pursuing a 5.5 MW municipal solid waste energy plant.
• SUNY – Cobleskill Bioenergy Center

* Information provided by Daniela Caughron, APG
Use of biogas for hydrogen production as transportation fuel and stationary fuel cells for power and heat generation will be impacted by contaminant content and cleanup costs.

### Barriers

- High level of contaminants
- High variability of contaminant concentrations
- High capital cost for contaminant removal
- Low experience level with biogas cleanup
- Location of resources relative to demand centers and understanding cost impacts of transportation

### Activities

- Held workshops to understand gaps for utilizing biogas for hydrogen and power production
- Working with Argonne National Laboratory to understand impact of biogas impurities on stationary fuel cell performance
- Working with National Renewable Energy Laboratory on location of biogas resources and development of biogas H2A model for biogas cost analysis
### Funding Opportunity Announcements & Requests for Information

#### FY 2012 FOAs

<table>
<thead>
<tr>
<th>Project Description</th>
<th>FY 2012 Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect Performance Data on Fuel Cell Electric Vehicles (deadline extended 6/18)</td>
<td>$6.0 million</td>
</tr>
<tr>
<td>Hydrogen Fueling Stations and Innovations in Hydrogen Infrastructure Technologies</td>
<td>$2.0 million</td>
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<tr>
<td></td>
<td>(closed 5/11)</td>
</tr>
<tr>
<td>Fuel Cell Powered Baggage Vehicles at Commercial Airports</td>
<td>$2.5 million</td>
</tr>
<tr>
<td>Zero-Emission Cargo Transport Vehicles (Vehicle Technologies, closes 5/15)</td>
<td>$10.0 million</td>
</tr>
</tbody>
</table>

#### Requests for Information

- Fuel Cell RFIs on Targets for Lift Trucks and Backup Power
- Potential Topics for H-Prize—*extended to May 31, 2012*
  (www.hydrogenandfuelcells.energy.gov/m/news_detail.html?news_id=18182)
- Storage RFI on Early Market Targets
  (Posted on eXCHANGE at https://eere-exchange.energy.gov/Default.aspx#6d785cb1-552e-44bd-98e3-e27a7e3fea0b)