Tennessee Valley Authority, 1101 Market Street, LP 5A, Chattanooga, Tennessee 37402-2801

June 12, 2008

10 CFR 52.80

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

In the Matter of )
Tennessee Valley Authority ) Docket Numbers 52-014 and 52-015

NUCLEAR REGULATORY COMMISSION (NRC) – BELLEFONTE NUCLEAR PLANT (BLN) – RESPONSE TO NRC INFORMATION NEEDS RELATED TO ALTERNATIVES

Reference: Letter from Ashok Bhatnagar (TVA) to Mr. R. William Borchardt (NRC), "Application for Combined License for BLN Units 3 and 4," dated October 30, 2007.

The purpose of this letter is to provide responses to the information needs relating to Alternatives, as identified by the NRC reviewers during the Environmental Report (ER) site audit conducted at the Tennessee Valley Authority (TVA) Bellefonte Nuclear Plant, Units 3 and 4 (BLN) site during the week of March 31 through April 4, 2008.

By the referenced letter, TVA submitted an application for a combined license for two AP1000 advanced passive pressurized-water reactors at the BLN site. Included in the review of a combined license application (COLA) is an environmental site audit during which the NRC staff tours the proposed plant site and environs and reviews the applicable documents that support the information provided in the ER. At the April 4, 2008 exit meeting for the BLN site audit, the NRC staff provided a list of information that was determined to be necessary to complete the review of the ER.

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The enclosure to this letter provides responses to the NRC information needs related to alternatives and identifies changes that will be made in a future revision of the BLN application. The enclosure also provides the status of the alternatives information needs. Attachments A1 through N to the enclosure provide the documents that are identified in the BLN responses.

If there are any questions regarding this application, please contact Phillip Ray at 1101 Market Street, LP 5A, Chattanooga, Tennessee 37402-2801, by telephone at (423) 751-7030, or via email at pmray@tva.gov.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on this 12th day of June, 2008.

Jack A. Bailey

Jack A. Bailey
Vice President, Nuclear Generation Development
Nuclear Generation Development & Construction

Enclosure and Attachments A1 - N
See Page 8

Enclosure: Response to NRC Information Needs – Alternatives (Alt)

Attachments A1 – N:

A1. Business Week, July 4, 2005, News Analysis and Commentary, "Alternate Power: A Change Is in the Wind," Website, http://www.businessweek.com/magazine/content/05_27/b3941036_mz011.htm, accessed January 12, 2007.

A2. U.S. Department of Energy (DOE), Energy Information Administration (EIA), Nuclear Power., Website, no date, http://www.eia.doe.gov/cneaf/nuclear/page/analysis/nuclearpower.html (pages 1 - 7), accessed April 9, 2008.

A3. Iowa Energy Center, Wind Energy Manual, "Wind Energy Economics," 2006, Website, http://www.energy.iastate.edu/renewable/wind/wem/wem-13_econ.html, accessed January 18, 2007.

A4. New Jersey's Clean Energy Program, "Frequently Asked Questions – Offshore Wind Systems," April 2006, Website, http://www.njcep.com/html/faqs/offshorewind.html, accessed January 12, 2007.

A5. Tennessee Valley Authority (TVA), "The Role of Renewable Energy in Reducing Greenhouse Gas Buildup," September 2003, Website, http://www.tva.gov/ environment/air/ontheair/renewable.htm, accessed January 12, 2007.

B1. Solarbuzz LLC, Fast Solar Energy Facts, "Global Performance," March 2006, Website, http://www.solarbuzz.com/FastFactsIndustry.htm, accessed January 12, 2007.

B2. University for Applied Sciences, Esslingen, Germany, "Solar Power Towers," Mesanovic & Philippsen, 1996, Website, http://www.stud.fhtesslingen.de/projects/alt_energy/sol_thermal/powertower.html, accessed January 12, 2007.

B3. U.S. Department of Energy (DOE), Concentrating Solar Power (CSP) Technologies, "Overview," no date , Website, http://www.energylan.sandia.gov/sunlab/overview.htm#cost, accessed January 12, 2007.

B4. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Solar Energy Technology Program, "Furthering Energy Independence," July 2006, Website, http://www1.eere.energy.gov/office_eere/pdfs/solar_fs.pdf, accessed November 2006.

B5. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Program, "Program Areas," October 2006, Website, http://www1.eere.energy.gov/solar/program_areas.html, accessed January 12, 2007.

B6. U.S. National Renewable Energy Laboratory (NREL), "Fuel from the Sky: Solar Power's Potential for Western Energy Supply," Leitner, July 2002, Website, http://www.nrel.gov/csp/pdfs/32160.pdf, accessed November 2006.

B7. U.S. National Renewable Energy Laboratory (NREL), U.S. Solar Radiation Resource Maps, "Atlas for the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors," no date, Website, http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas, accessed November 2006.

C. Idaho National Engineering and Environmental Laboratory, Renewable Energy Products Department, "U.S. Hydropower Resource Assessment, Final Report," December 1998, Website, http://hydropower.inel.gov/resourceassessment/pdfs/doeid-10430.pdf, accessed November 2006.

D1. Geothermal Energy Association, "All about Geothermal Energy – Basics," no date, Website, http://www.geoenergy.org/aboutGE/basics.asp#cap, accessed January 12, 2007.

D2. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Program, "Geothermal Power Plants," January 2006, Website, http://www1.eere.energy.gov/geothermal/powerplants.html, accessed April 26, 2007.

D3. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Program, "U.S. Geothermal Resource Map," January 2006, Website, http://www1.eere.energy.gov/geothermal/geomap.html, accessed January 18, 2007.

E1. REPP, Biomass, "What Can a Dash of Biomass Do?" no date, Website, http://www.repp.org/bioenergy/link3.htm, accessed April 23, 2007.

E2. State of Oregon, Renewable Resources, "Biomass Energy: Cost of Production," no date, Website, http://www.oregon.gov/ENERGY/RENEW/Biomass/Cost.shtml, accessed April 26, 2007.

E3. U.S. Department of Agriculture (DOA) and U.S. Department of Energy (DOE) Joint Study, "Biomass as Feedstock for A Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," ORNL/TM-2005/66, April 2005, Website, http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf, accessed November 2006.

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F1. Florida Public Service Commission and the Department of Environmental Protection, "An Assessment of Renewable Electric Generating Technologies for Florida," January 2003, Website, http://www.psc.state.fl.us/publications/pdf/electricgas/Renewable_Energy_Assessment.pdf, accessed November 2006.

F2. U.S. Environmental Protection Agency (EPA), "Electricity from Municipal Solid Waste," November 2006, Website, http://www.epa.gov/cleanenergy/muni.htm, accessed January 12, 2007.

G1. RTI International, Jeffrey Cole, "Beyond-The-Floor Analysis for Existing and New Coal- And Oil-Fired Electric Utility Steam Generating Units National Emission Standards for Hazardous Air Pollutants," December 2003, Website, http://www.epa.gov/ttn/atw/utility/beyond_floor_012804.pdf, accessed November 2006.

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G4. U.S. Department of Energy (DOE), Energy Information Administration (EIA), "Summary Statistics: Receipts and Cost of Fossil Fuels for the Electric Power Industry by Sector, BTUs," October 2006, Website, http://www.eia.doe.gov/cneaf/electricity/epm/tablees2b.html, accessed January 18, 2007.

H1. Breakthrough Technologies Institute (BTI), Fuel Cells 2000, "Fuel Cells 2000 Projects Database," November 2000, Website, http://www.fuelcells.org/db/projects.php, accessed March 25, 2008.

H2. Electric Power Research Institute (EPRI), "Status & Trends for Stationary Fuel Cell Power Systems," 2005, Website, http://www.mitstanfordberkeleynano.org/events_past/0507%20-%20Fuel%20Cell/ Stanford%20Fuel%20Cell%20Symposium.pdf, accessed November 2006.

H3. Fuel Cell Today, "Facts & Figures," no date, Website, http://www.fuelcelltoday.com/FuelCellToday/EducationCentre/EducationCentreExternal/edukit09en.pdf, accessed November 2006.

H4. University of California, Berkeley, "Fuel Cell System Economics: Comparing the Costs of Generating Power with Stationary and Motor Vehicle PEM Fuel Cell Systems," April 2004 ( pages 1 and 113), Website, http://rael.berkeley.edu/files/2004/ lipman-edwards-kammen-fuelcelleconomics-2004.pdf, accessed March 25, 2008.

I1. U. S. Department of Energy (DOE) and JEA Joint Study, "The JEA Large-Scale CFB Combustion Demonstration Project," Clean Coal Technology Technical Report Number 22, March 2003 (cover page and pages 1 – 4), Website, www.fossil.energy.gov/programs/powersystems/publications/ Clean_Coal_Topical_Reports/topical22.pdf, accessed June 1, 2008.

I2. The University of Chicago, "The Economic Future of Nuclear Power," August 2004 (cover page, Table 1-1, and page 5-1),Website, http://213.130.42.236/wna_pdfs/uocstudy.pdf, accessed November 2006.

I3. U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), "Combustion - Fluidized-Bed Combustion, Program Overview," no date, Website, http://www.netl.doe.gov/technologies/coalpower/Combustion/ FBC/fbcoverview.html, accessed April 23, 2007.

J. Gasification Technologies Conference, San Francisco, Higman, DellaVilla, & Steele, "The Reliability of Integrated Gasification Combined Cycle (IGCC) Power Generation Units," October 2005, Website, http://www.gasification.org/Docs/2005_Papers/ 38HIGM%20Paper.pdf, accessed November 2006.

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K2. Instituto Nacional de Investigaciones Nucleares, México, Palacios & others, "Levelized Costs for Nuclear, Gas and Coal for Electricity, under the Mexican Scenario," 2004, Website, http://www.osti.gov/bridge/servlets/purl/840500-YJxBpR/native/840500.pdf, accessed November 2006.

K3. California Energy Commission, "Moss Landing Power Plant Project," August 1, 2007, Website, http://www.energy.ca.gov/sitingcases/mosslanding/index.html, accessed June 4, 2008.

L. Big Stone II, "Plant project overview," 2006, Website, http://www.bigstoneii.com/PlantProject/PlantProjectOverview.asp, accessed April 23, 2007.

M1. Hill & Associates report "Economic Benefits of a Coal-Fueled Power Plant Compared to Natural Gas, prepared for Peabody Energy, Website,

http://coalcandothat.com/pdfs/EconBeneCoalFuel.pdf, accessed November 2006.

M2. Portland General Electric (PGE), "Frequently Asked Questions about Port Westward Power Plant," 2005, Website, http://www.portlandgeneral.com/about_pge/current_issues/portwestward/timeline.asp?bhcp=1, accessed April 23, 2007.

M3. Portland General Electric (PGE), News Room, "Portland General Electric Announces Port Westward Plant Available for Commercial Generation," no date, Website, http://www.portlandgeneral.com/about_pge/news/06_12_2007_pge_announces_that_its_port_w.asp?bhcp+1, accessed April 9, 2008.

N. Topographical Map Showing Dry Creek Basin and 630 Ft. Elevation Contour

cc (Enclosure and Attachments A1 - N):
M. A. Hood, NRC/HQ

cc (w/o Enclosure and Attachments A1 - N):
S. P.Frantz, Morgan Lewis
R. C.Grumbir, NuStart
P. S. Hastings, NuStart
R. H. Kitchen, PGN
M.C. Kray, NuStart
A. M Monroe, SCE&G
M.C. Nolan, Westinghouse
N. T. Simms, Westinghouse
C. R. Pierce, SNC
L. Reyes, NRC/RII
R. F. Smith-Kevern, DOE/HQ
J. M Sebrosky, NRC/
G. A. Zinke, NuStart

# RESPONSE TO NRC INFORMATION NEEDS

# ALTERNATIVES (Alt)

This enclosure provides the status of the 33 NRC information needs related to the NRC review of Alternatives (Alt) and provides BLN responses to 17 of these Alt Information Needs.

Status of "Alt" Information Needs

| NRC Information Need Number | Status |
|---|---|
| • Alt-01 | Resolved at BLN site audit. |
| • Alt-02 | Response provided in this enclosure. |
| • Alt-03 | Response provided in this enclosure. |
| • Alt-04 | Response provided in this enclosure. |
| • Alt-05 | Response provided in this enclosure. |
| • Alt-06 | Response provided in this enclosure. |
| • Alt-07 | Response provided in this enclosure. |
| • Alt-08 | Response provided in this enclosure. |
| • Alt-09 | Response provided in this enclosure. |
| • Alt-10 | Response provided in this enclosure. |
| • Alt-11 | Response provided in this enclosure. |
| • Alt-12 | Response provided in this enclosure. |
| • Alt-13 | Response provided in this enclosure. |
| • Alt-14 | Response provided in this enclosure. |
| • Alt-15 | Response to be included in a separate TVA response letter providing Alternatives White Paper No. 3 (WP#3). |
| • Alt-16 | Response to be included in a separate TVA response letter providing Alternatives White Paper No. 3 (WP#3). |
| • Alt-17 | Response to be included in a separate TVA response letter providing Alternatives White Paper No. 3 (WP#3). |
| • Alt-18 | Response to be included in a separate TVA response letter providing Alternatives White Paper No. 2 (WP#2). |
| • Alt-19 | Response to this information need to be provided in separate TVA letters providing Alternatives White Paper No. 1 (WP#1) for subparts 1, 2 and 4 and White Paper No. 2 (WP#2) for subpart3. |
| • Alt-20 | Response provided in this enclosure. |
| • Alt-21 | Response to be included in a separate TVA response letter providing |

| NRC Information Need Number | Status |
|---|---|
| | Alternatives White Paper No. 2 (WP#2). |
| • Alt-22 | Response provided in this enclosure. |
| • Alt-23 | Response provided in TVA ER Ltr. 15 (Ref. 2) |
| • Alt-24 | Response provided in TVA ER Ltr. 08 (Ref. 3) |
| • Alt-25 | Response to be provided in a separate TVA response letter. |
| • Alt-26 | Resolved at BLN site audit. |
| • Alt-27 | Response provided in TVA ER Ltr. 08 (Ref. 03) |
| • Alt-28 | Response provided in TVA ER Ltr. 08 (Ref. 03) |
| • Alt-29 | Response provided in this enclosure. |
| • Alt-30 | Resolved at BLN site audit. |
| • Alt-31 | Response provided in this enclosure. |
| • Alt-32 | Response to be included in a separate TVA response letter providing Alternatives White Paper No. 4 (WP#4). |
| • Alt-33 | Response to be included in a separate TVA response letter providing Alternatives White Paper No. 3 (WP#3). |

References

1. Letter from Andrea L. Sterdis, Tennessee Valley Authority, to NRC Document Control Desk, "Response to Environmental Report (ER) Sufficiency Review Comments," dated May 2, 2008.
2. Letter from Jack A. Bailey, Tennessee Valley Authority, to NRC Document Control Desk, "Response to NRC Information Needs Related to Reservoir Vital Signs Monitoring Reports and Coal Gasification Project Environmental Impact Statement," dated June 11, 2008.
3. Letter from Jack A. Bailey, Tennessee Valley Authority, to NRC Document Control Desk, "Response to NRC Information Needs Related to Hydrology," dated June 12, 2008.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Wind Section, 9.2.2.1.

**BLN INFORMATION NEED: Alt-02**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.1 are provided as Attachments A1 through A5 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments A1, A2, A3, A4, and A5 to this enclosure:

A1. Business Week, July 4, 2005, News Analysis and Commentary, "Alternate Power: A Change Is in the Wind," Website, http://www.businessweek.com/magazine/content/05_27/b3941036_mz011.htm, accessed January 12, 2007.

A2. U.S. Department of Energy (DOE), Energy Information Administration (EIA), Nuclear Power., Website, no date, http://www.eia.doe.gov/cneaf/nuclear/page/analysis/nuclearpower.html (pages 1 – 7), accessed April 9, 2008.

A3. Iowa Energy Center, Wind Energy Manual, "Wind Energy Economics," 2006, Website, http://www.energy.iastate.edu/renewable/wind/wem/wem-13_econ.html, accessed January 18, 2007.

A4. New Jersey's Clean Energy Program, "Frequently Asked Questions – Offshore Wind Systems," April 2006, Website, http://www.njcep.com/html/faqs/offshorewind.html, accessed January 12, 2007.

A5. Tennessee Valley Authority (TVA), "The Role of Renewable Energy in Reducing Greenhouse Gas Buildup," September 2003, Website, http://www.tva.gov/environment/air/ontheair/renewable.htm, accessed January 12, 2007.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Solar Section, 9.2.2.2 (specific to solar technology and capacity).

**BLN INFORMATION NEED: Alt-03**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.2 are provided as Attachments B1 through B-7 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments B1 through B7 to this enclosure:

B1. Solarbuzz LLC, Fast Solar Energy Facts, "Global Performance," March 2006, Website, http://www.solarbuzz.com/FastFactsIndustry.htm, accessed January 12, 2007.

B2. University for Applied Sciences, Esslingen, Germany, "Solar Power Towers," Mesanovic & Philippsen, 1996, Website, http://www.stud.fhtesslingen.de/projects/alt_energy/sol_thermal/powertower.html, accessed January 12, 2007.

B3. U.S. Department of Energy (DOE), Concentrating Solar Power (CSP) Technologies, "Overview," no date , Website, http://www.energylan.sandia.gov/sunlab/overview.htm#cost, accessed January 12, 2007.

B4. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Solar Energy Technology Program, "Furthering Energy Independence," July 2006, Website, http://www1.eere.energy.gov/office_eere/pdfs/solar_fs.pdf, accessed November 2006.

B5. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Program, "Program Areas," October 2006, Website, http://www1.eere.energy.gov/solar/program_areas.html, accessed January 12, 2007.

B6. U.S. National Renewable Energy Laboratory (NREL), "Fuel from the Sky: Solar Power's Potential for Western Energy Supply," Leitner, July 2002, Website, http://www.nrel.gov/csp/pdfs/32160.pdf, accessed November 2006.

B7. U.S. National Renewable Energy Laboratory (NREL), U.S. Solar Radiation Resource Maps, "Atlas for the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors," no date, Website, http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas, accessed November 2006.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

> Provide formal reference for "The Idaho National Laboratory Hydro Resource Assessment" (Section 9.2.2.3).

**BLN INFORMATION NEED: Alt-04**

**BLN RESPONSE:**

The requested source document for ER Subsection 9.2.2.3 is provided as Attachment C to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENT:**

The following document is provided as Attachment C to this enclosure:

C. Idaho National Engineering and Environmental Laboratory, Renewable Energy Products Department, "U.S. Hydropower Resource Assessment, Final Report," December 1998, Website, http://hydropower.inel.gov/resourceassessment/pdfs/doeid-10430.pdf, accessed November 2006.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Geothermal Section, 9.2.2.4.

**BLN INFORMATION NEED: Alt-05**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.4 are provided as Attachments D1 through D3 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments D1, D2, and D3:

D1. Geothermal Energy Association, "All about Geothermal Energy – Basics," no date, Website, http://www.geoenergy.org/aboutGE/basics.asp#cap, accessed January 12, 2007.

D2. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Program, "Geothermal Power Plants," January 2006, Website, http://www1.eere.energy.gov/geothermal/powerplants.html, accessed April 26, 2007.

D3. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Program, "U.S. Geothermal Resource Map," January 2006, Website, http://www1.eere.energy.gov/geothermal/geomap.html, accessed January 18, 2007.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Biomass Related Fuels Section. 9.2.2.5.

**BLN INFORMATION NEED: Alt-06**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.5 are provided as Attachments A5 and E1 through E5 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following document is provided as Attachment A5, in response to Information Need Alt-02:

A5. Tennessee Valley Authority (TVA), "The Role of Renewable Energy in Reducing Greenhouse Gas Buildup," September 2003, Website, http://www.tva.gov/environment/air/ontheair/renewable.htm, accessed January 12, 2007.

The following documents are provided as Attachments E1 through E5 to this enclosure:

E1. REPP, Biomass, "What Can a Dash of Biomass Do?" no date, Website, http://www.repp.org/bioenergy/link3.htm, accessed April 23, 2007.

E2. State of Oregon, Renewable Resources, "Biomass Energy: Cost of Production," no date, Website, http://www.oregon.gov/ENERGY/RENEW/Biomass/Cost.shtml, accessed April 26, 2007.

E3. U.S. Department of Agriculture (DOA) and U.S. Department of Energy (DOE) Joint Study, "Biomass as Feedstock for A Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," ORNL/TM-2005/66, April 2005, Website, http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf, accessed November 2006.

E4. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), Biopower Fact Sheet, "Biomass Cofiring: A Renewable Alternative for Utilities," DOE/GO-102000-1055, June 2000, Website, http://www.nrel.gov/docs/fy00osti/28009.pdf, accessed November 2006.

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**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Municipal Solid Waste Section. 9.2.2.6.

**BLN INFORMATION NEED: Alt-07**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.6 are provided as Attachments F1 and F2 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments F1 and F2 to this enclosure:

F1. Florida Public Service Commission and the Department of Environmental Protection, "An Assessment of Renewable Electric Generating Technologies for Florida," January 2003, Website, http://www.psc.state.fl.us/publications/pdf/electricgas/Renewable_Energy_Assessment.pdf, accessed November 2006.

F2. U.S. Environmental Protection Agency (EPA), "Electricity from Municipal Solid Waste," November 2006, Website, http://www.epa.gov/cleanenergy/muni.htm, accessed January 12, 2007.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Petroleum Liquids Section. 9.2.2.7.

**BLN INFORMATION NEED: Alt-08**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.7 are provided as Attachments G1 through G4 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments G1 through G4 to this enclosure:

G1. RTI International, Jeffrey Cole, "Beyond-The-Floor Analysis for Existing and New Coal- And Oil-Fired Electric Utility Steam Generating Units National Emission Standards for Hazardous Air Pollutants," December 2003, Website, http://www.epa.gov/ttn/atw/utility/beyond_floor_012804.pdf, accessed November 2006.

G2. U.S. Department of Energy (DOE), Energy Information Administration (EIA), "Net Generation by Energy Source by Type of Producer," October 2006, Website, http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html, accessed January 18, 2007.

G3. U.S. Department of Energy (DOE), Energy Information Administration (EIA), "Share of U.S. Net Electric Utility Generation by Energy Source," no date, Website, http://www.eia.doe.gov/emev/25opec/sld027.htm, accessed April 9, 2008.

G4. U.S. Department of Energy (DOE), Energy Information Administration (EIA), "Summary Statistics: Receipts and Cost of Fossil Fuels for the Electric Power Industry by Sector, BTUs," October 2006, Website, http://www.eia.doe.gov/cneaf/electricity/epm/tablees2b.html, accessed January 18, 2007.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Fuel Cells Section. 9.2.2.8.

**BLN INFORMATION NEED: Alt-09**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.8 are provided as Attachments H1 through H4 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments H1 through H4 to this enclosure:

H1. Breakthrough Technologies Institute (BTI), Fuel Cells 2000, "Fuel Cells 2000 Projects Database," November 2000, Website, http://www.fuelcells.org/db/projects.php, accessed March 25, 2008.

H2. Electric Power Research Institute (EPRI), "Status & Trends for Stationary Fuel Cell Power Systems," 2005, Website, http://www.mitstanfordberkeleynano.org/events_past/0507%20-%20Fuel%20Cell/Stanford%20Fuel%20Cell%20Symposium.pdf, accessed November 2006.

H3. Fuel Cell Today, "Facts & Figures," no date, Website, http://www.fuelcelltoday.com/FuelCellToday/EducationCentre/EducationCentreExternal/edukit09en.pdf, accessed November 2006.

H4. University of California, Berkeley, "Fuel Cell System Economics: Comparing the Costs of Generating Power with Stationary and Motor Vehicle PEM Fuel Cell Systems," April 2004 ( pages 1 and 113), Website, http://rael.berkeley.edu/files/2004/lipman-edwards-kammen-fuelcelleconomics-2004.pdf, accessed March 25, 2008.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Reference/s needed for Pulverized Coal Section. 9.2.2.9. Specifically references needed for following conclusions/numbers:

- See paragraph 5, "FBC is not a cost-effective alternative for the proposed project."
- See paragraph 6, "PFBC systems would eventually exceed 50 percent."
- See paragraph 8, "Recent estimates indicate that capital costs for conventional pulverized-coal-fired power plants range from $1094/kW to $1169/kW. The levelized cost of electricity produced from pulverized-coal-fired power plants is $0.033/kWh to $0.041/kWh.

**BLN INFORMATION NEED: Alt-10**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.2.9 are provided as Attachments I1 through I3 to this enclosure, as addressed below.

During the review of the documentation provided in response to this information need, it was identified that the capital cost information from Table 1-1 of the University of Chicago paper (Attachment I2) is misstated in Subsection 9.2.2.9, paragraph 8. The high-end capital cost estimate should be $1350/kW, rather than $1169/kW. This information is corrected in the BLN COL Application below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

Revise COLA Part 3, ER Chapter 9, Section 9.2.2.9, by revising the first sentence in the 8th paragraph, as follows:

Recent estimates indicate that capital costs for conventional pulverized-coal-fired power plants range from $1094/kW to ~~$1169/kW~~ $1350/kW.

**ATTACHMENTS:**

The following documents are provided as Attachments I1 through I3 to this enclosure:

I1. U. S. Department of Energy (DOE) and JEA Joint Study, "The JEA Large-Scale CFB Combustion Demonstration Project," Clean Coal Technology Technical Report Number 22, March 2003 (cover page and pages 1 – 4), Website,

www.fossil.energy.gov/programs/powersystems/publications/Clean_Coal_Topical_Reports/topical22.pdf, accessed June 1, 2008.

I2. The University of Chicago, "The Economic Future of Nuclear Power," August 2004 (cover page, Table 1-1, and page 5-1),Website, http://213.130.42.236/wna_pdfs/uocstudy.pdf, accessed November 2006.

I3. U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), "Combustion - Fluidized-Bed Combustion, Program Overview," no date, Website, http://www.netl.doe.gov/technologies/coalpower/Combustion/FBC/fbcoverview.html, accessed April 23, 2007.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

> Explain who/what is the source of "experience" (listed as basis for Integrated Gasification Combined Cycle conclusions – Section 9.2.2.10, paragraph 4). Describe experience or list reference.

**BLN INFORMATION NEED: Alt-11**

**BLN RESPONSE:**

The source of the experience listed as the basis for the Integrated Gasification Combined Cycle conclusions in the fourth paragraph of ER Subsection 9.2.2.10, is provided as Attachment J to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENT:**

The following document is provided as Attachment J to this enclosure:

J. Gasification Technologies Conference, San Francisco, Higman, DellaVilla, & Steele, "The Reliability of Integrated Gasification Combined Cycle (IGCC) Power Generation Units," October 2005, Website, http://www.gasification.org/Docs/2005_Papers/38HIGM%20Paper.pdf, accessed November 2006.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

> Provide reference for studies listed as source of Natural Gas discussion and verify sizing assumptions throughout assessment of reasonable alternatives.

**BLN INFORMATION NEED: Alt-12**

**BLN RESPONSE:**

The source documents for the studies listed in the natural gas discussion are provided as Attachments K1 through K3 to this enclosure, as addressed below.

Sizing assumptions throughout the assessment of reasonable alternatives were verified to confirm they are reasonable for the alternative energy source plants used in the comparison. The 530 MW plant sizes were chosen to provide a plant configuration that could be developed for an easy comparison with the AP1000 net capacity. As stated in ER Subsection 9.2.3.2, TVA understands that four 530 MW units would provide less capacity than the proposed two AP1000 nuclear units, as this configuration would minimize the potential for overestimating environmental impacts from the alternatives. The capacity of TVA's current fleet of coal-fired plants ranges from less than 100 MW to greater than 1200 MW. Based on this range, a 530 MW pulverized-coal-fired generation was determined to be both reasonable and achievable. Similarly, the 530 MW combined-cycle natural-gas-fired generation units were chosen based on research that determined the feasibility of constructing units that meet this sizing criterion. An example of 530 MW natural-gas-fired units is presented in Attachment K3.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments K1 through K3 of this enclosure:

K1. U.S. Department of Energy (DOE), Energy Information Administration (EIA), "Assumptions to the Annual Energy Outlook," DOE/EIA-0554(2006), March 2006, Website, http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2006).pdf, accessed November 2006.

K2. Instituto Nacional de Investigaciones Nucleares, México, Palacios & others, "Levelized Costs for Nuclear, Gas and Coal for Electricity, under the Mexican Scenario," 2004, Website, http://www.osti.gov/bridge/servlets/purl/840500-YJxBpR/native/840500.pdf, accessed November 2006.

K3. California Energy Commission, "Moss Landing Power Plant Project," August 1, 2007, Website, http://www.energy.ca.gov/sitingcases/mosslanding/index.html, accessed June 4, 2008.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Provide source of socioeconomic data listed in "Other Impacts," Section 9.2.3.1.3.

**BLN INFORMATION NEED: Alt-13**

**BLN RESPONSE:**

The source document for the socioeconomic data listed in ER Subsection 9.2.3.1.3 is provided as Attachment L to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENT:**

The following document is provided as Attachment L to this enclosure:

L. Big Stone II, "Plant project overview," 2006, Website, http://www.bigstoneii.com/PlantProject/PlantProjectOverview.asp, accessed April 23, 2007.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Provide source of socioeconomic data listed in "Other Impacts," Section 9.2.3.2.3.

**BLN INFORMATION NEED: Alt-14**

**BLN RESPONSE:**

The source documents for ER Subsection 9.2.3.2.3 are provided as Attachments M1 through M3 to this enclosure, as addressed below.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

The following documents are provided as Attachments M1, M2, and M3 to this enclosure:

M1. Hill & Associates report "Economic Benefits of a Coal-Fueled Power Plant Compared to Natural Gas, prepared for Peabody Energy, Website, http://coalcandothat.com/pdfs/EconBeneCoalFuel.pdf, accessed November 2006.

M2. Portland General Electric (PGE), "Frequently Asked Questions about Port Westward Power Plant," 2005, Website, http://www.portlandgeneral.com/about_pge/current_issues/portwestward/timeline.asp?bhcp=1, accessed April 23, 2007.

M3. Portland General Electric (PGE), News Room, no date, "Portland General Electric Announces Port Westward Plant Available for Commercial Generation," Website, http://www.portlandgeneral.com/about_pge/news/06_12_2007_pge_announces_that_its_port_w.asp?bhcp+1, accessed April 9, 2008.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

> Page 9.3-4 of ER, #2, states that "The selected sites received subsequent evaluations under NEPA (from both TVA and the NRC) that included comparisons for environmental impacts and engineering feasibility as nuclear plant sites with the alternative sites." Describe evaluation activities that took place, including dates, and reference formal documents if available.

**BLN INFORMATION NEED: Alt-20**

**BLN RESPONSE:**

Item 2 on page 9.3-4 is referring to the analyses and documentation in the Final Environmental [Impact] Statements, prepared for the Bellefonte, Hartsville, and Yellow Creek nuclear sites and the Murphy Hill Coal Gasification site, and the Environmental Report prepared for the Phipps Bend nuclear site. The pertinent TVA documents are the five cited on page 9.3-3 of the ER (References 2 through 6). The statement simply means that the selected and alternative candidate sites identified in those review documents underwent comparison of environmental impacts and engineering feasibility under the NEPA process. These references were made available to the NRC reviewers as references for the BLN ER. A change to the text in Item 2 is provided to delete the word "subsequent," which leads to the misunderstanding that additional evaluations occurred after the completion of the Final Environmental Statements.

Evaluations performed for these documents were typical of EIS-level reviews involving siting and construction of nuclear generation facilities. They included review of potential impacts for the selected site; consideration of alternative sites, plant operations; construction and operation of transmission and other ancillary infrastructure requirements; and management and transportation of new fuel, spent fuel, and radioactive waste. Issue areas and potential impacts to resources considered included geology, soils, seismology, climatology and meteorology, air quality, solid waste, noise, socio-economics, surface water (quality, use, thermal impacts) and groundwater, land use and land use compatibility, aesthetics, transportation, recreation, aquatic and terrestrial ecology (plants and animals), rare and endangered species, cultural resources, and human health.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

Revise COLA Part 3, ER Chapter 9, Section 9.3.2.2, by revising item 2 on page 9.3-4, as follows:

2. The selected sites received ~~subsequent~~ evaluations under NEPA (from both TVA and the NRC) that included comparisons for environmental impacts and engineering feasibility as nuclear plant sites with the alternative sites.

**ATTACHMENTS:**

None.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

> It is stated that the 4 alternative sites conformed with land use urban and industrial development controls and policies during the original construction planning was taking place (1970s and 1980s); however, there is no description of the current land use zoning and policies may be for the 4 alternative sites. An updated description of these local government controls and policies (if any) is needed.

**BLN INFORMATION NEED: Alt-22**

**BLN RESPONSE:**

As an instrument of the federal government, TVA is not subject to local zoning or state regulation, but considers such factors in its review of sites. In support of this review, TVA staff contacted local county governments to update the status of local zoning and land use planning for the alternative sites. At three of the alternative sites, local governments exercise no zoning controls and do not have other land use plans or reviews that could conflict with the use of the sites for nuclear power production. These include the Phipps Bend nuclear (PBN) site in Hawkins County, Tennessee, the Yellow Creek nuclear (YCN) site in Tishomingo County, Mississippi, and the Murphy Hill (MH) site in Marshall County, Alabama.

Although acquired for power production purposes, the MH site is currently designated by TVA for natural resource conservation purposes. The Alabama Department of Transportation is re-evaluating a segment of a planned interstate highway, the Memphis to Atlanta Corridor, that would cross through the southern part of the MH site, between river miles 368 and 369. This potential highway expansion is currently under consideration; no firm plans have been made to move forward on this project.

As shown in ER Figure 9.3-4, the Hartsville nuclear (HVN) site is located within two Tennessee counties. Most of the current site is in Trousdale County, but a small portion on the east side of the site is in Smith County. The land in the Trousdale County portion of the HVN site is currently zoned either M-1 or M-2. These zoning classifications are different categories of light to intermediate impact industries. The portion in Smith County and the immediate area around the eastern side of the site is zoned either agricultural or light industry (I-1). In addition, there is adjoining land along the east side, also in Smith County, that could be considered for nuclear construction. In both counties, the County Commission has zoning authority. Zoning requests are reviewed by the county planning commission and, in Trousdale County, by the county Building and Codes Department. Recommendations by these bodies are sent to the County Commissions for final action.

As discussed with the NRC reviewers during the HVN site visit on May 14, 2008, Corrections Corporation of America recently announced (February 22, 2008) its intention to build the

Trousdale Corrections Center on the PowerCom Industrial Center site. A customer for this maximum-security prison facility has not yet been finalized.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

None.

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Location of Dry Creek Basin

**BLN INFORMATION NEED: Alt-29**

**BLN RESPONSE:**

The Dry Creek "basin" would be the depression in which Dry Creek runs (i.e., the creek valley). Dry Creek is several miles away from the plant, and any impoundment to elevation 630 ft. msl for a cooling pond would be a significant distance from the site and impact not only Dry Creek, but Town Creek as well. A topographical map that shows the Dry Creek basin and the 630 ft. elevation contour (in red) is provided as Attachment N. This alternative was determined not to be viable, because of the large amount of land that would be required to support it. Therefore, no effort was made to develop a more detailed design of this cooling pond, and the map provided as Attachment N is not modified to include dikes, bridges, or any other engineering features that would be required to pursue this alternative further.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENT:**

N. Topographical Map Showing Dry Creek Basin and 630 Ft. Elevation Contour

**NRC Review of the BLN Environmental Report**

**NRC Information Needs - BLN ER Site Audit Exit Meeting**

**NRC Environmental Category: ALTERNATIVES**

During the BLN Environmental Report site audit exit meeting on April 4, 2008, the NRC staff identified the following information need:

Explanation of Fish Return Alternate Systems for intake systems

**BLN INFORMATION NEED: Alt-31**

**BLN RESPONSE:**

TVA has no plan to install a fish return system for the BLN intake system. BLN's through-screen velocities are estimated to be 0.12 fps at maximum pool elevation of 595 feet, well below the Section 316(b) 0.5 fps requirement. Because the BLN through-screen velocities are less than the Section 316(b) requirement, BLN is exempt from the EPA Phase II rule and is not required to collect impingement mortality studies to comply with the rule. Similarly, Watts Bar Nuclear Plant was not required to collect impingement mortality samples on their intake below Watts Bar Dam, because they were also exempt. While impingement mortality at Widows Creek Fossil Plant (WCF) is low compared to other TVA plants on the Tennessee River, BLN impingement mortality of fish and shellfish is expected to be extremely low in comparison to WCF, due to BLN's very low, through-screen velocities.

**ASSOCIATED BLN COL APPLICATION REVISIONS:**

None.

**ATTACHMENTS:**

None.

# Business Week
# News Analysis and Commentary

# "Alternate Power: A Change is in the Wind"

# July 4, 2005



JULY 4, 2005

NEWS: ANALYSIS & COMMENTARY

# Alternate Power: A Change Is In The Wind

**The industry is gaining critical mass, but its economic future remains iffy**

The words "solar power" conjure up images of ungainly rooftop panels mounted by die-hard environmentalists. But Jigar Shah plans to change all that. As CEO of Baltimore-based SunEdison LLC, he dreams of the sun supplying up to 10% of the electricity needed in many parts of the country. And now he has the financial muscle to embark on his vision. On June 9, SunEdison announced a $60 million fund, financed by Goldman Sachs (GS) and Hudson United Bank (HU), to oversee BP Solar's (BP) installation of 25 electric systems on Staples (SPLS) and Whole Foods Market (WFMI) stores, along with other locations. The recipients get reliable power at a guaranteed price, providing a hedge against cost spikes during periods of peak electricity demand. The financiers catch a ride on a global solar market that's already more than $7 billion per year and expanding at a rate of more than 30% annually. "The growth opportunities are tremendous," says Shah.



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The new dawn isn't limited to solar power. An array of alternative-energy, energy-efficiency, and other green technologies -- together known as "cleantech" -- are beginning to boom. A host of forces is responsible for the trend: high prices for oil, gas, and coal; expanded government incentives and mandates; advances in technology that are reducing costs; concern over global warming; and investors looking for the Next Big Thing. "What has changed dramatically is the number of mainstream institutions that have decided they can make money in this area," says Dan Reicher, president of New Energy Capital Corp. and a former top Energy Dept. official. "Who would have thought two years ago that Goldman Sachs would be investing in wind and solar power?"

**SHIFT IN THE GROUND**

Indeed, an increasing number of major corporate players like General Electric and Siemens (SI ), traditional venture-capital firms such as Kleiner Perkins Caufield & Byers, and even states are putting money into the market. In its so-called Green Wave Initiative, California plans to use $500 million from two state pension funds -- CalPERS and CalSTRS -- to seed proposals for alternative energy. "Clean technology is becoming the enabling technology of the 21st century industrial society," says Nicholas Parker, chairman of Cleantech Venture Network LLC, which tracks the field for its investor members.

But cleantech comes with daunting risks as well as opportunities. The big uncertainty: Its economics and profitability vary dramatically with changes in energy prices and government policies. "For a long time, with low gas and coal

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prices, renewables of all kinds couldn't compete," explains Jerry Peters, senior vice-president at Hudson United Bank. But now, with natural gas rising to more than $7 per million BTUs and eastern coal up to $60 per ton, average U.S. electricity prices, by state, now range from 5 cents to 16 cents per kilowatt hour (kwh). In some states, that's a 25% jump since 1995. At the same time, technological improvements and economies of scale have significantly lowered the costs of alternatives. Wind-power costs have declined to as little as 3 cents to 5 cents per kwh, making wind cost competitive. That's one reason why GE's wind business has soared from $500 million in 2002 to a predicted $2 billion this year.

Yet wind power wouldn't be growing at its current U.S. rate of 37% per year without government mandates and incentives. When Congress delayed renewing the 1.8 cents per kwh credit for wind power last summer, for instance, the business tanked until the credit was restored.

The delicate interplay of prices and policies is even more complicated for solar power, which is still at least 3 to 5 times as costly as conventional sources and thus dependent on subsidies. Germany has become a leader in solar electricity because of what Erik Straser, general partner at Mohr, Davidow Ventures, calls a "masterful" policy: When companies or individuals install photovoltaic panels, the government pays them about four times the going rate of electricity for any power that flows back into the grid. The approach has been "successfully copied by South Korea, Japan, and Spain," says Straser. "It's a way for a country to take a fundamental step toward energy independence."

While that may seem a high price to pay for energy alternatives, such policies are paving the way for a lower-cost future. Because of the growing worldwide market and manufacturing advances at big silicon-panel makers like Sharp Corp. (**SHCAY**), installed costs for solar systems have been dropping at a steady 5% per year for the past decade -- and should continue to do so. By 2010 or 2015, predicts SunEdison's Shah, solar electricity will be cost-competitive in some parts of the U.S.

In the meantime, U.S. subsidies are fueling growth. The federal government offers tax credits for wind, solar, and other renewables. In addition, 19 states have so-called renewable portfolio standards, requiring that a percentage of energy come from green sources. That has created a market for renewable energy credits that utilities can trade to meet the goals.

As a result, SunEdison's solar power project, for instance, brings many financial benefits. Hudson Bank gets revenue from sales of electricity and renewable-energy credits, while Goldman Sachs gets a write-off from the tax credits and accelerated depreciation. "This is a great example of how innovative financing and

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the right technology can deliver solar or alternatives now," says Raymond Crespo, vice-president at Energy Conservation & Supply Inc., a New York consultancy that helps office buildings and retailers improve energy efficiency.

**BUBBLE AHEAD?**

Meanwhile, venture capitalists are betting that innovative new technologies can bring down the costs of solar power far faster than the current 5% rate of decline. In early June, San Jose (Calif.)-based Miasolé, which uses the technology underlying computer disk drives to make thin-film solar cells, snared $16.5 million from venture-capital firm Kleiner Perkins.

On June 13, Nanosolar announced that it had closed $20 million in Series B funding from investors such as Mohr, Davidow Ventures, and Benchmark Capital Management Co. The Menlo Park (Calif.) company uses new materials and processes to sidestep the problems of conventional silicon cells.

While promising, these technologies carry plenty of risk. One of them might emerge as the eventual winner, or downturns in conventional energy prices or government policies could put a damper on the market. Some venture capitalists caution that the current rush to invest could create a bubble similar to the one that happened with fuel cells a few years ago. "Oil prices are on the front page, and there has been a bit of herd mentality," says Bill Green, venture capitalist with VantagePoint Venture Partners.

Still, high demand for energy around the world is likely to keep oil, gas, and coal prices high. And environmental concerns will bring more incentives for alternative energy and energy efficiency, not fewer. "If people are convinced that subsidies will remain, capital will follow," says Howard H. Newman, vice-chairman of private equity investor Warburg Pincus.

A powerful convergence of events, from global action against climate change to rising demand for oil, is happening. There will be bumps in the road, but renewable energy and energy-efficiency technologies look set to command an increasing share of investment dollars and markets.

---

By John Carey in Washington and Adam Aston in New York, with Justin Hibbard in San Mateo, Calif., and Ronald Grover in Los Angeles

BACK TO TOP

ATTACHMENT A2
ENERGY INFORMATION ADMINISTRATION
"NUCLEAR POWER"
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## Nuclear Power

### Nuclear Power: 12 percent of America's Generating Capacity, 20 percent of the Electricity

Charts on plant ownership, costs, license extensions, and future trends.

Opinions vary regarding the future of nuclear power, but it is a fact that existing U.S. plants are performing well. Nuclear power plants now operate at a 90 percent capacity factor, compared to 56 percent in 1980. Additionally and in contrast to oil and gas, nuclear fuel costs are low and relatively stable. Fuel costs now average less than one half cent per kilowatthour. This is well below the costs of major competing fossil fuels. Production costs for nuclear power, operation and maintenance plus fuel costs, are also low, averaging 1.8 cents per kilowatt-hour. This cost roughly matches coal and is significantly below the costs of operating a natural gas plant.

Despite all of this relatively attractive news regarding nuclear power, there has been no new order for a nuclear power plant since the 1970s. The last nuclear plant to be completed went on line in 1996. A few, perhaps four, construction licenses are still valid or are being renewed for half-completed reactors, but there are no active plans to finish these reactors.

What follows is an attempt to describe the sources of nuclear power's apparent strength. This will also include a brief overview of the varied problems that nuclear power industry faces if it seeks to expand its market share further.

### The Track Record of Nuclear Power

Nuclear power is a relatively new industry even though nuclear generation capacity has been almost constant since 1990. While prototype and early plant designs have been around since the 1950s, the first large scale and truly commercial units only began operating in the late 1960s in the United States. The following table includes only light water reactors that have been licensed for commercial operation since 1968. The oldest reactors still operating in the United States were licensed in 1969.

**U.S. Light Water Reactors Operating License Year**

| License Year | Reactors Licensed | Share of Reactors | Closed Reactors | Operable Reactors | Share of Operable |
|---|---|---|---|---|---|
| 1968-74 | 38 | 33.6% | 6 | 32 | 30.8% |
| 1975-78 | 23 | 20.4% | 3 | 20 | 19.2% |
| 1979-96 | 52 | 46.0% | 0 | 52 | 50.0% |
| **Total** | **43** | **100.0%** | **9** | **104** | **100.0%** |

Half of the commercial nuclear reactors operating in the United States are less than 24 years old. Because the newer units tend to be larger than the older units, this represents slightly more than half of the generating capacity of the operating units. The column of "closed" reactors illustrates that about 92 percent of all commercial reactors built in the United States since 1968 are still operable. The list also indicates that only the oldest reactors have had a problem with premature closures. Only one reactor (Three Mile Island 2) completed since 1976 has permanently closed. No U.S.

reactor has closed since 1998.

Although nuclear generating capacity has remained roughly constant from 1990, the amount of electric produced has increased 33 percent during the same period because capacity utilization has increased fr 66 percent in 1990 (56 percent in 1980) to over 90 percent in 2002. The increase in nuclear power generation due to capacity factor increases is roughly equivalent to building a number of new power pl operating at former capacity levels.

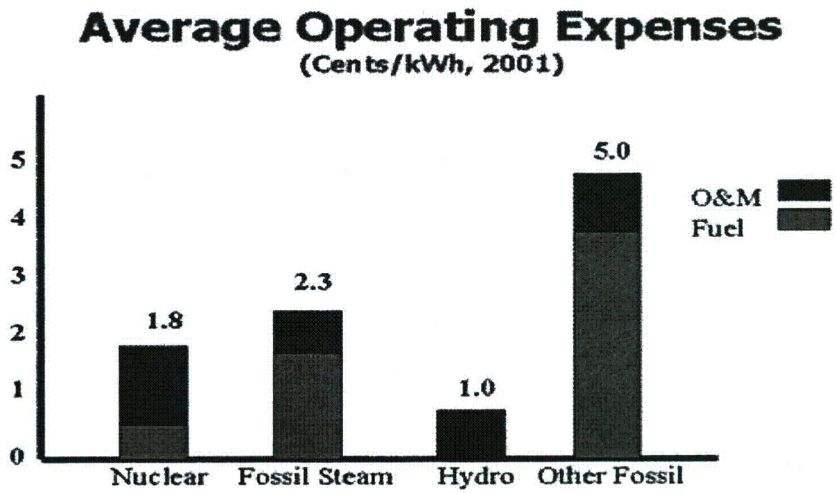
**Capacity Factors at U.S. Nuclear Power Plants, 1980-2002**

| Year | Capacity Factor |
|---|---|
| 1980 | 56% |
| 1990 | 66% |
| 2000 | 88% |
| 2002 | >90% |

Du the 19 ele utilities knew that for nuclear power to be commercially viable, operating and maintenance costs had tc reduced. One way to do this was to improve plant utilization. A series of institutional changes have facilitated the process since then. During the 1980s the Institute of Nuclear Plant Operators (INPO) wa up to share technical information. New fuel designs permitted higher burnups. Such improvements permitted the expansion of periods between refueling outages to be increased from 12 months to 18 mc and sometimes to two years. Refueling outages have also been cut from as much as three months in 19 about a month today. Methods of undertaking other maintenance and capital replacement during these outages or even during operations have also been improved. Time requirements for planned and unplar maintenance have been shortened. More recently techniques such as risk informed maintenance have a been expanded to the government regulatory environment, improving the contribution of regulators to and continued plant operation. Finally, the introduction of competition to the wholesale electricity marl has honed the motivations of plant operators toward safe and reliable plant operation.

It would be difficult to separate one of these trends out as more important than another, though the redu outage time is a major component. Because refueling and maintenance outages must still continue at reactors, we are clearly approaching a technical limit for average plant capacity factors. We are probab not there yet but it will not be more than a few percentage points higher. Improved nuclear power performance in the future must come from other sources.

In addition to increased availability, lower costs have influenced the use of nuclear power. Not all electricity is same. There are many means by which and locations where one can produce electricity. T are also cycles in demand that vary by day, week, and season. The incentive is to produce electricity fo each part of the cycle at the lowest possible cost. When it comes to average and marginal operating cos nuclear power usually has the advantage.




**Source: EIA, Electric Power Annual 2000**

A number of notes should be made on this chart. The first of these is that the data gather all steam-based fossil fuel energy together. Fuel costs are lower for steam-based power for coal than for oil or gas. Thus, coal-based power has only a slightly higher U.S. average production cost than does nuclear. The costs are so close that, while nuclear costs average lower than coal, there is a good deal of overlap when regions of the country or individual reactors are considered.

Nuclear power does, however, have an advantage in day-to-day operations in its low marginal costs. Day-to-day marginal costs are primarily fuel costs. A disproportionate part of nuclear power operating costs come from operations and maintenance costs that do not vary much with output. Because nuclear power's marginal costs are lower than coal's marginal costs, nuclear power plants tend to use their full output capacity before coal plants. This gives nuclear power an advantage in base load operations and results in a higher capacity factor.

**U.S. Capacity and Market Share by Fuel 2000**

| Fuel | Capacity Factor (percent) | Generation Share (percent) | Generation (billion kWh) |
|---|---|---|---|
| Coal | 71.0 | 51.7 | 1966 |
| Oil & Gas | 29.1 | 19.0 | 724 |
| Nuclear | 87.9 | 19.8 | 754 |
| Hydro | 39.6 | 7.3 | 276 |
| Geothermal | 57.6 | 0.4 | 14 |
| Biomass | 69.1 | 1.6 | 61 |
| Wind | 26.8 | 0.1 | 6 |
| Photovoltaic | 15.1 | <0.1 | 0.5 |

This table is a bit misleading though it does indicate the impact of availability, demand, and cost. In this case it is the oil and gas numbers that are not consistent with what one anticipates. The term "oil and gas" includes a good deal of peaking and cycling capacity. Thus while modern gas turbine-based combined cycle plants might see relatively high capacity factors, many oil and gas plants operate only rarely during the year. The peaking and cycling character of a large portion of oil and gas capacity makes capacity factor data look worse than it really is, though coal and nuclear plants will generally have higher capacity factors than oil and gas plants. Hydroelectric power capacity factors were low because of the drought during 2000. Also, cheap hydropower can be stored in the form of water. This allows it to be sold when prices are higher, during peak demand periods, when such cycles are permitted. Numbers for nuclear presently are around 90-91 percent capacity factor and 20-21 percent generation share.

One recent trend in the U.S. nuclear power industry that might influence future performance has been an increased concentration of operations into fewer and fewer hands. This had taken place almost exclusively through the acquisition of existing commercial reactors by firms that already manage commercial reactors.

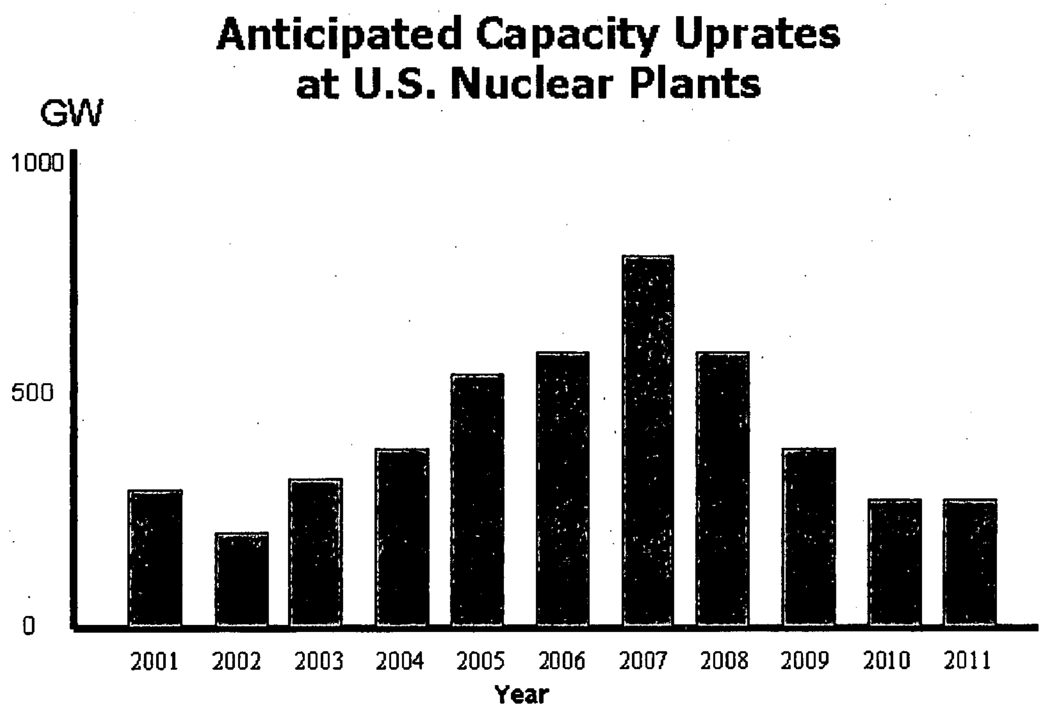
**Operators of U.S. Reactors**

| Organization | Capacity (MWe) | Share of Capacity |
|---|---|---|
| Exelon-AmerGen | 16,850 | 17.3% |
| Entergy | 9,033 | 9.2% |
| Duke | 6,996 | 7.2% |
| TVA | 6,658 | 6.8% |
| Southern | 5,698 | 5.8% |
| 2nd Five Firms | 22,680 | 23.2% |
| Others (3+ Reactors) | 7,164 | 7.3% |
| Others (<3 Reactors) | 22,588 | 23.1% |

If this were ownership rather than management the percentages would be smaller for many firms. This is because many reactors have joint ownership arrangements that differ from management arrangements. Of the top five managers, only Entergy and Exelon have been buying management rights at U.S. nuclear plants. Exelon has not done so lately and has talked about either buying or selling AmerGen claims and responsibilities. The second tier firms, plus those managing three plus units have also bought management rights. In some ways recent acquisitions have thus been a leveling process among managing firms. The data in the table do not include the Stars group which shares some responsibilities among the managers of many of the smaller managerial groupings.

Another recent trend that will result in increased nuclear capacity to help sustain the nuclear share of electricity generated is referred to as capacity uprates. Uprating capacity has been an ongoing process since the inception of the nuclear power industry. Uprates have also occurred in other power sub-sectors such as coal and hydroelectric. Nuclear uprates have however garnered a substantial portion of the media attention, if only because the regulatory environment makes nuclear uprates public knowledge.

Present technologies permit uprates of existing nuclear reactors of around 5-20 percent. In some cases these uprates have already occurred. EIA's projections place the near term potential around 4 GWe, based primarily on utility and regulatory announcements. Others such as the Nuclear Energy Institute go as high as 10 GWe. One restriction on higher numbers will be balance of plant considerations and occasionally the economics of the increase. When uprates are viable they provide low cost increases in plant capacity with little change in operations and maintenance costs. These low operations and maintenance costs can mean that some uprates might make economic sense even when they are more expensive than adding less expensive capacity using other fuels. The industry now investigating yet further means to raise plant capacity. These might result in additional uprates beyond present anticipations.




**Source:** Nuclear Regultory Commission Energy Information Administratioin Press Reports

License renewal has also been an issue in the nuclear power industry that is related to future nuclear power generation. Operating licenses expire after 40 years but may be extended with the approval of the Nuclear Regulatory Commission. License renewals add 20 years. The NRC has indicated that "substantially all" existing reactors intend to renew their licenses. The renewal process has been less burdensome than was once anticipated and is at best only an indicator of the future of particular plants. Because the license renewal process takes time to complete, reactors built during 1968-74 have to announce and implement proposed renewal applications within the next few years.

The following table is based on NRC's published list indicating which reactor managers have announced their intention to renew operating licenses.

**U.S. Nuclear Power Plant Renewal Status**

| License Year | Number of Reactors | On NRC List | Not On NRC | List Closed |
|---|---|---|---|---|
| 1968-74 | 38 | 22 | 10 | 6 |
| 1975-78 | 23 | 15 | 5 | 3 |
| 1979-96 | 52 | 15 | 37 | 0 |
| **Total** | **113** | **52** | **52** | **9** |

The 1968-74 group has been less forward with their plans than the later 1975-1978 group. In contrast the newest reactors have no reason to hurry their announcements. Just two firms manage most of the ten oldest excluded reactors. These firms thus might be withholding announcements for policy reasons rather than because of uncertain plans. The basic point is that there might still be issues related to eventual license renewal though the only reactors of immediate concern are the very oldest units. The NRC list is complicated by the inclusion of five potential applications described as "not publicly announced." Some plants in this group might include more than one reactor and sometimes more than one plant. Thus a minimum of five and probably more reactors should be added to the table. It is though where they belong and whether the apparent problem is statistical or real.

### New Nuclear Construction

Nuclear power's future share in electricity generation will decline if there are no new orders. The nuclear power industry presently has no commitments to build new reactors. The TVA has announced that by 2007 it hopes to bring Browns Ferry-1 back into operation. That reactor has been closed since 1985. The TVA also has three partially completed reactors for which construction licenses are either active or for which extended licenses are being sought. Three firms also plan to apply for early site permits, though such permits are not commitments to build. Nonetheless the business environment has not encouraged power plant construction of any type by any firm during 2002-03. Nuclear plants are no exception.

There are several reasons why there are no firm plans to build new nuclear power reactors. First among these in the short term is that many if not most regions of the Nation presently have surplus baseload generating capacity. There are exceptions to this conclusion. California imports much of its base load electricity needs but also effectively discourages new production from the typical base load power sources, coal and nuclear. This short term base load surplus must be worked off before any new nuclear construction can be seriously considered.

A longer-term reason why no nuclear power has been built is that the capital costs of building a new nuclear power plant have historically been high. There are also considerable financial costs and risks related to the long construction periods in the industry. The last completed nuclear reactor, Watts Bar-1, took 24 years to complete. There has been a history of regulatory uncertainty. The extreme case is the Shoreham plant on Long Island that was essentially completed before it was decided that it would not be allowed to operate. Policy issues such as spent fuel disposal methods, liability insurance questions, and overall safety concerns on the part of the public have also adversely affected nuclear construction.

The nuclear power industry and its promoters are addressing each of these issues. Prospective builders now promise lower costs. Regulatory processes are now better specified and, when possible, implemented early and consistently in the decision process. Financial risk, construction periods, waste disposal, and safety are now being handled in more direct and organized manners. Difficulties with public acceptance remain but are hard to gauge.

The Energy Information Administration in its Annual Energy Outlook 2003 projects in its reference case that no nuclear units will become operable between 2001 and 2025. This projection is a reference scenario that functions as a mid-term forecast under current laws and regulations. The EIA also examined a scenario where the costs of nuclear construction were lowered to a level that some vendors say they will achieve after first of a kind engineering and financing difficulties are worked out. The Annual Energy Outlook's conclusion under this "advanced nuclear cost case" is that additional nuclear power capacity would come on line if cost targets are reached.

Are the changes in the nuclear power industry enough to make a difference in its future? There are still no new orders. Thus in the short term recent achievements are not enough. Getting new orders is the challenge that the nuclear industry must still meet if it wishes to expand. Most of the risks in building nuclear power plants must be faced early in the plant's life cycle. A fossil fuel plant faces its greatest risks, uncertain demand and fuel prices, after the plant begins operation. This will discourage nuclear power investment when other anticipated costs are comparable. Nuclear power's task remains controlling its risks better than competing fuels control their risks.

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ATTACHMENT A3
IOWA ENERGY CENTER
WIND ENERGY MANUAL, "WIND ENERGY ECONOMICS"
2006

# Iowa Energy Center

# Wind Energy Manual
# "Wind Energy Economics"

## 2006

# Wind Energy Economics

**contents** > **wind issues** > wind energy economics

The energy supply market is very competitive, led by utilities and fuel companies that meet nearly all our energy demands. Alternative energy sources like wind power provide new options and certain advantages, but to be truly competitive with conventional energy sources, they also must be economical.

Throughout their lives, people make informed decisions on major purchases and financial investments. In the case of home and car purchases, the decision is usually which one to buy, rather than whether to buy, because these items are considered necessities. Many sources of professional advice are available to assist the buyer in making a sound decision for these common types of investments. For wind turbines, where the choice to buy is voluntary, good advice can be hard to find.

How does the average homeowner, farmer or business person choose between wind energy and the energy source he or she now uses? A wind energy system requires a large initial capital outlay, but over its lifetime it will provide years of energy with no fuel cost while the costs of other sources of energy may escalate.

How much do wind turbines cost and will they eventually pay for themselves? Will utility rates change in the future and by how much? This chapter addresses these kinds of questions and charts a course toward a well-informed investment decision. Previous chapters described the steps necessary to choose an efficient wind system for given wind conditions and energy needs. The following pages prepare prospective buyers to determine the potential financial gain available from the wind system chosen to fit a particular energy profile.

## Cost

The cost of a wind system has two components: initial installation costs and operating expenses. The initial installation cost includes the purchase price of the complete system (including tower, wiring, utility interconnection or battery storage equipment, power conditioning unit, etc.) plus delivery and installation charges, professional fees and sales tax.

The total installation cost can be expressed as a function of the wind system's rated electrical capacity. A grid-connected residential-scale system (1-10 kW) generally costs between $2,400 and $3,000 per installed kilowatt. That's $24,000-$30,000 for a 10 kW system. A medium-scale, commercial system (10-100 kW) is more cost-effective, costing between $1,500 and $2,500 per kilowatt. Large-scale systems of greater than l00 kW cost in the range of $1,000 to $2,000 per kilowatt, with the lowest costs achieved when multiple units are installed at one location. In general, cost rates decrease as machine capacity increases. The curve's width reflects the range of costs available. For exact figures applicable to you, contact a manufacturer or dealer. A partial list of manufacturers and dealers can be found at **Wind Turbine Manufacturers**.

Remote systems with operating battery storage typically cost more, averaging between $,4,000 and $5,000 per kilowatt. Individual batteries cost from $150 to $300 for a heavy--duty, 12 volt, 220 amp-hour, deep-cycle type. Larger capacity batteries, those with higher amp--hour ratings, cost more. A 110-volt, 220 amp-hour battery storage system, which includes a charge controller, costs at least

# New Jersey's Clean Energy Program

# "Frequently Asked Questions – Offshore Wind Systems"

## April 2006

# FREQUENTLY ASKED QUESTIONS

## Off Shore Wind Systems

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- Wind energy systems- wind turbines: What they are and how do they work?
- What is the current capacity of wind energy?
- How is the output of wind turbines determined?
- How are wind areas classified?
- What is the general capacity factor a wind energy system?
- What is the average wind speed offshore?
- Why look offshore for wind energy systems?
- How many homes can one offshore wind turbine supply?

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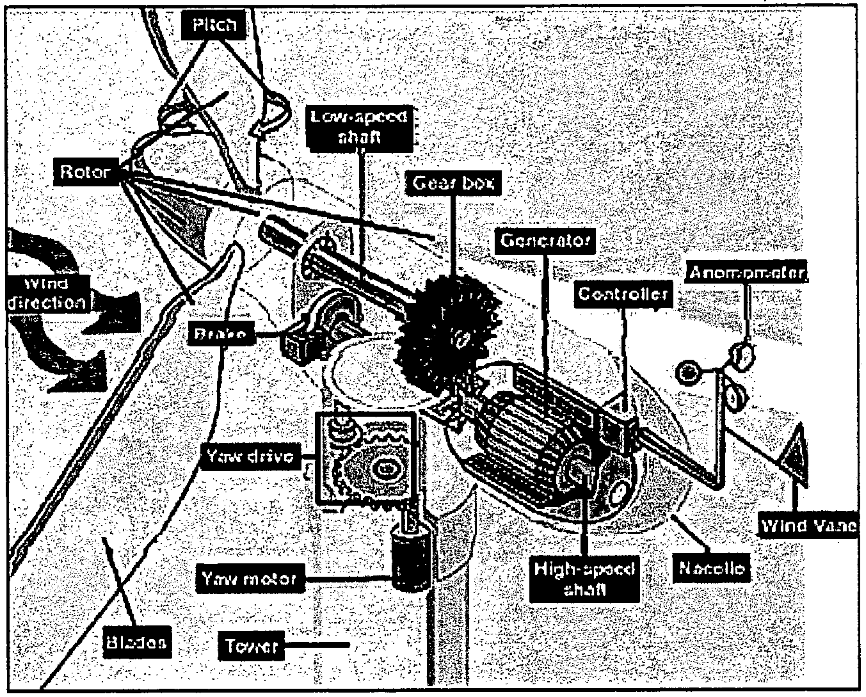
Q. Wind energy systems- wind turbines: What they are and how do they work?

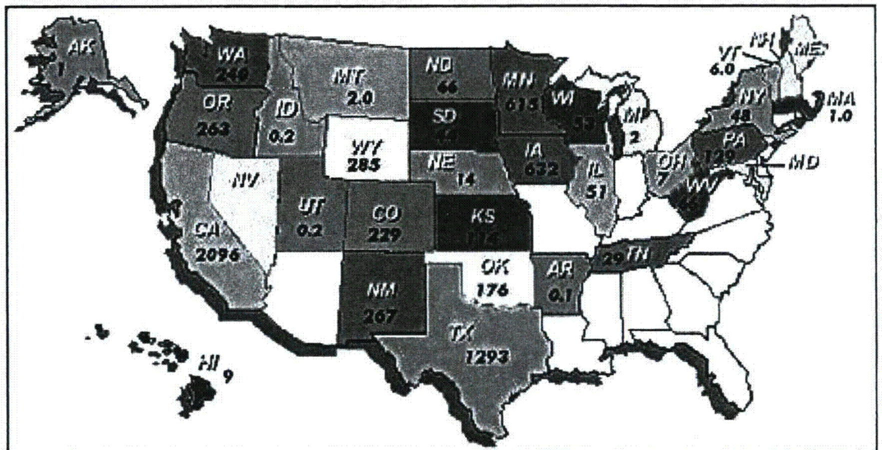
A. A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy. A wind turbine operates like a fan in reverse using wind to make electricity. The wind turns the blades, which spin a shaft, which is connected to a generator that makes electricity.




Back to top

Q. What is the current capacity of wind energy systems in the US and worldwide?

A. As of 2004, there were 6,740 MW of installed onshore wind energy systems in states. There are currently no installed offshore wind energy systems in the U.S. Several offshore wind projects are in the planning stage in a number of states. The furthest along are the 140 MW system off the shore of Long Island proposed by Long Island Power Authority and the Cape Wind 420 MW project in Nantucket Sound, MA. Both projects have developed detailed Environmental Impact Statements (EIS). As of 2003, there are 28,706 MW of installed wind energy systems in 29 countries, with over 500 MW offshore wind energy systems in 16 countries in Europe. There are over 10,000 MW of new offshore wind energy systems in various planning stages in these countries.




Back to top

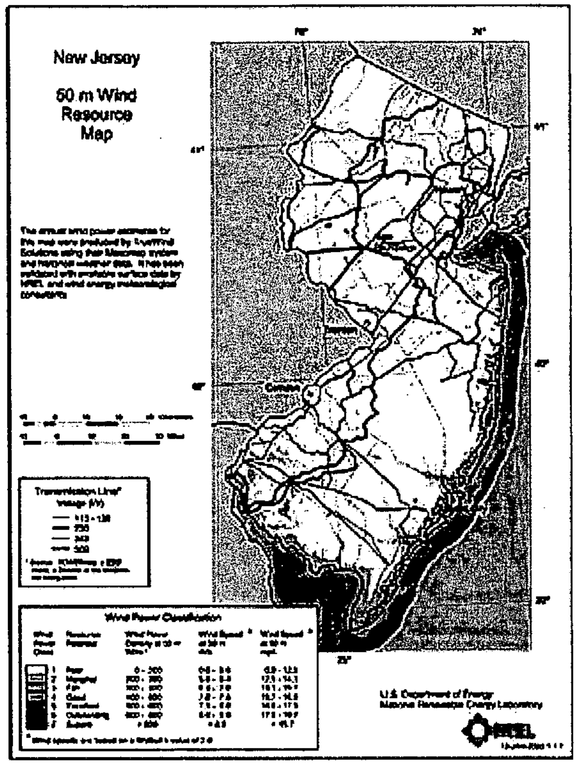
Q. How is the output of wind turbines determined?

A. The energy output of a wind turbine depends on the turbine's size and the wind's speed at the turbine height. Wind speed is the crucial element in projecting wind energy system performance. A site's wind speed is measured through a wind resource assessment prior to a wind system's construction. Generally, annual average wind speeds greater than six meters per second (m/s) or 14 miles per hour (mph) are required for large-scale wind systems.

Back to top

Q. How are wind areas classified?

A. Wind power is characterized by a simple system that assigns the wind potential to one of seven wind classes. The wind potential in Class 1 or 2 areas are low and not suitable for utility-scale wind energy systems. Class 3 and 4 are fair to good; and Class 5 and higher are excellent for utility-scale wind energy systems. Most of New Jersey is a Class 1 or Class 2 wind area. There are some Class 3 wind areas along the New Jersey coast and in the northwestern mountain ridges. There are Class 4, and higher wind areas off-shore.




Back to top

Q. What is the general capacity factor a wind energy system?

A. A wind energy system is "fueled" by the wind, which blows steadily at times and not at all at other times. During the year there are times when the wind does not blow or at speeds below which the wind turbine will turn to produce energy. Even when the wind is blowing the wind energy system does not always produce energy at its full rated capacity. The capacity factor of wind energy systems ranges from 25 percent to 45 percent. The theoretical maximum capacity factor for a rotor wind turbine is 59 percent. Offshore wind energy systems will achieve higher capacity factors.

Back to top

Q. What is the average wind speed offshore?

A. Over the year the wind speed offshore in New Jersey varies between 5 to 9 m/s. The offshore wind in New Jersey peaks between October to April and is highest in December/January. It is lowest in July/August. The wind speed offshore can varies roughly 1.5 m/s over the day. In addition, during the summer months because of the thermal difference between the temperature of the water and the land a sea breeze circulation develops along the shore. The sea breeze can increase wind speeds between four m/s one half mile offshore to one m/s six miles offshore. Overall the wind is steadier and more predictable offshore.

Back to top

Q. Why look offshore for wind energy systems?

A. There are a number of factors that influence the performance of a wind energy system. These includes: wind shear, turbulence, wake effect, and tunnel effect. These factors can lower the overall performance of as wind energy system and are evident to a lesser degree offshore. This coupled with higher wind speeds offshore increase the potential performance of offshore wind energy systems. With equivalent offshore and onshore wind energy systems (same MW capacity), an offshore wind energy system will produce more energy over the year.

Back to top

Q. How many homes can one offshore wind turbine supply?

A. A New Jersey household uses, on average, 8,500 kilowatthours (kWh) of electricity per year. Each home on average represents a 2 to 4 kW load. A 3.6 MW wind turbine in a Class 4 or higher wind area can produce more than 10,800,000 kWh of energy in a year – enough electricity to power more than 1,200 households on an annual basis.

Back to top

Q. How much does a wind system cost compared to other renewable energy or traditional energy systems?

A. Onsite wind can generate electricity for less than 5 cents per kWh in a Class 5 or higher wind area. In PJM, grid baseload power plants generate electricity for 1.5 to 3 cents per kWh. Solar electric or photovoltaic (PV) costs 21 cents per kWh and sustainably grown and harvested biomass (organic matter such as willow trees, switch grass, food waste) can generate electricity for approximately 6 to 7 cents per kWh. Offshore wind cost more than onshore wind because of additional costs which includes: additional construction cost to install the foundation; additional operating costs for a corrosive salt environment and more severe weather; and additional power collection and transmission costs. A 100 MW offshore wind energy facility, in an area with a wind speed of 8 to 8.5 m/s and a capacity factor between 32 to 35, would result in a levelized electricity cost of between 8.5 to 8.9 cents per kWh.

Back to top

Q. Can wind energy systems meet all of New Jersey's electric demand?

A. Wind is an intermittent resource and because of this intermittent nature some have looked at a limiting factor for wind of approximately 20% of the total system capacity. However, there is no firm or maximum limit. Development of future energy storage systems or advanced voltage regulation control technology with the wind energy system could significantly increase this factor. In addition, matched with other intermittent renewables like solar electric (photovoltaics), can also increase this factor.

Back to top

Q. How much energy can the offshore wind resource generate?

A. Based on the Atlantic Renewable Energy Corp. Feasibility Report dated May 2004, accounting for areas that would be excluded because of conflicting concerns, an area mostly beyond 3 miles offshore in up to 100 feet of water encompassing 1,223 square miles stretching 75 mile from Seaside Hts./Park to Cape May could be conditionally viable. At densities of 20 MW per sq mile, each MW of installed capacity could produce 3,000 MWh per year while occupying less than 0.01% of the seabed in the project area.

[Top] - [Back]

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Last updated Sunday, December 3, 2006

# Tennessee Valley Authority

# "The Role of Renewable Energy in Reducing Greenhouse Gas Buildup"

## September 2003

Return to On the Air Main

On the Air

# The Role of Renewable Energy in Reducing Greenhouse Gas Buildup

As a result of human activities, greenhouse gases (GHG) are increasing in the earth's atmosphere. Many in the scientific community now believe that this increase of carbon dioxide ($CO_2$), methane ($CH_4$), and other GHG is causing the earth's temperature to rise, and that this increase in GHG will lead to even greater global warming during this century. However, significant scientific disagreement still exists regarding the relative importance of anthropogenic GHG emissions versus natural variability in climate as the cause of these temperature changes.

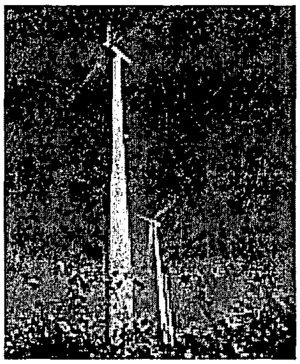

Figure 1. TVA wind turbines on Buffalo Mountain near Oak Ridge, Tennessee.

To address this uncertainty, the Bush Administration, in 2002, proposed increased funding for scientific research on the impact of anthropogenic GHG emissions on climate change and on GHG reduction and sequestration technologies. Also, the Administration announced the Global Climate Change Initiative, with the goal of reducing the U.S. GHG intensity by 18 percent over the next 10 years. To minimize the potential impact on TVA, various types of GHG mitigation technologies are being evaluated to determine costs, impacts on the system, timing of implementation, and any additional environmental benefits. One strong option is to increase the use of renewable energy in electric power generation.

**What is Renewable Energy?**
Electricity produced from wind (Figure 1), solar, or geothermal sources, biomass energy conversion systems, and increases resulting from modernization of hydroelectric systems (HMOD) generally are considered renewable energy. Biomass energy systems encompass a wide range of sources, including dedicated energy crops, wood waste, landfill gas, digester gas, animal waste, and municipal solid waste. However, what qualifies as a renewable energy source varies among private and governmental organizations.

**How Does Renewable Energy Reduce GHG Emissions?**
Unlike the combustion of coal, natural gas, and distillate fuel—which produces carbon dioxide—wind, solar, and hydroelectric energy

systems emit no GHG because their fuel or energy source is carbon-free. Thus, the amount of GHG emitted into the atmosphere can be reduced only when fossil-fuel generation is avoided or replaced by renewable systems or other non-GHG-emitting electric generation systems.

Although biomass energy systems utilize combustion and do produce carbon dioxide emissions in producing electricity, these emissions are considered "carbon dioxide neutral." The carbon dioxide in these emissions is not considered to increase the amount of GHG in the atmosphere because the carbon dioxide was removed from the atmosphere by plants within the very recent past as part of the natural global carbon cycle. Also, if not used for electricity generation, the biomass would have decayed, thus emitting an equivalent amount of carbon dioxide to the atmosphere. In contrast, coal and other fossil fuels contain carbon that has been "locked-up" for millions of years. Therefore, when fossil fuels are used to generate electric power, carbon dioxide that has been locked away and otherwise would not have been emitted is added to the atmosphere. Thus the use of biomass as an energy source reduces the amount of "fossil" carbon dioxide that is emitted to the atmosphere by displacing fossil fuels.

Co-firing wood waste with coal reduces the amount of methane that is emitted into the atmosphere. Wood waste, if disposed in a landfill, would decay and emit methane from the decomposition of the organic matter. Methane is a potent GHG that, pound-for-pound, has 21 times the impact of carbon dioxide on global warming. Therefore, significant GHG reductions can be achieved from co-firing wood waste with coal.

Landfill gas energy systems also reduce GHG emissions by combusting the methane that is generated within the landfill. Carbon dioxide is emitted from the combustion of the methane, but, as discussed above, this carbon dioxide comes from biomass sources that are considered carbon dioxide neutral. Therefore, using landfill gas to produce electricity reduces GHG emissions in two ways: (1) by destroying methane, and (2) by using it as a fuel to displace carbon dioxide emissions from fossil fuel combustion.

**Renewable Energy Resources in the Valley**

A preliminary study by TVA's Renewable Energy Team concluded that approximately 3,000 MW-equivalent of energy—from wind, HMOD, bioenergy (wood waste, energy crops, and landfill gas), and solar energy—exist within and directly adjacent to the TVA service territory. However, at present, less than 30 percent of this is cost-competitive with TVA's generation mix. But technology improvements over the next 15 years are expected to lower the cost of electricity produced by renewable energy systems.

**Biomass.** Biomass is the largest renewable energy resource in the Tennessee Valley. Approximately 11 million tons of wood waste (mill residue, forest residue, and urban wood waste) is generated each year. Also, studies project that approximately 10 million tons of switchgrass, a native, high-yielding grass, could be grown annually as an energy crop in the TVA service area. Combined, these could produce an energy equivalent of approximately 900 MW in the TVA service territory. However, the cost of switchgrass and other energy crops currently is almost twice the cost of coal on a Btu basis. Furthermore, the lack of adequate infrastructure, along with transportation and handling costs, are primary obstacles when considering the economic and technical feasibility of this renewable energy source.

**Wind.** Approximately 800 MW of wind capacity energy is available within 5 miles of the TVA service area. Since the average capacity factor for wind energy systems in the Valley is about 25 percent, the 800 MW of wind capacity is equivalent to only 267 MW of fossil capacity.

**HMOD.** It is projected that modernization of TVA's hydroelectric generating facilities will increase the total hydro capacity by 750 MW.

**Landfill Gas.** The installation of waste-to-energy systems at municipal landfills can provide significant GHG reductions; however, the capacity of the system, existing electrical infrastructure, and the age and projected life of the landfill must be taken into account when considering such systems. Electricity also can be produced from methane generated at wastewater treatment and animal waste treatment facilities. In 1999, it was estimated that a total of 150 MW of landfill gas energy capacity exists in the TVA service territory. However, only about 70 MW of that was considered economically viable.

**Solar.** Although a considerable amount of solar photovoltaic (PV) capacity exists in the Valley—roughly 400 MW of capacity—the large land requirement and high capital cost of solar PV systems make them a non-viable renewable energy source at the present time.

**GHG Reduction Costs**

Although renewable energy systems produce little or no GHG emissions, the electricity produced by these systems typically costs more than electricity generated from fossil, hydroelectric, and/or nuclear power plants. The higher cost is the result of higher capital and fuel costs and the availability of the energy source.

Figure 2 reveals the range in generation costs (dollars per kilowatt hour) and GHG reduction costs (dollars per ton of carbon dioxide-equivalent) for HMOD, wood waste co-firing (with and without assuming methane reductions), landfill gas, and wind energy systems. As the graph indicates, HMOD has the lowest generation cost, and wood waste co-firing and landfill gas energy systems can generate electricity at a lower cost than wind. Solar PV is not shown because of the very high generation costs associated with this system—from 35 to 60 cents/kWh.

The cost per unit of GHG reduction from renewable energy sources is lowest with wood waste (with methane reduction) and landfill gas. The lines in the graph depicting these two energy systems exhibit different slopes than the other systems because their reduction in carbon-dioxide-equivalents per dollar is greater as a result of reductions in both carbon dioxide and methane emissions. Wind and solar energy systems avoid coal-based carbon dioxide emissions, but they have rather high capital costs and low capacity factors that make them less attractive for reducing GHG emissions at the present.

**Potential Issues**

Wind and solar energy systems depend on the availability of sufficient wind and sunlight to produce electricity. The lack of control over when and how much wind and solar energy will be available makes these renewable energy systems non-dispatchable, thus reducing their value to the system. TVA is investigating energy storage technologies that may help solve this problem.

Unlike sulfur dioxide and nitrogen oxide emissions, which can be readily measured and monitored by gas analyzers and flow rate meters, reductions in, or avoidance of, GHG emissions may require that an independent third-party be brought in to verify that the reduction has occurred. Depending on the size of the GHG reduction/avoidance project, third-party verification costs can be significant.

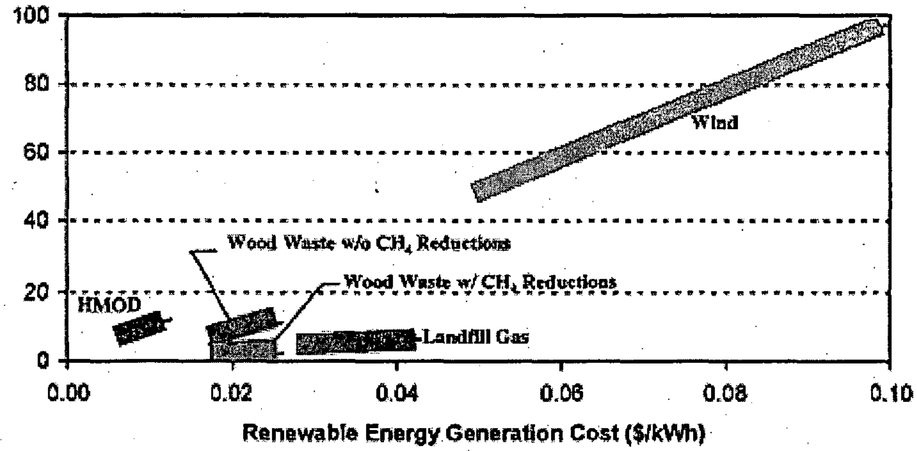


Figure 2. Current estimated ranges in costs per kWh and per ton of carbon-dioxide-equivalent (CO2e) for five types of renewable energy systems. HMOD refers to modernization of hydroelectric facilities.

**Conclusions**

The use and incorporation of renewable energy systems into the electric power generation mix is one way that utilities could address the buildup of GHG in the atmosphere. The utilization of renewable energy depends upon resource availability, capital, and fuel cost. Reductions in generation cost, and possibly tax incentives, are needed if the utilization of renewable energy is to increase in the Tennessee Valley and the nation.

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If you would like additional information on important air quality topics, please contact Jeanie Ashe by telephone (256-386-2033), E-mail (jbashe@tva.gov), facsimile (256-386-2499), or mail at TVA, CEB 2A-M, Muscle Shoals, Alabama 35662.

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MARCH 2006

# Solarbuzz, LLC

# Fast Solar Energy Facts
# "Global Performance"

## March 2006

**Information updated as of March 2006**

**Solar Energy Demand** (click here to try our Solar Industry statistics section)

Worldwide photovoltaic installations increased by 1460 MW in 2005, up from 1,086 MW installed during the previous year. In 1985, annual solar installation demand was only 21 Megawatts.

For comparison purposes, total worldwide wind energy installations in 2000 were around 4000 Megawatts, growing at about 35% pa.

Cumulative solar energy production accounts for less than 0.01% of total Global Primary Energy demand.

Solar Energy demand has grown at about 25% per annum over the past 15 years (hydrocarbon energy demand typically grows between 0-2% per annum).

The US market showed 27% growth in 2004 compared to 17% in the previous year. Japan's market reached 277 MW, an increase of 27%, but a fall from 36% growth in 2003.

The "Feed-in Law" in Germany permits most customer applications to receive 45.7 euro cents/kWh for solar generated electricity. The program now calls for a total of 1000 Megawatts to be installed. By the end of 2003, the Kreditanstaldt fur Wiederaufbau (KfW) Bank who administer the 100,000 Roof Program in Germany, had approved loans for over 250 Megawatts of PV systems.

For the Fiscal Year 2002, the Japanese solar roof top program received applications from 42,838 households.

Jobs in the solar and renewable energy industries may be found at greenjobs.com

**Photovoltaic Manufactured Solar Cells**

Around 50 % of the world's solar cell production was manufactured in Japan in 2003. United States accounted for 12%.

On the supply side, the amount of product manufactured by PV cell manufacturers worldwide reached 742 Megawatts in 2003.

Japan has taken over from the United States as the largest net exporter of PV cells and modules.

Four Companies account for over 50% of solar cell production: Sharp, Kyocera, BP Solar, and Shell Solar.

Among the top five manufacturers, Sharp remains the largest and has shown the fastest growth over the last five years. Sanyo, fifth largest, has shown the second highest rate of growth over the same period.

Click here to find worldwide solar energy product manufacturers.

**Solar Energy Prices**

Solar Energy (photovoltaic) prices have declined on average 4% per annum over the past 15 years. Progressive increase in conversion efficiencies and manufacturing economies of scale are the underlying drivers.

The Solarbuzz global price survey on this site shows that prices have consistently declined for over the last two years. A detailed analysis of the worldwide PV Market is in our premier industry report, Marketbuzz 2006. The US Grid Connect Market is analyzed in detail in this report.

A residential solar energy system typically costs about $8-10 per Watt. Where government incentive programs exist, together with lower prices secured through volume purchases, installed costs as low as $3-4 watt - or some 10-12 cents per kilowatt hour can be achieved. Without incentive programs, solar energy costs (in an average sunny climate) range between 22-40 cents/kWh for very large PV systems.

### Other Solar Energy Facts

Did you know that solar energy is dependent upon nuclear power? Solar Energy's nuclear power plant, though, is 93 million miles away.

An average crystalline silicon cell solar module has an efficiency of 15%, an average thin film cell solar module has an efficiency of 6%. Thin film manufacturing costs potentially are lower, though.

A Megawatt is 1,000,000 Watts; a Gigawatt is 1000 Megawatts.

The earth receives more energy from the sun in just one hour than the world uses in a whole year.

Two billion people in the world have no access to electricity. For most of them, solar photovoltaics would be their cheapest electricity source, but they cannot afford it.

Crystalline Silicon cell technology forms about 90% of solar cell demand. The balance comes from thin film technologies.

Approximately 45% of the cost of a silicon cell solar module is driven by the cost of the silicon wafer, a further 35% is driven by the materials required to assemble the solar module.

### Global Energy and Electricity Industry

The United States, Russia, China, Saudi Arabia, and Canada were the world's five largest producers of energy in 1999, supplying 47.9 percent of the world's total energy. Worldwide oil consumption rose by slightly less than 1 million barrels per day in 2000 (vs 1999).
Source: US DOE

World energy consumption is projected to increase by 59% from 1999 to 2020. Much of the growth in worldwide energy use is expected in the developing world

Source: International Energy Outlook 2001, EIA

### 1999 World Production of Primary Energy (Quadrillion (10x15) Btu) Source: US DOE EIA

| | | | |
|---|---|---|---|
| Petroleum | 149.7 | Hydroelectric | 27.10 |
| Natural Gas | 87.31 | Nuclear | 25.25 |
| Coal | 84.90 | Geothermal, solar, wind, wood, waste | 2.83 |

Renewable energy use is expected to increaes 53% between 1999 and 2020. Much of the growth is attributable to large scale hydroelectricity projects in the developing world. Renewable Energy currently accounts for 9% of total energy consumption and is projected to decline to 8%.

Source: US DOE EIA

A conventional energy Power Plant can range in size from 500-3000 Megawatts.

Total USA Megawatt hour demand was 3,312,087,081 across 125,945,003 customers in 1999.
Source: US DOE, 1999

Total European Union Megawatt hour demand is around 2,300,000,000. (1999)

Electricity Price tariffs by country can be found on this site by clicking here.

| Uses of Solar Energy | Utility Power | Distributed Generation | Types of Plants | Technologies | Codes and Certifications | Fast Facts Global | Solar Manufacturers | Home |
|---|---|---|---|---|---|---|---|---|

**If you have a Fast Fact you would like us to include in our listing, please email us at info@solarbuzz.com. We like our Fast Facts to be interesting, accurate, quantified where appropriate and insightful to those researching the solar energy industry for the first time.**

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# University for Applied Sciences

# "Solar Power Towers"

# 1996

# *Solar Power Towers*



## *How it works*

Solar power towers consist of a large field of sun-tracking mirrors, called heliostats, which focus solar energy on a receiver atop a centrally located tower. The enormous amount of energy, coming out of the sun rays, concentrated at one point (the tower in the middle), produces temperatures of approx. 550°C to 1500°C. The gained thermal energy can be used for heating water or molten salt, which saves the energy for later use.
Heatened water gets to steam, which is used to move the turbine-generator. This way thermal energy is converted into electricity.

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## *Heat storage and transfer*

As already mentioned there are two main fluids which are used for the heat transfer, water and molten salt. Water for example is the oldest and simplest way for heat transfer. But the difference is that the method in which molten salt is used, allows to store the heat for the terms when the sun is behind clouds or even at night. Molten salt - better: the heat of it - can be used until the next dawn when the sun will be back to heat the cooled down salt again.

The molten salt consists of 60% sodium nitrate an 40% potassium nitrate (salpeter). The salt melts at about 700°C and is liquid at approx. 1000°C, it will be kept in an insulated storage tank until the time, when it will be needed for heating up the water in the steam generator.
This way of energy storage has an efficiency of approx. 99%, i.e. due to the imperfect insulation 1% of the stored energy gets lost .

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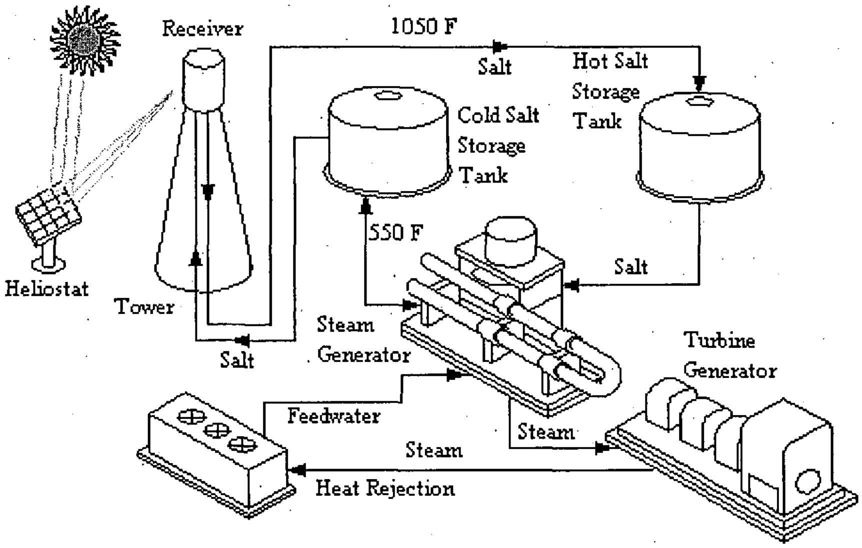
## *Scheme*

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## *Technical, Facts and Tests*

E.g.: The Power Tower Project "Solar II" (California):

- 1,926 sun-tracking heliostats (mirrors)
- molten salt thermal storage system
- tower (300 ft) with central receiver
- conventional steam driven turbine and generator
- produces about 10 MWe, enough power to serve 10,000 homes with electricity
- costs about 40 million US$
- will be used in an experiment until 1998

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## *Location*

Until now, there are only few solar power towers because they're rentable only in regions with a high amount of sunshine and the costs are at a fairly high level.

Back Up

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***Questions, comments, t-shirts, cookies, pizza, milk and honey to:***
*Mustafa Mesanovic <mm@rhlx01.rz.fht-esslingen.de>*
*Nils Philippsen <nils@rhlx01.rz.fht-esslingen.de>*

*Fri Dec 20 10:44:48 MET 1996*

ATTACHMENT B3
U.S. DEPARTMENT OF ENERGY
CONCENTRATING SOLAR POWER TECHNOLOGIES
"OVERVIEW"
(NO DATE)

# U. S. Department of Energy

# "Concentrating Solar Power Technologies Overview"

## (no date)

Concentrating Solar Power and Sun Lab — CSP Overview

HOME
OVERVIEW
CSP PROGRAM
TECHNOLOGY PATHS
MAJOR PROJECTS
R & D
SUN•LAB
SOLARPACES
CSP INDUSTRY
PHOTOGRAPHS
DOCUMENTS
MEETINGS
FAQs
CONTACTS
RELATED LINKS
Feature

# CSP Technologies Overview

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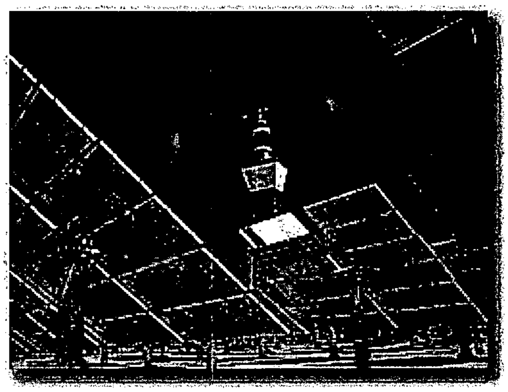
## Technology Overview

Concentrating solar power plants produce electric power by converting the sun's energy into high-temperature heat using various mirror configurations. The heat is then channelled through a conventional generator. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts heat energy to electricity.

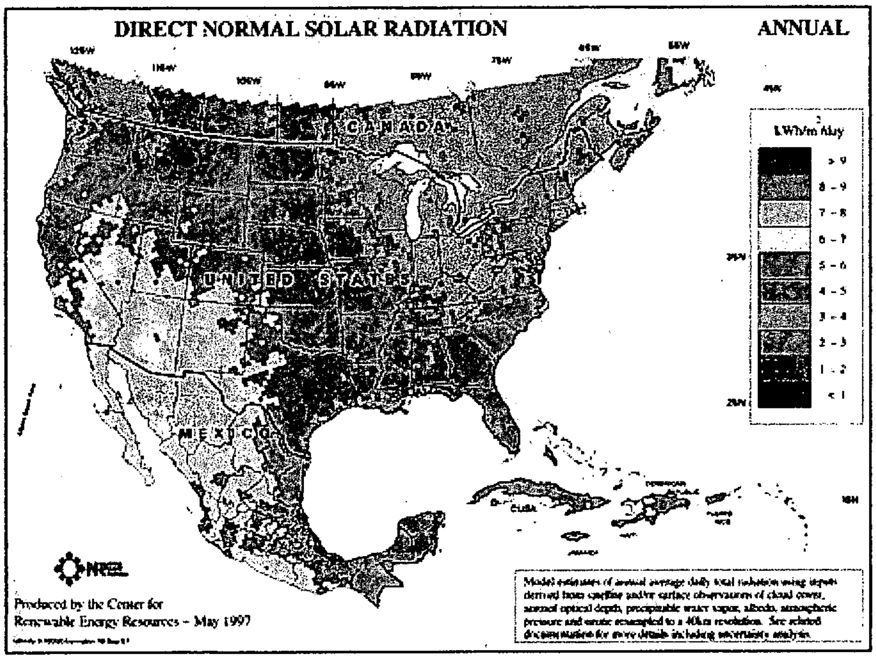


**By collecting solar energy during daylight hours and storing it in hot molten salt, concentrating solar power technologies like power towers give utilities an alternative method for meeting peak loads. (Warren Gretz)**

Concentrating solar power systems can be sized for village power (10 kilowatts) or grid-connected applications (up to 100 megawatts). Some systems use thermal storage during cloudy periods or at night. Others can be combined with natural gas and the resulting hybrid power plants provide high-value, dispatchable power. These attributes, along with world record solar-to-electric conversion efficiencies, make concentrating solar power an attractive renewable energy option in the Southwest and other sunbelt regions worldwide.

## The Solar Resource

The solar resource for generating power from concentrating solar power systems is plentiful. For instance, enough electric power for the entire country could be generated by covering about 9 percent of Nevada—a plot of land 100 miles on a side—with parabolic trough systems.




**The solar resources for generating power from concentrating solar power systems is plentiful. For instance, enough electric power for the entire country could be generated by covering about 9 percent of Nevada – a plot of land 100 miles on a side – with parabolic trough systems.**

The amount of power generated by a concentrating solar power plant depends on the amount of direct sunlight. Like concentrating photovoltaic concentrators, these technologies use only direct-beam sunlight, rather than diffuse solar radiation.

The southwestern United States potentially offers the best development opportunity for concentrating solar power technologies in the world. There is a strong correlation between electric power demand and the solar resource due largely to air conditioning loads in the region. In fact, the Solar Electric Generating System plants operate for nearly 100% of the on-peak hours of Southern California Edison.

**How Does It Work?**
There are three kinds of concentrating solar power systems—troughs, dish/engines, and power towers—that are classified by how they collect solar energy.

**Trough systems:**
The sun's energy is concentrated by parabolically curved, trough-shaped

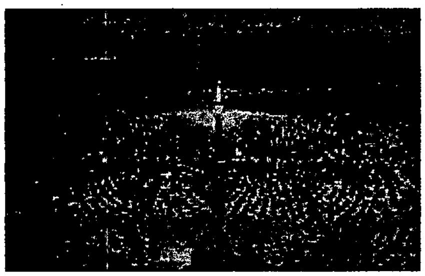
reflectors onto a receiver
pipe running along the inside of the curved surface. This energy heats oil flowing through the pipe, and the heat energy is then used to generate electricity in a conventional steam generator.

A collector field comprises many troughs in parallel rows aligned on a north-south axis. This configuration enables the single-axis troughs to track the sun from east to west during the day to ensure that the sun is continuously focused on the receiver pipes. Individual trough systems currently can generate about 80 megawatts of electricity.

Trough designs can incorporate thermal storage—setting aside the heat transfer fluid in its hot phase—allowing for electricity generation several hours into the evening. Currently, all parabolic trough plants are "hybrids," meaning they use fossil fuel to supplement the solar output during periods of low solar radiation. Typically a natural gas-fired heat or a gas steam boiler/reheater is used; troughs also can be integrated with existing coal-fired plants.

*For more information, see the following documents:*
Technology Characterization: Solar Parabolic Trough (PDF Format 303KB)
Solar Trough Power Plants (HTML Format; PDF Format 230KB)
Parabolic Trough Roadmap (PDF Format 1053KB)

**Power tower systems:**



What is a Power Tower and How Does it Work?
A power tower converts sunshine into clean electricity for the world's electricity grids. The technology utilizes many large, sun-tracking mirrors (heliostats) to focus sunlight on a receiver at the top of a tower. A heat transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine-generator to produce electricity. Early power towers (such as the Solar One plant) utilized steam as the heat transfer fluid; current designs (including Solar Two, pictured) utilize molten nitrate salt because of its superior heat transfer and energy storage capabilities. Individual commercial plants will be sized to produce anywhere from 50 to 200 MW of electricity.

What are the Benefits of Power Towers?
Solar power towers offer large-scale, distributed solutions to our nation's energy needs, particularly for peaking power. Like all solar technologies, they are fueled by sunshine and do not release greenhouse gases. They are unique among solar electric technologies in their ability to efficiently store solar energy and dispatch electricity to the grid when needed — even at night or during cloudy weather. A single 100-megawatt power tower with 12 hours of storage needs only 1000 acres of otherwise non-productive land to supply enough electricity for 50,000 homes.

Throughout the sunny Southwest, millions of acres are available with solar resources that could easily produce solar power at the scale of hydropower in the Northwest U. S.

What is the Status of Power Tower Technology?
Power towers enjoy the benefits of two successful, large-scale demonstration plants. The 10-MW Solar One plant near Barstow, CA, demonstrated the viability of power towers, producing over 38 million kilowatt-hours of electricity during its operation from 1982 to 1988. The Solar Two plant was a retrofit of Solar One to demonstrate the advantages of molten salt for heat transfer and thermal storage. Utilizing its highly efficient molten-salt energy storage system, Solar Two successfully demonstrated efficient collection of solar energy and dispatch of electricity, including the ability to routinely produce electricity during cloudy weather and at night. In one demonstration, it delivered power to the grid 24 hours per day for nearly 7 straight days before cloudy weather interrupted operation.

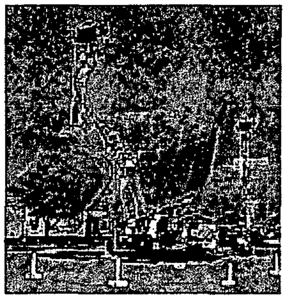
The successful conclusion of Solar Two sparked worldwide interest in power towers. As Solar Two completed operations, an international consortium, led by U. S. industry including Bechtel and Boeing (with technical support from Sandia National Laboratories), formed to pursue power tower plants worldwide, especially in Spain (where special solar premiums make the technology cost-effective), but also in Egypt, Morocco, and Italy. Their first commercial power tower plant is planned to be four times the size of Solar Two (about 40 MW equivalent, utilizing storage to power a 15MW turbine up to 24 hours per day).

This industry is also actively pursuing opportunities to build a similar plant in our desert Southwest, where a 30 to 50 MW plant would take advantage of the Spanish design and production capacity to reduce costs, while providing much needed peaking capacity for the Western grid. The first such plant would cost in the range of $100M and produce power for about 15¢/kWh. While still somewhat higher in cost than conventional technologies in the peaking market, the cost differential could be made up with modest green power subsidies and political support, jump-starting this technology on a path to 7¢/kWh power with the economies of scale and engineering improvements of the first few plants. It would, at that point, provide clean power as economically as more conventional technologies.

*For more information, see the following documents:*
Technology Characterization: Solar Power Towers (PDF Format 303KB)
Solar Two Demonstrates Clean Power for the Future (HTML format; PDF format 557KB)

**Dish/engine systems:**
What is a Solar Dish-Engine System?
A Solar Dish-Engine System is an electric generator that "burns" sunlight instead of gas or coal to produce

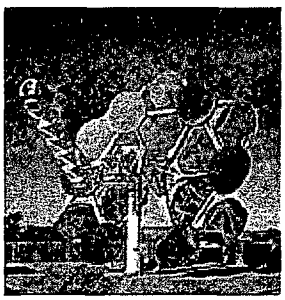
electricity. The major parts of a system are the solar concentrator and the power conversion unit. Descriptions of these subsystems and how they operate are presented below.



**The Boeing/Stirling Energy Systems DECC project will evaluate the performance of the "critical" parts of the Stirling engine and develop the next-generation of the 25 kW Dish-Stirling System.**

THE DISH, which is more specifically referred to as a concentrator, is the primary solar component of the system. It collects the solar energy coming directly from the sun (the solar energy that causes you to cast a shadow) and concentrates or focuses it on a small area. The resultant solar beam has all of the power of the sunlight hitting the dish but is concentrated in a small area so that it can be more efficiently used. Glass mirrors reflect ~92% of the sunlight that hits them, are relatively inexpensive, can be cleaned, and last a long time in the outdoor environment, making them an excellent choice for the reflective surface of a solar concentrator. The dish structure must track the sun continuously to reflect the beam into the thermal receiver.

THE POWER CONVERSION UNIT includes the thermal receiver and the engine/generator. The thermal receiver is the interface between the dish and the engine/generator. It absorbs the concentrated beam of solar energy, converts it to heat, and transfers the heat to the engine/generator. A thermal receiver can be a bank of tubes with a cooling fluid, usually hydrogen or helium, which is the heat transfer medium and also the working fluid for an engine. Alternate thermal receivers are heat pipes wherein the boiling and condensing of an intermediate fluid is used to transfer the heat to the engine.

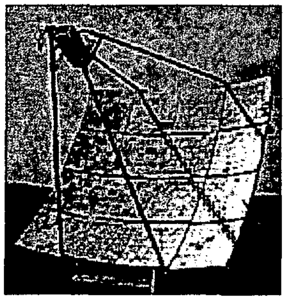


**This Science Application International Corporation/STM Power Inc. 25 kW Dish-Stirling System is operating at a Salt River Project site in Phoenix, AZ.**

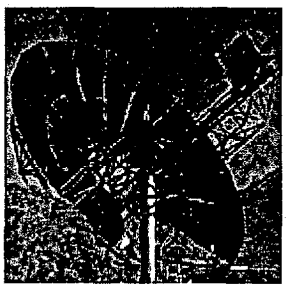
The engine/generator system is the subsystem that takes the heat from the thermal receiver and uses it to produce electricity. The most common type of heat engine used in dish-engine systems is the Stirling engine. A Stirling engine uses heat provided from an external source (like the sun) to move pistons and make mechanical power, similar to the internal combustion engine in your car. The mechanical work, in the form of the rotation of the engine's crankshaft, is used to drive a generator and produce electrical power.

In addition to the Stirling engine, microturbines and concentrating photovoltaics are also being evaluated as possible future power conversion unit technologies. Microturbines are currently being manufactured for distributed generation systems and could potentially be used in dish-engine systems. These engines, which are similar to (but much smaller than) jet engines, would also be used to drive an electrical generator. A photovoltaic conversion system is not actually an engine, but a semi-conductor array, in which the sunlight is directly converted into electricity.

What are the markets for Solar Dish-Engine Systems?
Solar dish-engine systems are being developed for use in emerging global markets for distributed generation, green power, remote power, and grid-connected applications. Individual units, ranging in size from 9 to 25 kilowatts, can operate independent of power grids in remote sunny locations to pump water or to provide electricity for people living in remote areas. Largely because of their high efficiency and "conventional" construction, the cost of dish-engine systems is expected to compete in distributed markets.



**This small photovoltaic solar dish conversion system is being developed by Concentrating Technologies, LLC.**



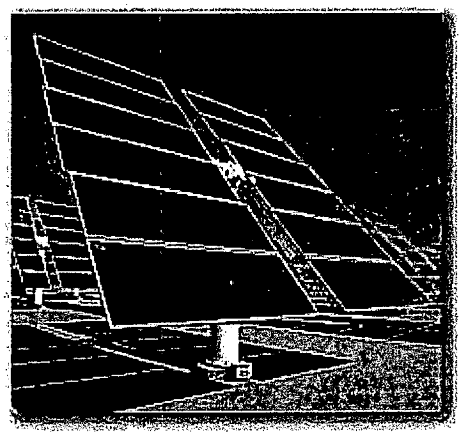
**The Advanced Dish Development System is a 10 kW water pumping system developed by WG Associates for use by Native Americans in the southwest U.S.**

Opportunities are emerging for the deployment of dish-engine systems in the Southwest U.S. Many states are adopting green power requirements in the form of "portfolio standards" and renewable energy mandates. While the potential markets in the U.S. are large, the size of developing worldwide markets is immense. The International Energy Agency projects an increased demand for electrical power worldwide more than doubling installed capacity. More than half of this is in developing countries and a large part is in areas with good solar resources, limited fossil fuel supplies, and no power distribution network. The potential payoff for dish-engine system developers is the opening of these immense global markets for the export of power generation systems.

*For more information, see the following documents:*
Technology Characterization: Solar Dish Engine (PDF Format 888KB)
Solar Dish/Engine Systems (PDF Format 200KB)

**Business and Market Opportunities**
With one of the best direct normal insolation resources anywhere on earth, the southwestern

states are poised to reap large and as yet largely uncaptured economic benefits from this important natural resource. California, Nevada, Arizona, and New Mexico are each exploring policies that will nurture the development of their solar-based industries.



**Experience gained with Solar Two has established a foundation on which industry can develop its first commercial plants.**
**(Joe Flores, Southern California Edison)**

In addition to the concentrating solar power projects under way in this country, a number of projects are being developed in India, Egypt, Morocco, and Mexico. In addition, independent power producers are in the early stages of design and development for potential parabolic trough power projects in Greece (Crete) and Spain. Given successful deployment of one or more of these initial markets, additional project opportunities are expected in these and other regions.

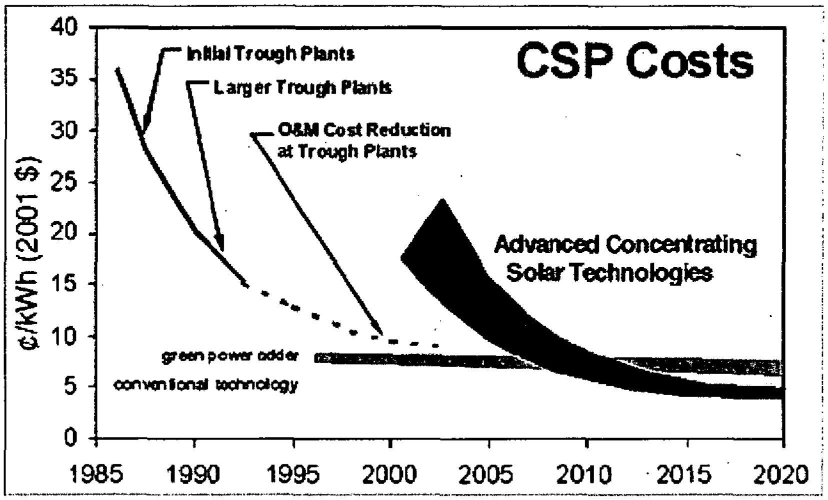
One key competitive advantage of concentrating solar energy systems is their close resemblance to most of the power plants operated by the nation's power industry. Concentrating solar power technologies utilize many of the same technologies and equipment used by conventional central station power plants, simply substituting the concentrated power of the sun for the combustion of fossil fuels to provide the energy for conversion into electricity. This "evolutionary" aspect—as distinguished from "revolutionary" or "disruptive"—results in easy integration into today's central station-based electric utility grid. It also makes concentrating solar power technologies the most cost-effective solar option for the production of large-scale electricity generation.

Analysts predict the opening of specialized niche markets in this country for the solar power industry over the next 5 to 10 years. The U.S. Department of Energy estimates that by 2005 there will be as much as 500 megawatts of concentrating solar power capacity installed worldwide.

*For more information, see the following document:*
Markets for Concentrating Solar Power (HTML Format; PDF Format 82KB)

**What Does It Cost?**
Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation (10 megawatt-electric and above). Current technologies cost $2–$3 per watt. This results in a cost of solar power of 9¢–12¢ per kilowatt-hour. New innovative hybrid systems that combine large

concentrating solar power plants with conventional natural gas combined cycle or coal plants can reduce costs to $1.5 per watt and drive the cost of solar power to below 8¢ per kilowatt hour.




Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours. Future advances are expected to allow solar power to be generated for 4¢–5¢ per kilowatt-hour in the next few decades.

For more information about how concentrating solar power technologies compare financially with one another, see page 3 of "Overview Of Solar Thermal Technologies" (PDF Format 296KB).

For more information about how concentrating solar power technologies compare financially with other renewable energy electricity technologies, see page 3 of "Project Financial Evaluation" (PDF Format 34KB).

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Questions/Comments • Privacy & Security Notice

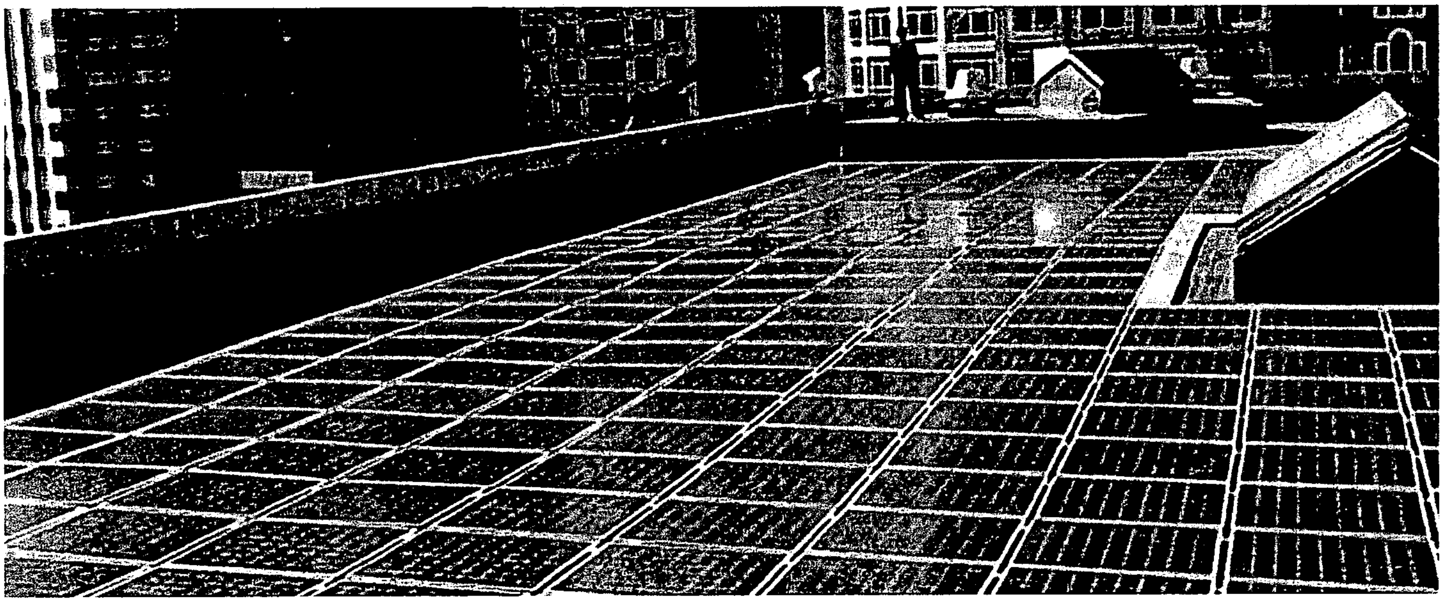
# U. S. Department of Energy
# Energy Efficiency and Renewable Energy
# Solar Energy Technology Program

# "Furthering Energy Independence"

## July 2006

## Solar Energy Technology Program

# Furthering Energy Independence



### A Portfolio of Solar Technologies

Solar technologies use the sun to provide heat, light, hot water, electricity and even cooling for homes, businesses and industry. Through public-private partnerships, the U.S. Department of Energy's Solar Energy Technologies Program sponsors research and development that improves the performance and reduces the cost of solar power. To achieve this goal, the Program supports the research activities of world-class scientists and engineers in industry, academia and the national laboratories.

### Program Basics

The Program has two primary research efforts:

- **Photovoltaics** (PV) develops semiconductor materials to convert sunlight directly into electricity, through an instantaneous, quiet process that uses no moving parts
- **Concentrating Solar Power** (CSP) develops reliable, cost-competitive systems that drive steam turbines and engines using heat from concentrated sunlight

In his 2006 State of the Union address, President Bush launched the Solar America Initiative, marking a new drive to make PV cost-competitive with other forms of retail energy by 2015.

### Multiple Markets, Multiple Solutions

With continued R&D, solar technologies can provide our nation with low-cost energy from abundant sunlight, and help reduce the country's greenhouse gas emissions. Through a combination of photovoltaic and thermal technologies, it will be practical to provide all the energy needed by an energy efficient home. It will also be cost-effective in some regions to generate power at a utility-scale through concentrating solar power systems

Improvements in performance and cost will continue to open new markets for solar technologies. Photovoltaics are already making significant inroads in high-value niche markets, such as remote, stand-alone power for telecommunications and other "off-grid" applications. International market growth is also strong for photovoltaics, fueled by incentives by such countries as Germany. Domestic growth is increasing as a result of the Energy Policy Act of 2005 tax incentives for residential and commercial use as well as State incentives. As manufacturing costs fall, photovoltaics are increasingly used for homes and other businesses already connected to the grid.

While it is true that some solar technologies have been commercialized, we still have a long way to go to reach market competitiveness for photovoltaic (PV) technologies in the U.S. without incentives. Due in large part to the research funded by the Department of Energy the cost of electricity from PV has dropped from more than $2.00 per kilowatt-hour in 1976 to $0.18-$0.23 per kilowatt hour today. Yet, to compete with conventional power sources, PV costs still need to fall by another two-thirds. Under the President's Solar America Initiative,

ATTACHMENT B5
U.S. DEPARTMENT OF ENERGY
ENERGY EFFICIENCY AND RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES PROGRAM
"PROGRAM AREAS"
OCTOBER 2006

# U. S. Department of Energy
# Energy Efficiency and Renewable Energy
# Solar Energy Technology Program

# "Program Areas"

# October 2006

The U.S. Department of Energy's Solar Program encompasses three major types of solar energy technologies: photovoltaics, concentrating solar power, and solar heating and lighting. These technologies are introduced briefly below, but you can learn much more about them in the Technologies Section.

This Chesapeake, Virginia, home takes advantage of both solar water heating and photovoltaics. The solar pool-heating system, located over the front porch, keeps the pool temperature in the 80º range from March to October. The solar collectors, located over the garage, face east, but still produce 75% of the annual hot water needs for this family of four. The PV modules are on the highest part of the roof, and they produce 1 kilowatt of electricity.

**Concentrating solar power (CSP)** systems concentrate the thermal energy of the sun to drive a steam turbine or heat engine. The turbine or engine then drives a generator to produce electricity. The three distinct CSP technologies are parabolic troughs, power towers, and dish-engine systems. The troughs and towers are applicable to large utility-scale projects in the megawatt range, but dish systems have been demonstrated at the 10-25-kilowatt scale.

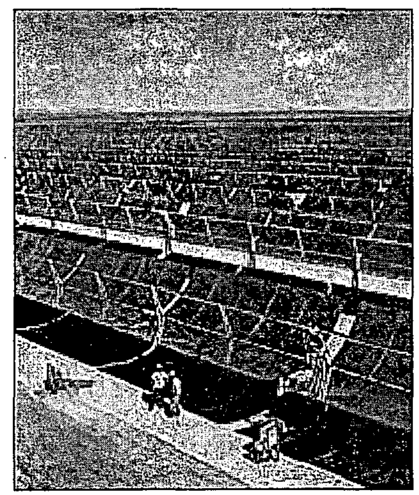
**Photovoltaics (PV)** is the direct conversion of light energy into electricity using semiconductor materials. PV systems are composed of groups of solar cells wired in series to form modules, which can then be interlinked to form arrays. This modular nature allows PV to be used for applications ranging from a fraction of a watt, such as for handheld calculators, to large-scale, multi-megawatt power plants containing millions of solar cells. The most common type of PV device is the flat-plate module, which consists of flat sheets of glass or other materials containing the solar cells. Concentrating PV systems use lenses or mirrors to focus sunlight onto the solar cells, which enhances the light-to-electricity conversion efficiency of the solar cell.

**Solar heating** includes solar thermal systems that heat a working fluid for various applications. Solar collectors can provide thermal energy for direct use in the form of hot water for domestic water heating, space heating, and process heat, and in the form of hot air for space heating and process heat. Higher-temperature collectors can drive absorption and desiccant air-conditioning systems and can provide low-temperature steam.

**Solar lighting** is a newly emerging field. The Solar Program is also investigating hybrid lighting, which uses small solar concentrators and fiber optics to bring daylight into building interiors.

## Evaluating Research Progress

Annually, all program research activities are formally reviewed at the National Center for Photovoltaics (NCPV) and Solar Program Review Meeting. Researchers from the national laboratories, universities, and industry present the latest developments for photovoltaics, concentrating solar power, solar thermal, solar lighting, and building technologies. Program managers present status report for their technologies and outlooks



Parabolic troughs are currently the

for the future. Invited speakers from outside the Solar Program offer fresh perspectives, which help to energize the meeting and those who attend. The Program Review Highlights describe the presentations and activities of the 2003 meeting.

most proven of the concentrating solar power technologies. Nine commercial-scale solar-electric generating stations, the first of which began operating in 1984, produce electricity in the California Mojave Desert.

## More about the Program Areas

Under the Solar Program's Deployment section you'll see how Solar Program research is being put to practical use. Financial Opportunities features links for consumers who are interested installing solar energy and research professionals who may want to partner with the Solar Program. Information Resources is the place to link to solar energy information generated within the United States and around the world.

Printable Version



Content Last Updated: 10/24/2006

ATTACHMENT B6
U.S. NATIONAL RENEWABLE ENERGY LABORATORY
"FUEL FROM THE SKY:
SOLAR POWER'S POTENTIAL FOR WESTERN ENERGY SUPPLY"
JULY 2002

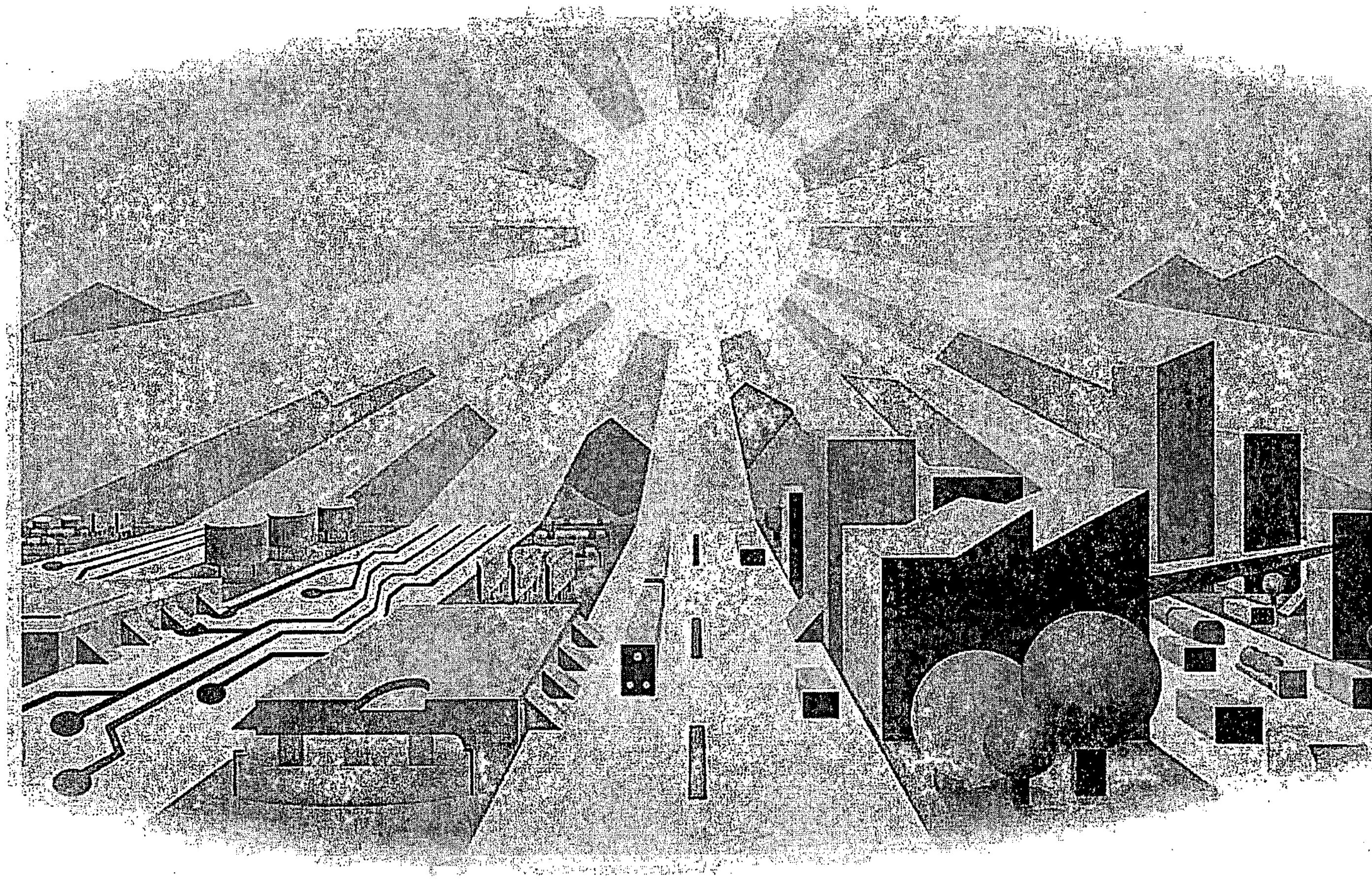
# U. S. National Renewable Energy Laboratory

# "Fuel from the Sky: Solar Power's Potential for Western Energy Supply"

## July 2002

# Fuel from the Sky

## Solar Power's Potential for Western Energy Supply



July 2002

NREL/SR-550-32160

# Executive Summary

## The Potential of Solar Power for Western Energy Supply

A reliable and affordable supply of electricity is essential to protect public health and safety and to sustain a vigorous economy in the West. Rolling blackouts in California in 2000 and 2001, low hydro generation in the Pacific Northwest in 2001, and a power plant construction boom in Texas have drawn attention to electricity issues in the West. All across the nation, demand for and supply of electricity have become unbalanced in the late 1990s, but nowhere has the issue been more pressing than in the West.

With population growing in the western states, electricity demand is poised for growth for the remainder of this decade. Both energy demand, that is the number of megawatt-hours (MWh) consumed over the course of the year, as well as peak demand, the highest hourly demand across the hours of the year, will continue to increase. Economic activity and population growth continue to be the most important drivers of electricity demand.

In 2001, a total of about 237,078 megawatts (MW) of capacity was installed in the West. Coal-fired generation provided about 44% of the electricity generated in the West and gas-fired generation accounted for about 24%. Hydroelectric power accounts for 22% of capacity and 18% of the generation in the states of the Western Governors' Association (WGA). Nuclear plants provide 7% of capacity and 11% of the energy. Of the remainder, about 1.5% comes from non-hydro renewables.

For almost 20 years, little new generating capacity has been built in the U.S. Now, however, new projects totaling over 133,747 MW by 2010 have been announced. Although not all of the announced projects will be completed, many thousands of megawatts, primarily gas-fired combined cycle power plants, are expected to come on-line in the West. The large amount of gas-fired capacity planned may result in more volatile gas prices for customers and will increase the reliance on fossil fuels for power generation. Energy conservation and energy efficiency can help offset the need for new generating capacity. However, renewable energy, in the form of wind or solar, provides one of the means of meeting the demand for power while minimizing adverse impacts on the environment, increasing fuel diversity, and hedging against fuel price volatility.

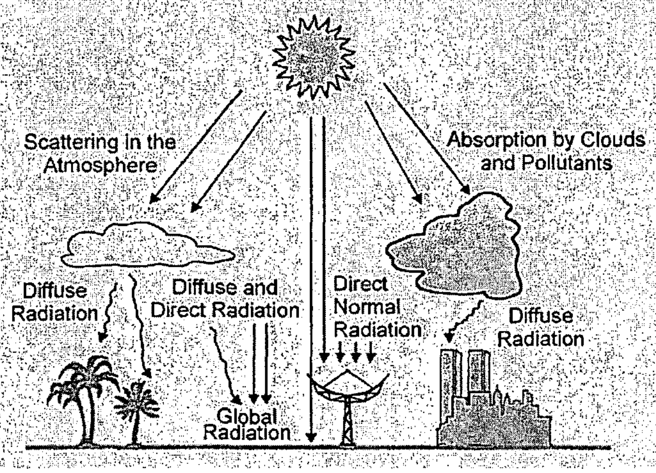
Concentrating solar power (CSP) is the most efficient and cost-effective way to generate electricity from the sun. Hundreds of megawatts of CSP solar-generating capacity could be brought on-direct normal, and global radiation. Global radiation is the sum of direct and diffuse radiation. Haze increases the amount of diffuse radiation while at the same time the amount of direct normal radiation decreases. Haze also results in reflection and absorption of sunlight, which reduces the overall amount of global radiation. On an overcast day, essentially all radiation that reaches the ground is diffuse, while on a clear day 93% to 95% of all radiation is direct normal.

While flat panel PV power plants use both diffuse and direct radiation, CSP power plants (CPV, dish Stirling, power tower, and parabolic trough) can only use the direct component of the sunlight. This makes CSP unsuitable for areas with high humidity and frequent cloud cover, both of which result in scattering. However, this imposes little limitation on CSP power plants, because for the western U.S., areas of highest total (global) radiation are also areas with low humidity and few clouds.

Radiation levels are affected by both weather conditions and the position of the sun above the horizon. The angle of the sun's rays relative to the Earth's surface changes during the day and with the seasons. In the winter, the sun is lower in the sky and less energy reaches the ground. In the summer, the sun is overhead and sunshine is stronger. In the Desert Southwest, toward the fall and winter, cloud cover increases and often shields the sun.

For solar power generation using CSP, the annual average amount of solar energy reaching the ground needs to be 6.0 kilowatt-hours per square meter per day (kWh/m$^2$/day) or higher. This is the case in many regions of the West (see "The Solar Energy Potential"). In premium solar resource areas, the average annual solar radiation exceeds 7.0 kWh/m$^2$/day. Using the most efficient solar generating technology (dish Stirling), an area the size of an NBA basketball court located in a premium solar resource would generate 60,740 kWh of electricity a year. To generate the same amount of electric energy, natural gas equivalent to 60 barrels of oil would have to be burned in a combined cycle power plant. Exhibit 20 displays this energy and shows that solar radiation is a concentrated form of power. Current technology can capture large amounts of this energy and convert it to electricity—indefinitely, domestically, and with no pollution or price volatility.

**Exhibit 19: Direct Normal, Diffuse, and Global Solar Radiation**




SOURCE: *Status Report on Solar Thermal Power Plants*, Pilkinton Solar International, 1996. Used by permission.

## Exhibit 37: Cost and Performance of Flat Panel PV and Concentrating PV

| | Flat Panel Photovoltaic (1) | | Concentrating PV |
|---|---|---|---|
| | Crystalline Silicon | Amorphous Silicon | |
| Unit Size | 50 x 2 kW=100 kW | 50 x 2 kW=100 kW | 22–28 kW |
| Max Conversion Efficiency % (2) | 13 | 6.5 | 18–19 |
| Generation Threshold W/m² | ≥50 (3) | ≥50 (3) | 50 |
| Annual Average Efficiency % (4) | 11 | 6 | TBD |
| Annual Avg. Capacity Factor % (4) | 24 | 24 | 30–32 |
| Equiv. Forced Outage Rate (EFOR) | TBD | TBD | 1–3 |
| Off-sun Generation | None | None | None |
| Acres/MW | 3.8 | 7.6 | 8–10 |
| Construction Time | 2 weeks | 4 weeks | 3–4 days per unit |
| Capital Cost $/kW | 7,500–8,500 | | TBD |
| Fixed O&M $/kW-year | 10 | TBD | 10 |
| Variable Non-fuel O&M $/MWh | 10 | TBD | 10 |
| Production Capacity for U.S. Market MW/year | 68 | 6.5 | TBD |
| Cumulative U.S. Sales | 140 MW | | 0.5 MW |
| Largest Unit in the U.S. | 1 MW | | TBD |
| Demonstrated System Hours | Unknown | Unknown | TBD |

SOURCE: National Renewable Energy Laboratory (NREL); Golden, Colorado, private communication; see reference in endnote 3.
(1) Commercially available technologies only. Crystalline silicon modules account for about 90% of the flat panel PV market, while amorphous silicon modules account for the remaining 10%.
(2) At 1,000 W/m².
(3) Direct normal and diffuse radiation.
(4) Premium solar resource area. Flat panel PV tilted to latitude.

# Concentrating PV

PV cells using multiple semiconductor junctions are capable of converting a much larger spectrum of sunlight to electricity than the single-junction cells used in conventional flat panel PV and thus have much higher efficiencies—up to 30%.[4] Nevertheless, multi-junction cells can be used more cost effectively if sunlight is concentrated first. The same solar module then produces more power than under normal light conditions. For example, if mirrors or lenses concentrate light on multi-junction cells and increase the sunlight concentration by a factor of 10, that cell will produce about 10 times more power than under direct sunlight. Concentrating PV (CPV) uses mirrors or lenses to focus sunlight on high-efficiency cells. The concentrating optics, as in all concentrating solar power technologies, can only focus direct normal radiation, but not diffuse light.

The idea behind CPV is that a few high-performance (and high-cost) PV cells are put to maximum use by concentrating light on them by using either mirrors or lenses. Because the concentrating optics is cheaper than PV modules, this approach is expected to result in an overall lower system cost. Currently, most CPV systems use lenses to concentrate sunlight and employ two-axis tracking mechanics to follow the sun as it makes its way across the sky. Exhibit 37 provides cost and performance data on CPV.

We believe that CPV is a promising form of PV power generation because it uses only one-tenth, or even less, semiconductor material than flat panel PV and it can thus employ more expensive

## Exhibit 40: Cost and Performance of Thermal Concentrating Solar Power Plants

| | Dish Stirling | Parabolic Trough | Power Tower |
|---|---|---|---|
| Standard Plant Size | 2.5 MW/100 MW | 100 MW | 100 MW |
| Max Conversion Efficiency % (1) | 30% | 24% | 22% |
| Generation Threshold W/m² | 200 | 300 | 300 |
| Annual Average Efficiency (2) | 21.40% | 13.70% | 16.00% |
| Annual Avg. Capacity Factor (2) | | | |
| Basic Plant | 25.20% | 23% | 29% |
| With Thermal Storage (3) | N/A | 33% (4 hrs, 1.8 x) | 48% (8 hrs, 1.8 x) |
| With Fossil Fuel Hybridization | N/A | 23-95% | 29-95% |
| Equiv. Forced Outage Rate (EFOR) % | 5 (estimate) | 5 | 5 (estimate) |
| Off-Sun Generation | Fossil Hybrid | Heat Storage/Fossil Hybrid | Heat Storage/Fossil Hybrid |
| Acres/MW of Collectors | 4 | 5 | 8 |
| Construction Time (4) | 3-4 days per unit; 35 days/6 months | 12 months | 12 months |
| Incremental Capital Cost | | | |
| Basic Plant $/kW | 2,650 | 1,956 | 2,065 |
| Heat Storage $/kWh | N/A | 103 | 27 |
| Additional Solar Field $/kW | N/A | 510 | 540 |
| Fossil Fuel Hybridization $/kW | Not commercial | 196 | 196 |
| Fossil Heat Rate (HHV) (4) | TBD | 10,800 | 10,000 |
| Incremental Fixed O&M $/kW-year | | | |
| Basic | 40/2.5 | 33 | 30 |
| Heat Storage | N/A | 2 | 1.5 |
| Additional Solar Field Only | N/A | 2 | 1.5 |
| Fossil Fuel Hybridization | N/A | – | – |
| Incremental Variable Non-fuel O&M $/MWh | | | |
| Basic | 16.80/15 | 2 | 2 |
| Heat Storage | N/A | – | – |
| Fossil Fuel Hybridization | N/A | – | – |
| RDI estimated new Capacity (MW) that could be built (5) | | | |
| 2002 | 0.7 | | – |
| 2003 | 3.1 | 30 | – |
| 2004 | 27.5 | 100 | 50 |
| 2005 | 75 | 200 | 50 |
| 2006 | 100 | 300 | 150 |
| Total | 206.3 | 630 | 250 |
| Cumulative U.S. Installations | 118 kW | 354 MW | 10 MW |
| Largest Unit in the U.S. | 25 kW | 80 MW | 10 MW (decommissioned) |
| Demonstrated System Hours | 80,000 | 300,000 | 2,000 |

(1) At 1,000 W/m².
(2) Premium solar resource area.
(3) The number of hours of full-load heat storage and the solar-to-electricity ratio are given in parentheses, e.g. "(3 hrs, 1.6 x)" means three hours of full-load electric generation from heat storage and a solar field, which is oversized by 60% with regard to the electric capacity of the power island.
(4) Based on natural gas.
(5) Assumes sufficient tax or buydown incentives and private sector financing, but no government-backed programs, such as loan guarantees.

ATTACHMENT B7
U. S. NATIONAL RENEWABLE ENERGY LABORATORY
U.S. SOLAR RADIATION RESOURCE MAPS
"ATLAS FOR THE SOLAR RADIATION DATA MANUAL
FOR FLAT-PLATE AND CONCENTRATING COLLECTORS"
(NO DATE)

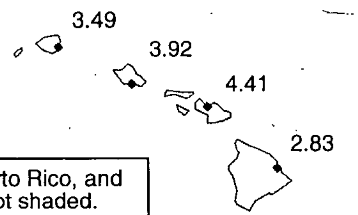
# U. S. National Renewable Energy Laboratory

# U.S. Solar Radiation Resource Maps "Atlas for the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors"

## (no date)

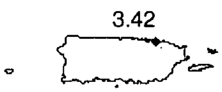
## Alaska

## Hawaii




Hawaii, Puerto Rico, and Guam are not shaded.

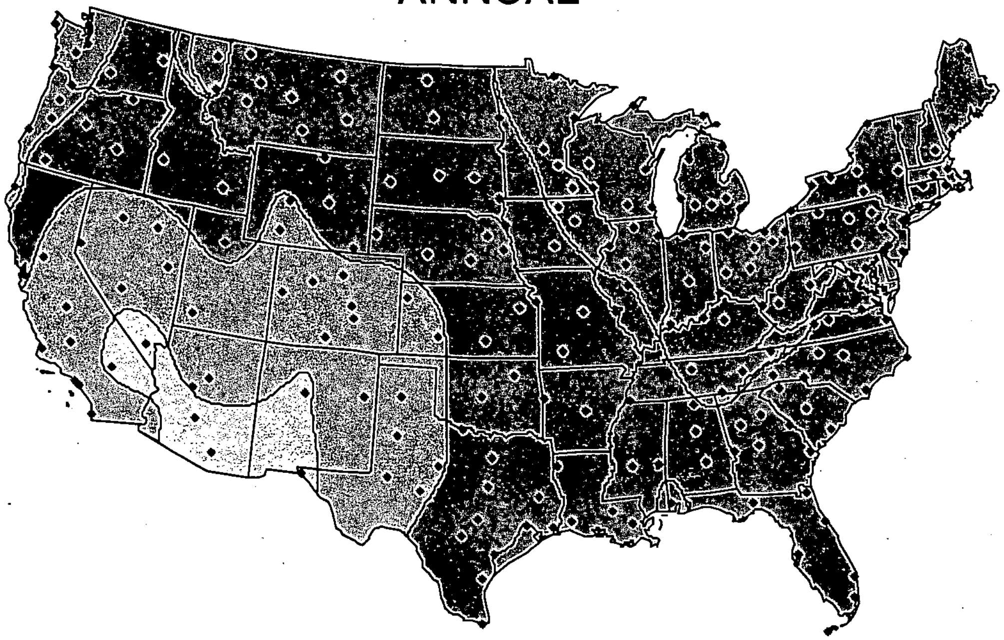
## San Juan, PR




## Guam, PI


# Average Daily Solar Radiation Per Month

## ANNUAL



**East-West Axis Tracking Concentrator**

## Collector Orientation

One-axis tracking parabolic trough with a horizontal east-west axis

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

* NREL

**National Renewable Energy Laboratory**
**Resource Assessment Program**

**kWh/m²/day**

- **10 to 14**
- **8 to 10**
- **7 to 8**
- **6 to 7**
- **5 to 6**
- **4 to 5**
- **3 to 4**
- **2 to 3**
- **0 to 2**
- **none**

C1XEA13-13

ATTACHMENT C
IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY
"U.S. HYDROPOWER RESOURCE ASSESSMENT, FINAL REPORT"
DECEMBER 1998

# Idaho National Engineering and Environmental Laboratory

# "U.S. Hydropower Resource Assessment" Final Report

## December 1998

DOE/ID-10430.2

# U.S. Hydropower Resource Assessment Final Report


Alison M. Conner
James E. Francfort
Ben N. Rinehart


Published December 1998


**Idaho National Engineering and Environmental Laboratory**
**Renewable Energy Products Department**
**Lockheed Martin Idaho Technologies Company**
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Prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-94ID13223

# ABSTRACT

To provide a more accurate assessment of the domestic undeveloped hydropower capacity, the U.S. Department of Energy's Hydropower Program developed a computer model, Hydropower Evaluation Software (HES). HES allows the personal computer user to assign environmental attributes to potential hydropower sites, calculate development suitability factors for each site based on the environmental, legal, and institutional attributes present, and generate reports based on these suitability factors. This report describes the development of HES, its data requirements, and its application to each state assessment; in addition, it summarizes the data derivation process and data for the states. Modeling of the undeveloped hydropower resources in the United States, based on environmental, legal, and institutional constraints, has identified 5,677 sites that have a total undeveloped capacity of about 30,000 megawatts.

# SUMMARY

This report presents the culmination of U.S. Department of Energy's (DOE's) efforts to produce a more definitive assessment of undeveloped hydropower resources within the United States. Initial efforts began in 1989 and information from the last state was received in 1998. State agencies contributed information about hydropower resources within their states to DOE's computer model, Hydropower Evaluation Software, and completed their review of the data. The state agencies involved in the project have included departments of dam safety, water resources, environmental quality, fish and game, history, and commerce. The Association of Dam Safety Officials has served as a conduit to identify the appropriate agencies from each state to assist in the modeling effort. Each state received on the average of $4,000 to complete the hydropower assessment. This level of funding did not cover each state's expenses, so the states provided the difference.

Past efforts to identify and measure the undeveloped hydropower capacity in the United States have resulted in estimates ranging from about 50,000 MW to almost 600,000 MW; these include the Hydropower Resource Assessment team's original estimate of 52,900 MW, the FERC's estimate of 70,000 MW, and the Corps of Engineers' theoretical estimate of 580,000 MW. None of these historical estimates have been universally accepted. These early estimates failed to consider the environmental, legal, and institutional constraints to developing hydropower projects. To provide a more accurate assessment of the domestic undeveloped hydropower capacity, the DOE Hydropower Program developed a computer model, Hydropower Evaluation Software (HES). HES allows the personal computer user to assign environmental attributes to potential hydropower sites, calculate development suitability factors for each site based on the environmental, legal, and institutional attributes present, and generate reports based on these suitability factors. Modeling of the undeveloped hydropower resources in the United States, based on environmental, legal, and institutional constraints, has identified 5,677 sites that have a total undeveloped capacity of about 30,000 megawatts.

This report summarizes the data derivation process and data for the United States. It also describes the development of HES, its data requirements, and its application to each state assessment. This report does not discuss or present the various user-friendly menus of HES. Readers are referred to the User's Manual for specifics. Information for ordering is provided on pages 33-34.

# ACKNOWLEDGMENTS

The authors would like to thank Peggy A. M. Brookshier and John V. Flynn of the Department of Energy for their active participation and timely comments. We also thank all those individuals from the states for providing valuable information and positive feedback.

# CONTENTS

## FIGURES



## TABLES

# U.S. Hydropower Resource Assessment Final Report

## INTRODUCTION

In June 1989, the U.S. Department of Energy (DOE) initiated the development of a National Energy Strategy to identify the energy resources available to support the expanding demand for energy in the United States. Public hearings conducted as part of the strategy development process indicated that the undeveloped hydropower resources were not well defined. One of the reasons was that no agency had previously estimated the undeveloped hydropower capacity based on site characteristics, stream flow data, and available hydraulic heads. The Federal Energy Regulatory Commission's (FERC's) Hydropower Resource Assessment (HPRA) database was used as the basis for this evaluation. The undeveloped capacity data is based on individual site evaluations that included capacity estimation. It was this information that for the first time was reviewed by the various state agencies and then modeled based on environmental, legal, and institutional constraints. As a result, DOE established an interagency Hydropower Resource Assessment Team to ascertain the country's undeveloped hydropower potential. The team consisted of representatives from each power marketing administration (Alaska Power Administration, Bonneville Power Administration, Western Area Power Administration, Southwestern Power Administration, and Southeastern Power Administration), the Bureau of Reclamation, the Army Corps of Engineers, the Federal Energy Regulatory Commission (FERC), the Idaho National Engineering and Environmental Laboratory (INEEL), and the Oak Ridge National Laboratory. The interagency team drafted a preliminary assessment of potential hydropower resources in February 1990. This assessment estimated that 52,900 MW of undeveloped hydropower energy existed in the United States.

Partial analysis of the hydropower resource database by groups in the hydropower industry indicated that the hydropower data included redundancies and errors that reduced confidence in the published estimates of developable hydropower capacity. The DOE has continued assessing hydropower resources to correct these deficiencies, improve estimates of developable hydropower, and determine future policy. To support these efforts by the DOE, the INEEL designed the Hydropower Evaluation Software (HES).

This report summarizes and discusses the undeveloped conventional hydropower capacity for the 5,677 sites within the United States. However, this capacity does not include that produced by pumped storage sites. The resource assessment is limited to sites with conventional undeveloped hydropower potential. In addition, while every reasonable effort was made to include all sites with undeveloped potential, the authors acknowledge that not every site in the United States with undeveloped hydropower potential was included. Only sites that have been either previously identified by third parties and included in the FERC HPRA database, or sites that local state agencies are aware of, are included in the database.

## Need For Uniform Criteria

The INEEL's HES, both a database and a probability-factor computer model, is a menu-driven software application that is intended to be user-friendly. Computer screens and report generation capabilities were developed to meet the needs of users nationwide. HES considers a uniform set of possible site-specific environmental attributes to assess the likelihood of developing the undeveloped hydropower resources of regions and states. These site-specific environmental attributes, derived from the Nationwide Rivers Inventory, include whether a site has Wild and Scenic Protection or is on a tributary of a site with such protection;

whether cultural, historical, fishery, geologic, recreational, scenic, or wildlife attributes are present; and whether threatened or endangered fish or wildlife are present. The attributes are based on the potential project's location, including whether the site is within a national park, national grasslands, national wildlife refuge, or other federal lands. HES's use of uniform criteria allows personal computer users nationwide to identify environmental attributes present at sites with undeveloped hydropower capacity, calculate development suitability factors for each site based on the attributes present, and generate uniform reports based on these factors.

HES was developed as a tool for use by regional power marketing administrations and state energy agencies, because they are the most likely to need accurate hydropower information. HES was not intended to provide precise development factors for individual sites, but to provide regional or state capacity totals. Because the software was developed as a generic measurement tool encompassing national issues, regional and state totals must be considered judiciously; various local issues may skew hydropower capacity totals. Employing HES as a national measurement tool will smooth any local anomalies.

## Model Development

HES uses environmental attribute data to generate an overall project suitability factor between 0.1 and 0.9, with 0.1 representing the lowest possibility of development and 0.9 representing the least impediment to development. A combination of attributes results in a lower suitability factor because multiple environmental considerations reduce the likelihood that a site may be developed to its physical capacity.

HES was developed with input from Oak Ridge National Laboratory, which provided the essential environmental evaluation support (Sale 1990). The INEEL also received valuable assistance from the Southwestern Power Administration, which helped defined the database requirements and the reporting capabilities required by a power marketing administration, and valuable managerial assistance from the Association of Dam Safety Officials.

## Model Validation

The INEEL used the HES to assess the undeveloped hydropower capacity in the Southwestern Power Administration area during the HES testing stage. The states in this area include Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas. HES identified about 250 sites with undeveloped hydropower capacity. After the HES computer model analysis was completed, the estimated Southwestern Power Administration hydropower resources were reduced 33.5%. This reduction resulted from the influence of various environmental attributes on the reality of successfully developing a hydropower site.

After successfully developing and testing HES in conjunction with the Southwestern Power Administration, the interagency team recognized that a process was necessary to successfully integrate the evaluation process between the individual states and the DOE's Hydropower Program. With administrative relationships already in place with the individual states, the team believed that using the DOE's Support Offices to coordinate the assessment process might prove to be a practical method to assess the entire United States. The Denver Support Office coordinated the assessments of the individual states within their administrative region (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming), as did the Boston Support Office (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont), the Kansas Support Office (Iowa), and the Chicago Support Office (Indiana). The test assessments, including obtaining individual state input, proved to be a viable method that could be used to assess hydropower capacity throughout the United States.

## Modeling Process

The basic modeling process incorporated the following steps:

1. The FERC HPRA database was used for basic site information such as site name, river, county, state, if a dam or power plant was previously developed, and the undeveloped hydropower potential.

2. This data was reviewed by the INEEL for redundancy and accuracy and entered into the HES model.

3. The National Rivers Inventory data, containing environmental, institutional, and legal attributes, was entered into the HES by the INEEL for those undeveloped sites that are located on river reaches containing NRI-listed attributes.

4. Wild and Scenic information was obtained from several sources and this information was also entered by the INEEL into the HES for those undeveloped sites that are located on river reaches with either wild and scenic designation or river reaches being considered for wild and scenic designation.

5. The HES containing the above information for each respective state was then sent to the individual states agencies for review and input.

6. After the state information was entered into the HES, the INEEL generated individual state reports for public dissemination via published reports and the internet (http://www.inel.gov/national/hydropower/state/stateres.htm)

## Model Goal

The goal of HES is to ensure that a set of uniform criteria is used to determine the viable national hydropower capacity. This undeveloped hydropower is not limited to that which could be produced at new sites; it also includes the hydropower that could be produced at sites that currently produce hydropower but are not developed to their full capacity. This undeveloped hydropower is a source of nonpolluting, renewable energy available to meet the growing power needs of the United States. HES has helped to make this goal obtainable and ensured the use of uniform criteria during the national assessment process.

The HES is not intended to be a static assessment, as sites can be added and changes can be made to the modeling dynamics if the need for additional renewable sites becomes such that the influence of the attributes changes in the future.

# DATA SOURCES

## Primary Data Sources

The Federal Energy Regulatory Commission's (FERC's) HPRA database and the National Park Service's Nationwide Rivers Inventory database are the two main information databases used for hydropower site data. State input is used to validate the HES-modeled results.

**Hydropower Resource Assessment Database.** This database is maintained by FERC and contains the best available national inventory of undeveloped hydropower capacity. It contains information about all sites that have been subject to any FERC hydropower licensing action and information on project sites that have been identified by FERC, or other agencies, as having development capacity even if no licensing action has taken place. This database lists project sites and corresponding basic site data. Approximately 5,700 sites with undeveloped hydropower capacity are listed in the HPRA database.

**Nationwide Rivers Inventory Database.** The Nationwide Rivers Inventory was initially completed in 1982 by the National Park Service and has been periodically updated since that time. Park Service regional offices systematically collected information on rivers and identified those with outstanding resources. Uniform procedures for identifying rivers for the Nationwide Rivers inventory, including field and map verification of each river's values, were applied throughout the country. Specific outstanding resources were identified for those river reaches selected for inclusion in the Nationwide Rivers Inventory. Reaches were identified if outstanding fisheries, wildlife, geologic features, historical resources, cultural resources, recreation resources, scenic values, or other resources were present. The Nationwide Rivers Inventory also indicates the presence of threatened and endangered species (classified as fish or terrestrial wildlife) and whether the reach is part of, or considered for, inclusion in a state or federal wild and scenic rivers program.

Although the National Park Service used uniform procedures to consider rivers throughout the United States for inclusion in the Nationwide Rivers Inventory, it would be incorrect to assume that if a potential site is not on a reach listed in the Nationwide Rivers Inventory there would be few environmental impediments to development: significant changes, such as new fisheries or increased recreational use, may have occurred since the Nationwide Rivers Inventory was last updated.

**State Resource and Energy Agencies.** After the information contained in FERC's HPRA database and the National Park Service's Nationwide Rivers Inventory database were entered into HES, the modeled results were presented to the natural resource departments or energy offices. Each state was then able to provide input, validate, and in many cases update the environmental and physical attributes present at each of the undeveloped hydropower sites. Additionally, the individual states were able to add previously unlisted sites that were known to state agencies as having undeveloped hydropower capacity.

State input is often the result of coordinated canvassing between several state agencies within each state. For instance, water management agencies may identify sites with undeveloped hydropower capacity that were not listed in FERC's HPRA database. Or, state agencies may be aware of state historical sites such as archeological sites of early Indian societies or other historical values that would impact the probability of developing a hydropower site. This state input often results in an adjustment of a site's overall project suitability value. In the case of the addition of previously unidentified sites with undeveloped hydropower capacity, a state's sum of undeveloped hydropower capacity may be increased. The value of state input to the modeling of undeveloped hydropower capacity cannot be overstated. Based on site visits such as dam safety inspections, wildlife field work, and cultural assessments, each state is the best source of local site knowledge.

## Secondary Data Sources

Other data sources can also be used to identify project locations and to assign environmental attributes to these locations. Some of these data sources are national in coverage, while others are available only for smaller areas such as individual states. Each additional database used will need to be obtained from its source, and the environmental attributes it lists will need to be extracted.

**Power Marketing Administrations.** Power marketing administrations possess significant information that is of primary importance to the successful application of HES. Each power marketing administration can verify any outside sources of data that are used; but, of greater importance, each power marketing administration can provide significant information about anything affecting potential hydropower development within its region. Power marketing administrations will be aware of possible state opposition and any local action regarding a specific project.

**State Environmental Databases.** Many states keep inventories of aquatic and riparian resources. These inventories can include lists of high-quality and possibly protected streams, natural areas, and recreational resources. State data is often very useful for determining the environmental feasibility of hydropower sites, but the data may require a great deal of manipulation before it can be incorporated into a regional database for hydropower evaluation. Because little state information is available in digital format, it is difficult to input state data into the HES database.

An example of a state database is the California Department of Fish and Game Wild Trout Program inventory, which lists streams identified as outstanding trout fisheries; such streams are protected from development under California law. As another example, the state of Utah has rated each of its streams by the following categories: (a) type of fishery, (b) productivity, (c) reproductive success, (d) spawning habitat, and (e) aesthetics. Projects on streams with high ratings in these categories will have greater environmental concerns.

**American Rivers Outstanding Rivers List.** During 1988, an organization named American Rivers published its Outstanding Rivers List. This list is a comprehensive, nationwide compilation of rivers that possess some outstanding ecological, recreational, natural, cultural, or scenic values. Rivers protected by legislation and rivers currently unprotected are included. The list contains an estimated 15,000 river reaches, totaling about 300,000 river-miles. Each river reach is described in terms such as its upriver and downriver end points, its total length, its significance, and the source of information. Some of this information is redundant with the Nationwide Rivers Inventory, which is included within the Outstanding River List, but much of it is additional information.

**Northwest Power Planning Council.** Streams under the jurisdiction of the Bonneville Power Administration have been studied by area states and rated by the Northwest Power Planning Council for the suitability of additional hydropower development. Streams were rated for values such as anadromous fish presence, resident fish populations, wildlife, natural features, cultural features, and recreation. In 1987, the Northwest Power Planning Council published a list of streams deemed unsuitable for hydropower development, which generally includes all streams containing anadromous fisheries. For projects proposed in the Bonneville Power Administration marketing area, the stream ratings are an important source of environmental attributes.

**Wetlands Inventories.** The presence of wetlands that could be affected by a potential hydropower project is an important environmental attribute because wetlands are protected under the Clean Water Act. The U.S. Fish and Wildlife Service has inventoried wetlands in some regions, and maps of these inventoried wetlands are available. Wetland inventories are also available from some states.

## Data Sources for Threatened and Endangered Species

**U.S. Fish and Wildlife Service Threatened and Endangered Species Database.** Geographic information in this database is given by county and hydrologic unit and sometimes at finer resolutions. Species information includes locations of species, life histories of species, legal histories of the designation as threatened and endangered species, habitat use, bibliographies, contact people, and key words that identify species as aquatic, wetland, or riparian species. The database has been in transition between in-house development and contracted management (by the Nature Conservancy) for several years. It appears that a wealth of information exists but may be difficult to access.

**Nature Conservancy.** The Nature Conservancy has a national database of all species that identifies threatened and endangered species. This database organizes geographic information by county.

# SITE ATTRIBUTES AND SUITABILITY FACTOR DETERMINATION

## Environmental, Legal, and Institutional Attribute Definitions

The INEEL derived the following 19 environmental attributes from the Nationwide Rivers Inventory. The corresponding suitability factors are fully explained in the Suitability Factor Determination section below.

**Wild/Scenic Protection.** This attribute identifies project sites that are included in the federal wild and scenic rivers system, under consideration for inclusion in the federal system, included in a state river protection program, in a designated wilderness area, or protected from development under another program. Relatively few sites have this status, but those that do are highly unlikely to be developed. Projects at undeveloped sites on state or federally protected wild and scenic rivers, or in wilderness areas, must be assumed to be legally protected from hydropower development. Also, projects at sites under consideration for protection are highly likely to be opposed by state and federal resource agencies, and protection will be approved at many such sites before hydropower development could occur. Since it is possible, but highly unlikely, that development could occur at a site with wild and scenic river protection, the suitability factor assigned to all such projects at undeveloped sites is 0.1.

It is highly unlikely that a project at an existing dam would be on a wild and scenic river since rivers are usually designated as wild and scenic only if they are free of developments such as dams. A suitability factor of 0.5 is assigned for such unusual cases.

**Wild and Scenic Tributary or Upstream or Downstream of a Wild and Scenic Location.** This attribute is assigned to a project if it is at the upstream or downstream end of a wild and scenic river reach or is on a tributary of a wild and scenic river. A project at a developed site would affect a downstream wild and scenic river if additional alterations to the flow regime resulted. A suitability factor of 0.75 is assigned for such projects. Projects at undeveloped sites are highly likely to alter the flow regime and may cause changes in downstream water quality, so a suitability factor of 0.5 is assigned to undeveloped sites.

**Cultural and Historic Values.** Project impacts on cultural and historic resources can often be mitigated (for example, by excavating archeological sites or relocating historic structures). Projects at existing dams are unlikely to affect such resources unless an increase in reservoir pool elevation occurs or major new structures are built. A suitability factor of 0.75 is assigned to such projects. Development of undeveloped sites is more likely to affect cultural and historic resources, so a suitability factor of 0.5 is assigned.

**Fish Presence Value.** A stream reach may or may not have legally protected fisheries. In either case, however, strong state opposition to new development must be expected if a valuable fishery resource exists. Relatively high instream flow release requirements can mitigate the impact on fisheries, but a high instream flow release would reduce the economic viability of the project. Projects at developed sites could have some impact, such as increased turbine mortality. A suitability factor of 0.75 is assigned to projects at developed sites. Development at undeveloped sites could have a major impact on aquatic habitat through inundation, migration blockage, turbine mortality, water quality, and altered flows. Some of these can be mitigated, but such mitigation could be expensive. A suitability factor of 0.25 is assigned to undeveloped sites.

**Geologic Value.** Geologic values such as rock formations are rarely protected legally and are not generally affected by small projects. Development at existing sites is not affected by geologic resources, so a suitability factor of 0.9 is assigned. Development at undeveloped sites may inundate geologic features, so a suitability factor of 0.5 is assigned.

**Recreation Value.** River recreation users tend to be effective opponents of hydropower development. Development at any storage dam would affect recreation by altering flow releases; mitigation typically includes higher flow releases during periods of high recreation use. Such releases can be made through turbines, but higher flow releases tend to occur when power demands are low. Projects at existing dams would have little effect on recreation besides flow alterations, so they are assigned a suitability factor of 0.75. Projects at undeveloped sites would inundate reaches, block the passage of boats, and reduce aesthetics. Because projects at undeveloped sites are likely to be strongly opposed, a suitability factor of 0.25 is assigned.

**Scenic Value.** Scenic values are not legally protected but must be considered in assessing the impact of a project. Scenic values are also important to recreational river users. The addition of power to existing dams would alter scenic values only through the addition of new structures and perhaps by reducing visually attractive spillage, so a suitability factor of 0.9 is assigned. New projects at undeveloped sites would have important effects on scenic resources because views would be altered by the project. Undeveloped projects are assigned a suitability factor of 0.5.

**Wildlife Value.** Terrestrial wildlife and wildlife habit are protected by fish and game agencies that are influential in determining mitigation requirements for hydropower projects. Development at existing sites would have little effect on wildlife unless reservoir pool elevations are altered or construction of major facilities is required. A suitability factor of 0.75 is assigned for projects at existing sites. Development at undeveloped sites could inundate wildlife habitat, and construction would cause a great deal of disturbance. It is difficult to mitigate for such impacts, so opposition to such a project could be strong. Undeveloped projects are assigned a suitability factor of 0.25.

**Other Value.** The effects of other values, such as the presence of rare wetland communities or consideration for wilderness designation, are assigned by using the most commonly assigned suitability factor for the other values. For projects at developed sites, the suitability factor is 0.75. For projects at undeveloped sites, the suitability factor is 0.5.

**Threatened and Endangered Fish or Wildlife.** The presence of threatened and endangered species near a project site requires additional consultations with wildlife agencies and can result in additional studies and mitigation requirements. The presence of threatened and endangered fish species may preclude development of new storage projects because new projects can involve the greatest alteration of aquatic habitat. Terrestrial threatened and endangered species are unlikely to be highly affected by run-rivers projects, but storage reservoirs could affect terrestrial habitat. For existing sites, a suitability factor of 0.75 is assigned when threatened and endangered species are present. For projects at undeveloped sites, a suitability factor of 0.5 is assigned when threatened and endangered species are present.

**Federal Land Code 103: National Park, Monument, Lakeshore, Parkway, Battlefield, Or Recreation Area.** These lands are legally protected from development. A suitability factor of 0.1 is assigned for such projects.

**Federal Land Code 104: National Forest or Grassland**. These lands are not legally protected from development, but the managing agency has the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned to projects at existing sites, since these projects typically have fewer impacts. A suitability factor of 0.5 is assigned for undeveloped sites.

**Federal Land Code 105: National Wildlife Refuge, Game Preserve, or Fish Hatchery.** These lands are managed for fish and wildlife habitats, and hydropower development would almost always be incompatible. A suitability factor of 0.1 is assigned for such projects.

**Federal Land Code 106: National Scenic Waterway or Wilderness Area.** These lands are legally protected from development. A suitability factor of 0.1 is assigned for such projects.

**Federal Land Code 107: Indian Reservation.** These lands are not legally protected from development, but Indian tribes have the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned for projects at developed sites, and a suitability factor of 0.5 is assigned for projects at undeveloped sites.

**Federal Land Code 108: Military Reservation.** These lands are not legally protected from development, but the managing agency has the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned for projects at developed sites, and a suitability factor of 0.5 is assigned for projects at undeveloped sites.

**Federal Land Code 198: Not on Federal Land.** This variable indicates that the project is not on federal land, so there are not any development constraints based on Federal Land Codes. The value for this variable is 0.9.

Figure 1 illustrates all of the data requirements presented above in a report printout from HES. The cultural, fish presence, historic, and scenic values combine to give the sample site a project suitability factor (PESF) of 0.5.

# Georgia Hydropower Resource Database Listing

| | | | |
|---|---|---|---|
| *FERC Number:* | 01218 | *Plant Name:* | FLINT RIVER |
| *Class:* | P | *Stream:* | FLINT R |
| *Owner:* | GEORGIA POWER CO | *County:* | DOUGHERTY |
| | | *Basin:* | APALACHICOLA RIVER BASIN |

| *Name Plate Rating (KW)* | *PESF* | *PESF*KW* | *Annual Energy Rating (MWh)* | *PESF Annual Energy Rating (MWh)* |
|---|---|---|---|---|
| 2800 | 0.5 | 1400 | 8700 | 4350 |

| *Unit Type* | *Plant Type* | *Project Status* | *Dam Status* | *Latitude* | *Longitude* |
|---|---|---|---|---|---|
| C | ROR | MO | W | 3137 | 8406 |

| *Factor* | *Exists* | *Prob* | *Factor* | *Exists* | *Prob* |
|---|---|---|---|---|---|
| *Wild/Scenic Protection* | | 0.9 | *Wildlife Value* | Y | 0.75 |
| *Wild/Scenic Tributary or Upstream/Downstream* | | | *Threatened/Endangered Fish* | | 0.9 |
| *Wild/Scenic Location* | | 0.9 | *Threatened/Endangered Wildlife* | | 0.9 |
| *Cultural Value* | | 0.9 | *Federal Land Code 103* | | 0.9 |
| *Fish Presence Value* | Y | 0.75 | *Federal Land Code 104* | | 0.9 |
| *Geologic Value* | Y | 0.9 | *Federal Land Code 105* | | 0.9 |
| *Historic Value* | | 0.9 | *Federal Land Code 106* | | 0.9 |
| *Other Value* | | 0.9 | *Federal Land Code 107* | | 0.9 |
| *Recreation Value* | Y | 0.75 | *Federal Land Code 108* | | 0.9 |
| *Scenic Value* | Y | 0.9 | *Federal Land Code 198* | | 0.9 |

**Figure 1.** Sample printout of resource database listing.

## Suitability Factor Values

Suitability factors depend on the environmental attributes of the potential project site. They reflect the probability that environmental considerations can make a project site unacceptable, prohibiting its development. The suitability factors were developed in conjunction with Oak Ridge National Laboratory staff who are experienced in hydropower licensing cases. Five potential values were selected, as shown in Table 1. *These suitability factors are appropriate only for the regional analysis of overall hydropower development capacity and are not useful for determining the ultimate viability of developing a specific project site.*

## Dam Status

The effects of environmental attributes vary by dam status. The dam status classifications follow FERC standard, which is

W = Developed hydropower site with power.

W/O = Developed site without power generation (the site has some type of developed impoundment or diversion structure).

U = Undeveloped site (the site does not have power generation capability, no developed impoundment, nor a diversion structure).

Undeveloped sites do not have any power or civil structures in place; developed sites without power do not have any power generation capability but do have some type of civil structure such as a dam or water diversion structure; and developed sites with power have current generation and a civil structure onsite with additional, undeveloped hydropower capacity.

The best way to explain the influence dam status has on a project's environmental suitability factor is to provide an example: development at an undeveloped site will have a greater impact on recreation than additional development at an existing site. So if a recreation value is present at an undeveloped site, a probability of 0.25 is assigned to reflect the decreased likelihood of development. If a recreation value is present at a developed site (either with or without power), then a value of 0.75 is assigned because additional development of a site already having a structure, either with or without power, is less likely to be impacted by any recreation value. These factors and all the other factors used are shown in Table 2.

**Table 1.** Valuation of environmental attributes.

| Effect of Environmental Attribute | Value of Suitability Factor |
|---|---|
| Least impediment to development | 0.90 |
| Minor reduction in likelihood of development | 0.75 |
| Likelihood of development reduced by half | 0.50 |
| Major reduction in likelihood of development | 0.25 |
| Development prohibited or highly unlikely | 0.10 |

**Table 2.** Suitability factors by dam status for environmental attributes.

| Environmental Attribute | Suitability Factors: Existing Dam With/Without Power | Undeveloped Site | Not Applicable |
|---|---|---|---|
| Wild/Scenic Protection | 0.50 | 0.10 | 0.90 |
| Wild/Scenic Tributary or Upstream/Downstream Wild/Scenic Location | 0.75 | 0.50 | 0.90 |
| Cultural Value | 0.75 | 0.50 | 0.90 |
| Fish Presence Value | 0.75 | 0.25 | 0.90 |
| Geologic Value | 0.90 | 0.50 | 0.90 |
| Historic Value | 0.75 | 0.50 | 0.90 |
| Other Value | 0.75 | 0.50 | 0.90 |
| Recreation Value | 0.75 | 0.25 | 0.90 |
| Scenic Value | 0.90 | 0.50 | 0.90 |
| Wildlife Value | 0.75 | 0.25 | 0.90 |
| Threatened/Endangered Fish | 0.75 | 0.50 | 0.90 |
| Threatened/Endangered Wildlife | 0.75 | 0.50 | 0.90 |
| Federal Land Code 103 | 0.10 | 0.10 | 0.90 |
| Federal Land Code 104 | 0.75 | 0.50 | 0.90 |
| Federal Land Code 105 | 0.10 | 0.10 | 0.90 |
| Federal Land Code 106 | 0.10 | 0.10 | 0.90 |
| Federal Land Code 107 | 0.75 | 0.50 | 0.90 |
| Federal Land Code 108 | 0.75 | 0.50 | 0.90 |
| Federal Land Code 198 | 0.90 | 0.90 | 0.90 |

The "not applicable" column in Table 2 assigns the default value of 0.90 if the user indicates the attribute is not present or if the entry is left blank. Environmental concerns will exist even if no environmental attributes are assigned, so a default value of 0.90 (rather than 1.0) is used to reflect this reality.

## Overall Project Suitability Factor

The final step in evaluating the environmental suitability of each project site is to combine the suitability factors for the individual environmental attributes into a single factor for each project site. This overall suitability factor is an estimate of the probability of a project's successful development, considering only the attributes identified in Table 2 and their effects on site development. The project environmental suitability factors will be used to predict the contribution that each individual project makes to the aggregate potential energy supply for a state or region.

The overall suitability factor is a function of the suitability factors for the individual environmental attributes. The presence of more than one environmental attribute means that more than one environmental concern affects a project. *The overall suitability factor should obviously be no greater than the lowest factor for individual attributes, and it should be less than the lowest factor if multiple significant environmental constraints are present.* For example, if an undeveloped project has both fish values (suitability factor = 0.25) and recreation values (suitability factor = 0.25), the cumulative effects of these two concerns will make its overall suitability even less than 0.25; so an overall suitability factor of 0.1 is assigned.

If the environmental suitability factors for individual environmental attributes were truly the probability of the project's being developed, then the overall probability of development could be mathematically calculated. And, if the individual suitability factors were true and independent probabilities, then the probability of developing the project site because of environmental concerns would be equal to the product of all the individual factors. However, FERC's licensing process is not a statistical probability function, and it cannot be assumed that suitability factors can be handled as independent probabilities (for example, there is a strong correlation between the scenic, recreational, and fishing values of a stream). In addition, environmental attributes not considered by HES would bias the value of the overall suitability factor if it were calculated as a probability.

The procedure outlined in Table 3 is used for assigning overall suitability factors. This procedure assumes that the lowest suitability factor dominates the likelihood of a project's development. However, it also considers the reduced likelihood of development resulting from the occurrence of multiple low suitability factors.

**Table 3.** Overall project suitability factor computation.

| Individual Environmental Suitability Factors | Project Suitability Factors |
|---|---|
| No environmental attributes assigned | 0.90 |
| Lowest individual factor(s) = 0.90 | 0.90 |
| Lowest individual factor = 0.75 | 0.75 |
| Two or more lowest individual factors = 0.75 | 0.50 |
| Lowest individual factor = 0.50 | 0.50 |
| Two or more lowest individual factors = 0.50 | 0.25 |
| Lowest individual factor = 0.25 | 0.25 |
| Two or more lowest individual factors = 0.25 | 0.10 |
| Lowest individual factor(s) = 0.10 | 0.10 |

# LIMITATIONS AND APPLICABILITY

HES is not intended to model the likelihood of development of any specific hydropower project. To perform this function, HES would have had to encompass the many site-specific factors affecting a distinctive site. With so many unique sites in the nation, an unmanageable number of single-site-specific attributes would be required, the database and software would become burdensome and unmanageable, and it would fail to provide a uniform nationwide evaluation. In the Pacific Northwest, for instance, if HES incorporated single-site-specific criteria it would have included any outcomes from the "Salmon Summit," the attempt to aid the migration of salmon and steelhead. This consideration would have been unique to the Northwest area only, not to the majority of the United States. Additionally, if a single state decreed that there would be no additional hydropower development within its boundaries, HES would fail in its mission if it included an attribute unique to that single state but not pertinent to the remaining 49 states. If there is significant state opposition, it will most likely be based on factors such as fish and recreation values, which HES is designed to model; and if the site is undeveloped and fish and recreation values are present, then HES would assign an overall project suitability factor of 0.1. Tests conducted with the Southwestern Power Administration, and through them several states, indicated that HES does satisfactorily model local concerns affecting hydropower development when environmental, legal, and institutional constraints to development are present. The model provides a uniform evaluation of hydropower capacity, and it should be used to accumulate regional capacity, not individual project capacity. Summing the regional totals provides a national total of the undeveloped hydropower resources available.

## ASSESSMENT PROCESS AND ASSUMPTIONS

The assessment process uses a logical extraction of data from the two primary data sources discussed previously: the Nationwide Rivers Inventory and the HPRA databases. The basic site data is relatively easy to download. However, extracting the environmental attributes data is somewhat tedious because of the cross-referencing needed between the two database sources and the interpretation of narrative descriptions of outstanding environmental attributes.

Environmental attributes for sites on river reaches listed in the Nationwide Rivers Inventory can be assigned several ways. The first and simplest is to assign the environmental attributes of a Nationwide Rivers Inventory reach to any undeveloped hydropower project that is located in the same state and county and on the same river that is listed in the Nationwide Rivers Inventory. This method relies on the state, county, and river identifiers in the HPRA database for location; these identifiers are unlikely to be inaccurate.

A second method for assigning Nationwide Rivers Inventory attributes to projects is to (a) use the river mile designations for Nationwide Rivers Inventory reaches to locate the reaches on FERC river basin maps, (b) use the Geographic Information System to map the projects at the same scale, and (c) overlay the project maps on the Nationwide Rivers Inventory reach maps to see which projects fall on Nationwide Rivers Inventory reaches. This method is potentially more accurate since only the projects actually on the Nationwide Rivers Inventory reach would be identified. Sites within a specified distance upstream or downstream of the Nationwide Rivers Inventory reach could also be identified and assigned the environmental attributes of the Nationwide Rivers Inventory reach. The main disadvantage of this method is that it uses the latitude-longitude coordinates of projects from the HPRA database, which are occasionally missing or inaccurate. For this and other reasons, the first method was used. The first method also ensures that any upstream or downstream impacts from development are also considered.

The application of suitability factors is straightforward once all of the environmental attributes have been identified. One simply follows the specifications in Table 2.

The underlying assumption in the evaluation process is that the suitability factors being assigned to environmental attributes represent the degree to which these attributes will decrease the likelihood of developing a site. One must also assume that the combination of suitability factors is not multiplicative but can be represented by the weighing scheme shown in Table 3.

# SUMMARY OF COMPLETED HYDROPOWER RESOURCE ASSESSMENT

This status report discusses the undeveloped hydropower capacity within the United States. The hydropower resource assessment utilized the Hydropower Evaluation Software (HES).

As stated in the Abstract, the Southwestern Power Administration was used for model testing. The six states in this power marketing administration are Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas. The remaining 44 states have also been assessed. The information for the resource assessment was obtained primarily from FERC's Hydroelectric Power Resources Assessment database and the National Park Service's National Rivers Inventory database. Input was also obtained from individual state agencies regarding the undeveloped hydropower capacity and the natural resources present within their respective states. Note, Delaware was not asked to participate due to only one site reported in Delaware.

The goal of HES is to ensure that a set of uniform criteria is used to determine the viable national hydropower capacity. Undeveloped hydropower is not limited to that which could be developed at new sites; it also includes power that could be produced at sites that currently have hydropower but are not developed to their full capacity. This criterion includes environmental, legal, and institutional attributes. These attributes can include (1) scenic, cultural, historical, and geological values; (2) Federal and state land-use, which includes parks, wildlife preserves, recreation areas, forests, wilderness areas, scenic waterways, and military or Indian reservations; and (3) legal protection issues such as Wild and Scenic legislation, and Threatened or Endangered Fish and Wildlife legislative protection.

The amount that each attribute affects the likelihood of development depends on the physical state of a site. HES assumes that a site can have one of three development states. These are (a) completely undeveloped with no structures present; (b) developed site without power—some type of civil structure such as a dam, weir, or abandoned power plant may be present, but there is no power being generated; or (c) ongoing power generation with additional undeveloped capacity.

Using the hydropower summary report menu feature of HES, the 50 states are summarized in Table 4. Figures 2 through 7 elaborate on the capacity adjustments presented in Table 4. The figures show that HES will adjust the undeveloped capacity downward due to the effects of environmental, legal, and institutional attributes. The figures also demonstrate the wide variation in the number of sites and the undeveloped capacities that are unique to each state.

Figures 2 and 3 summarize the number of potential hydropower sites in each of the 50 states, based on environmental and legal conditions existing as of 1998 or earlier. The number of sites does not change after HES adjustments are made. California has the highest total number of sites (763) and the most undeveloped sites (463), and Delaware has the fewest sites (1). Wisconsin has the largest number of developed sites (46) that also have additional undeveloped hydropower capacity. While Delaware, Florida, Louisiana, Mississippi, New Hampshire, New Jersey, Rhode Island, Tennessee, West Virginia, and Wyoming do not have any sites with existing power production that are not already developed to their full capacity. The total number of sites for the 50 states is 5,677. Developed sites with existing power (389) account for about 7% of the total number of sites while there are 2,527 developed sites without power, and 2,761 undeveloped sites.

**Table 4.** Hydropower capacity summary modeled by HES.

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Alabama | With Power | 4 | 71 | 35 |
| | W/O Power | 21 | 281 | 216 |
| | Undeveloped | 8 | 146 | 112 |
| | State Total | 33 | 498 | 363 |
| Alaska | With Power | 3 | 65 | 58 |
| | W/O Power | 60 | 2,866 | 1,610 |
| | Undeveloped | 56 | 1,111 | 490 |
| | State Total | 119 | 4,042 | 2,158 |
| Arizona | With Power | 2 | 207 | 157 |
| | W/O Power | 6 | 51 | 15 |
| | Undeveloped | 13 | 1,552 | 166 |
| | State Total | 21 | 1,810 | 338 |
| Arkansas | With Power | 13 | 193 | 174 |
| | W/O Power | 28 | 378 | 332 |
| | Undeveloped | 20 | 638 | 231 |
| | State Total | 61 | 1,209 | 737 |
| California | With Power | 26 | 1,745 | 653 |
| | W/O Power | 274 | 4,812 | 1,894 |
| | Undeveloped | 463 | 3,834 | 843 |
| | State Total | 763 | 10,391 | 3,390 |
| Colorado | With Power | 5 | 156 | 78 |
| | W/O Power | 91 | 782 | 377 |
| | Undeveloped | 155 | 1,408 | 209 |
| | State Total | 251 | 2,346 | 664 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Connecticut | With Power | 3 | 21 | 11 |
| | W/O Power | 50 | 27 | 14 |
| | Undeveloped | 15 | 191 | 19 |
| | State Total | 68 | 239 | 44 |
| Delaware | With Power | 0 | 0 | 0 |
| | W/O Power | 1 | 0.18 | 0.02 |
| | Undeveloped | 0 | 0 | 0 |
| | State Total | 1 | 0.18 | 0.02 |
| Florida | With Power | 0 | 0 | 0 |
| | W/O Power | 8 | 49 | 34 |
| | Undeveloped | 5 | 12 | 9 |
| | State Total | 13 | 61 | 43 |
| Georgia | With Power | 7 | 145 | 89 |
| | W/O Power | 31 | 717 | 486 |
| | Undeveloped | 24 | 275 | 37 |
| | State Total | 62 | 1,137 | 612 |
| Hawaii | With Power | 1 | 3 | 3 |
| | W/O Power | 7 | 20 | 13 |
| | Undeveloped | 17 | 406 | 52 |
| | State Total | 25 | 429 | 68 |
| Idaho | With Power | 14 | 1,003 | 504 |
| | W/O Power | 86 | 541 | 447 |
| | Undeveloped | 273 | 6,169 | 704 |
| | State Total | 373 | 7,713 | 1,655 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Illinois | With Power | 9 | 80 | 41 |
| | W/O Power | 35 | 457 | 242 |
| | Undeveloped | 5 | 58 | 18 |
| | State Total | 49 | 595 | 301 |
| Indiana | With Power | 3 | 16 | 8 |
| | W/O Power | 24 | 51 | 34 |
| | Undeveloped | 3 | 17 | 2 |
| | State Total | 30 | 84 | 44 |
| Iowa | With Power | 7 | 115 | 61 |
| | W/O Power | 69 | 310 | 219 |
| | Undeveloped | 3 | 30 | 25 |
| | State Total | 79 | 455 | 305 |
| Kansas | With Power | 1 | 0.06 | 0.03 |
| | W/O Power | 12 | 53 | 45 |
| | Undeveloped | 5 | 100 | 38 |
| | State Total | 18 | 153 | 83 |
| Kentucky | With Power | 1 | 19 | 10 |
| | W/O Power | 46 | 851 | 425 |
| | Undeveloped | 4 | 43 | 4 |
| | State Total | 51 | 913 | 439 |
| Louisiana | With Power | 0 | 0 | 0 |
| | W/O Power | 14 | 78 | 67 |
| | Undeveloped | 8 | 148 | 133 |
| | State Total | 22 | 226 | 200 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Maine | With Power | 24 | 83 | 47 |
| | W/O Power | 74 | 1,069 | 768 |
| | Undeveloped | 269 | 554 | 227 |
| | State Total | 367 | 1,706 | 1,042 |
| Maryland | With Power | 1 | 196 | 20 |
| | W/O Power | 32 | 32 | 10 |
| | Undeveloped | 3 | 1 | 0.10 |
| | State Total | 36 | 229 | 30 |
| Massachusetts | With Power | 12 | 28 | 14 |
| | W/O Power | 87 | 118 | 62 |
| | Undeveloped | 31 | 179 | 56 |
| | State Total | 130 | 325 | 132 |
| Michigan | With Power | 11 | 25 | 17 |
| | W/O Power | 53 | 459 | 354 |
| | Undeveloped | 22 | 129 | 18 |
| | State Total | 86 | 613 | 389 |
| Minnesota | With Power | 12 | 98 | 72 |
| | W/O Power | 21 | 73 | 51 |
| | Undeveloped | 7 | 55 | 14 |
| | State Total | 40 | 226 | 137 |
| Mississippi | With Power | 0 | 0 | 0 |
| | W/O Power | 13 | 81 | 62 |
| | Undeveloped | 6 | 47 | 29 |
| | State Total | 19 | 128 | 91 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Missouri | With Power | 6 | 116 | 104 |
| | W/O Power | 12 | 203 | 181 |
| | Undeveloped | 11 | 378 | 38 |
| | State Total | 29 | 697 | 323 |
| Montana | With Power | 7 | 470 | 235 |
| | W/O Power | 72 | 1,129 | 502 |
| | Undeveloped | 79 | 2,073 | 277 |
| | State Total | 158 | 3,672 | 1,014 |
| Nebraska | With Power | 3 | 46 | 28 |
| | W/O Power | 23 | 117 | 62 |
| | Undeveloped | 19 | 182 | 59 |
| | State Total | 45 | 345 | 149 |
| Nevada | With Power | 9 | 5 | 4 |
| | W/O Power | 48 | 41 | 31 |
| | Undeveloped | 124 | 80 | 32 |
| | State Total | 181 | 126 | 67 |
| New Hampshire | With Power | 0 | 0 | 0 |
| | W/O Power | 63 | 51 | 25 |
| | Undeveloped | 34 | 65 | 7 |
| | State Total | 97 | 116 | 32 |
| New Jersey | With Power | 0 | 0 | 0 |
| | W/O Power | 9 | 6 | 5 |
| | Undeveloped | 3 | 5 | 4 |
| | State Total | 12 | 11 | 9 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| New Mexico | With Power | 2 | 11 | 6 |
| | W/O Power | 12 | 48 | 24 |
| | Undeveloped | 8 | 31 | 5 |
| | State Total | 22 | 90 | 35 |
| New York | With Power | 44 | 286 | 162 |
| | W/O Power | 212 | 754 | 495 |
| | Undeveloped | 96 | 1,079 | 652 |
| | State Total | 352 | 2,119 | 1,309 |
| North Carolina | With Power | 6 | 16 | 14 |
| | W/O Power | 57 | 594 | 369 |
| | Undeveloped | 30 | 848 | 125 |
| | State Total | 93 | 1,458 | 508 |
| North Dakota | With Power | 2 | 86 | 43 |
| | W/O Power | 10 | 13 | 7 |
| | Undeveloped | 2 | 0.04 | 0.04 |
| | State Total | 14 | 99 | 50 |
| Ohio | With Power | 1 | 2 | 1 |
| | W/O Power | 33 | 183 | 138 |
| | Undeveloped | 9 | 57 | 44 |
| | State Total | 43 | 242 | 183 |
| Oklahoma | With Power | 9 | 274 | 179 |
| | W/O Power | 18 | 78 | 68 |
| | Undeveloped | 6 | 190 | 94 |
| | State Total | 33 | 542 | 341 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Oregon | With Power | 3 | 45 | 11 |
| | W/O Power | 101 | 2,549 | 1,916 |
| | Undeveloped | 118 | 950 | 318 |
| | State Total | 222 | 3,544 | 2,245 |
| Pennsylvania | With Power | 5 | 207 | 105 |
| | W/O Power | 67 | 310 | 187 |
| | Undeveloped | 32 | 1,701 | 411 |
| | State Total | 104 | 2,218 | 703 |
| Rhode Island | With Power | 0 | 0 | 0 |
| | W/O Power | 27 | 12 | 10 |
| | Undeveloped | 3 | 2 | 1 |
| | State Total | 30 | 14 | 11 |
| South Carolina | With Power | 2 | 6 | 3 |
| | W/O Power | 31 | 855 | 444 |
| | Undeveloped | 16 | 273 | 33 |
| | State Total | 49 | 1,134 | 480 |
| South Dakota | With Power | 5 | 569 | 285 |
| | W/O Power | 25 | 548 | 405 |
| | Undeveloped | 3 | 6 | 5 |
| | State Total | 33 | 1,123 | 695 |
| Tennessee | With Power | 0 | 0 | 0 |
| | W/O Power | 11 | 20 | 10 |
| | Undeveloped | 11 | 476 | 128 |
| | State Total | 22 | 496 | 138 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Texas | With Power | 23 | 56 | 46 |
| | W/O Power | 26 | 164 | 140 |
| | Undeveloped | 40 | 1,014 | 832 |
| | State Total | 89 | 1,234 | 1,018 |
| Utah | With Power | 8 | 48 | 8 |
| | W/O Power | 69 | 900 | 414 |
| | Undeveloped | 245 | 990 | 472 |
| | State Total | 322 | 1,938 | 894 |
| Vermont | With Power | 29 | 69 | 32 |
| | W/O Power | 70 | 261 | 130 |
| | Undeveloped | 50 | 90 | 12 |
| | State Total | 149 | 420 | 174 |
| Virginia | With Power | 9 | 16 | 12 |
| | W/O Power | 52 | 690 | 376 |
| | Undeveloped | 27 | 544 | 229 |
| | State Total | 88 | 1,250 | 617 |
| Washington | With Power | 11 | 1,033 | 875 |
| | W/O Power | 238 | 3,373 | 1,777 |
| | Undeveloped | 313 | 3,069 | 762 |
| | State Total | 562 | 7,475 | 3,414 |
| West Virginia | With Power | 0 | 0 | 0 |
| | W/O Power | 27 | 1,597 | 1,002 |
| | Undeveloped | 10 | 328 | 147 |
| | State Total | 37 | 1,925 | 1,149 |

**Table 4.** (continued).

| State | Category | Number Of Projects | Name Plate Capacity (MW) | HES Adjusted Capacity (MW) |
|---|---|---|---|---|
| Wisconsin | With Power | 46 | 190 | 111 |
| | W/O Power | 35 | 53 | 16 |
| | Undeveloped | 21 | 210 | 26 |
| | State Total | 102 | 453 | 153 |
| Wyoming | With Power | 0 | 0 | 0 |
| | W/O Power | 36 | 920 | 487 |
| | Undeveloped | 36 | 708 | 317 |
| | State Total | 72 | 1,628 | 804 |
| Totals | With Power | 389 | 7,820 | 4,316 |
| | W/O Power | 2,527 | 29,625 | 16,998 |
| | Undeveloped | 2,761 | 32,452 | 8,466 |
| | Grand Total | 5,677 | 69,897 | 29,780 |

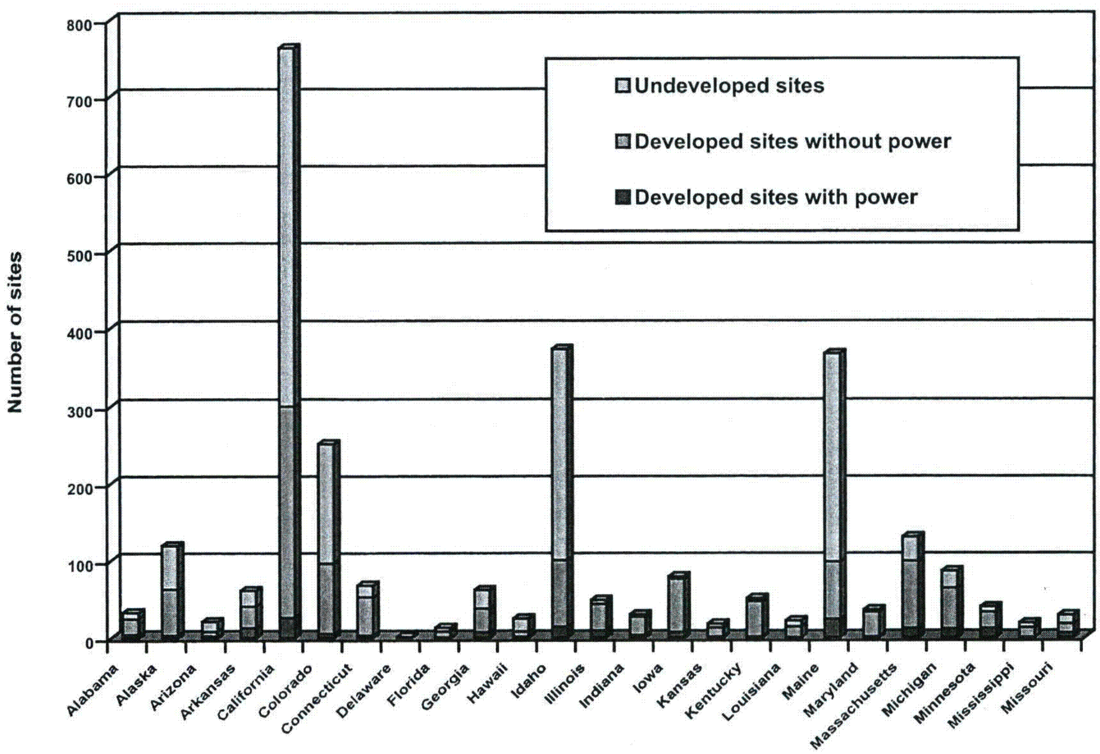


**Figure 2.** Number of sites with undeveloped hydropower capacity by state for Alabama through Missouri.

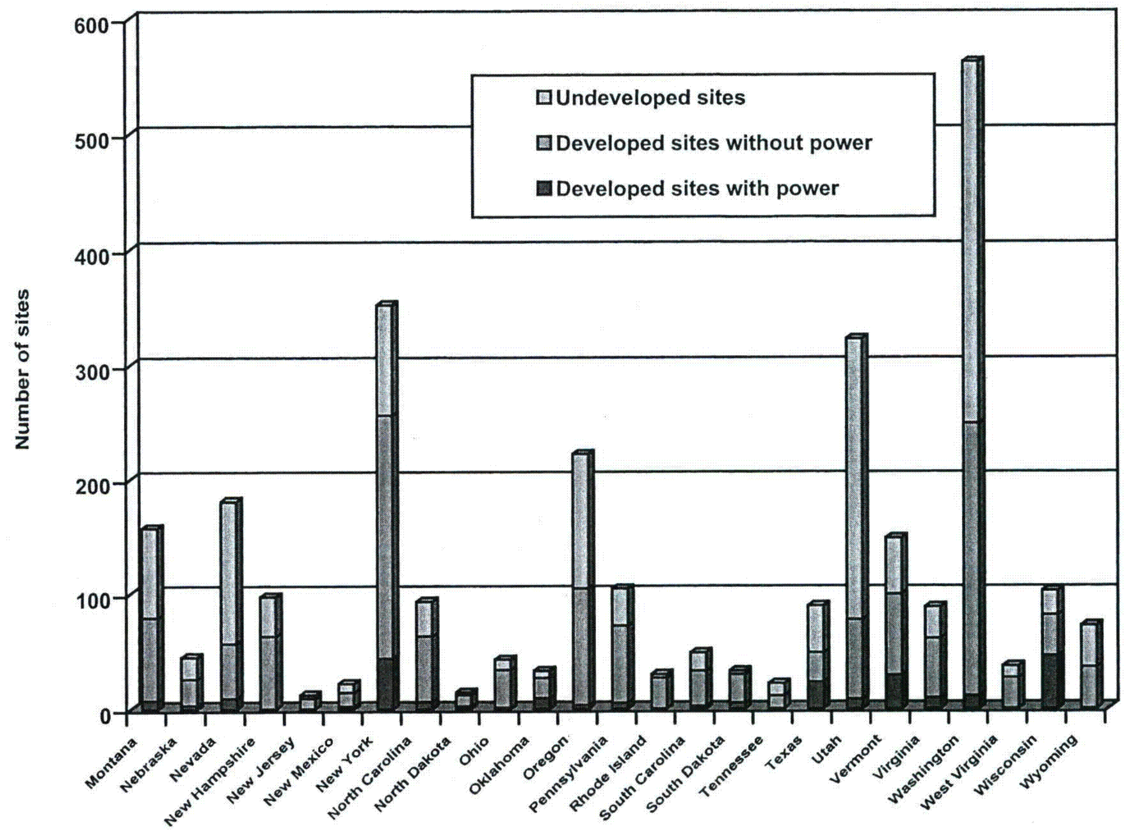


**Figure 3.** Number of sites with undeveloped hydropower capacity by state for Montana through Wyoming.

Figures 4 and 5 summarize the nonmodeled (unadjusted) and the HES-modeled (adjusted) total undeveloped hydropower capacity. California has the highest unadjusted undeveloped capacity, and Washington has the highest undeveloped capacity after adjustment for environmental attributes using HES. California also has the largest adjustment decrease (7,001 MW). Delaware and New Jersey show the smallest capacity decreases of 0.16 MW and 2 MW, respectively. Delaware also remains the state with the least undeveloped capacity with or without modeling. The unadjusted undeveloped hydropower capacity total for the 50 states is 69,897 MW. HES results lowers this estimate about 57% to 29,780 MW.

Figure 6 compares unadjusted and adjusted total undeveloped hydropower capacity by site status. As expected by the probability-weighing scheme, the capacity associated with an undeveloped site has the largest reduction from 32,452 to 8,466 MW, or a loss of 23,986 MW (74%). Developed sites with power (389 sites) have a reduction in undeveloped capacity from 7,820 MW to 4,316 MW, or a loss of 3,504 MW (45%). Developed sites without power (2,527 sites) have a reduction from 29,625 MW to 16,998 MW, or a loss of 12,627 MW (43%). Developed sites without power have the greatest overall capacity after adjustment (16,998 MW). The additional hydropower capacity for developed sites with current power generation remains considerably less (4,316 MW).

As shown in Figure 7, the majority of the hydropower sites (53% or 2,990) are located within seven states: California, Colorado, Idaho, Maine, New York, Utah, and Washington; five of those states are in the western United States.

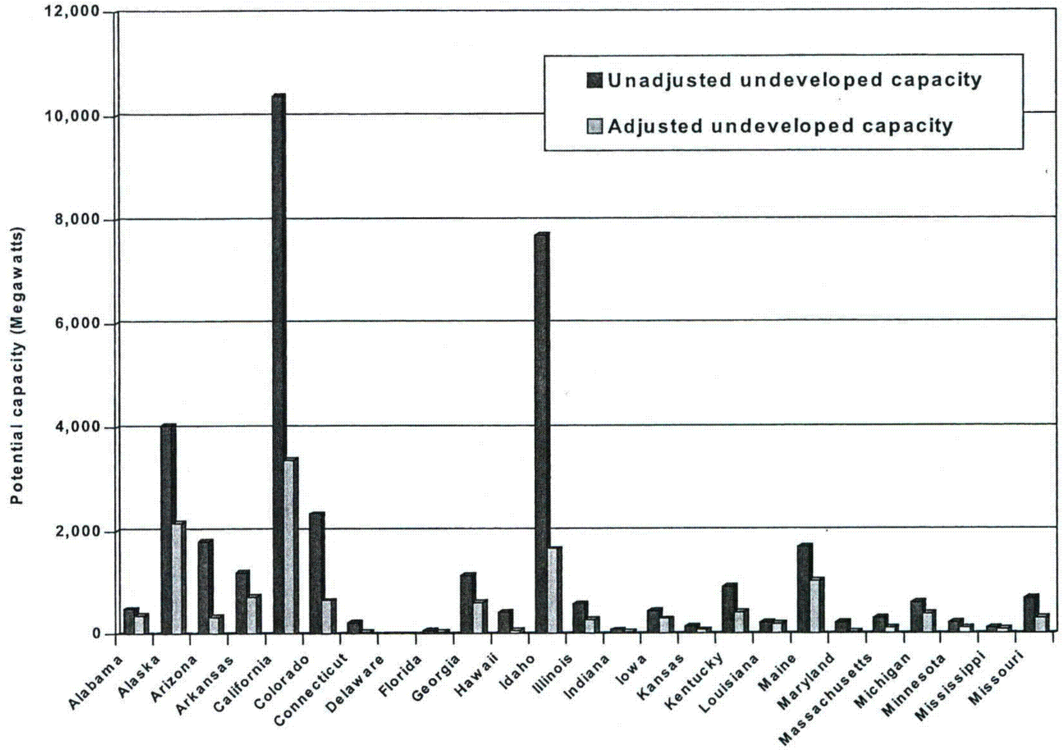


**Figure 4.** Total undeveloped hydropower capacity by state for Alabama through Missouri.

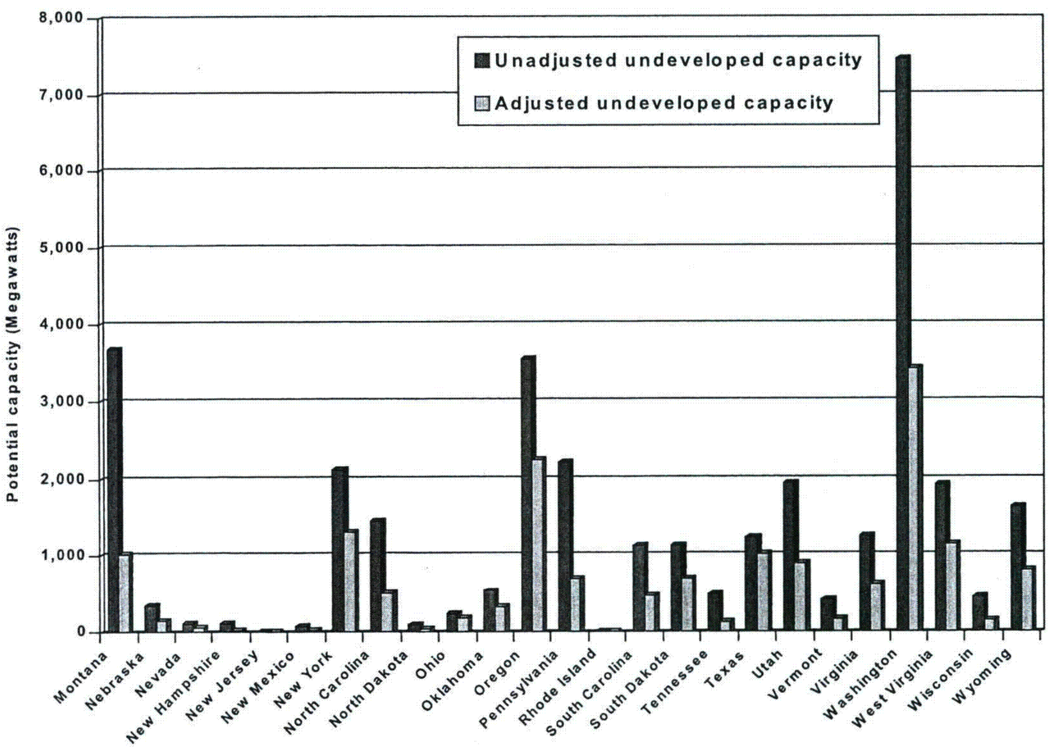


**Figure 5.** Total undeveloped hydropower capacity by state for Montana through Wyoming.

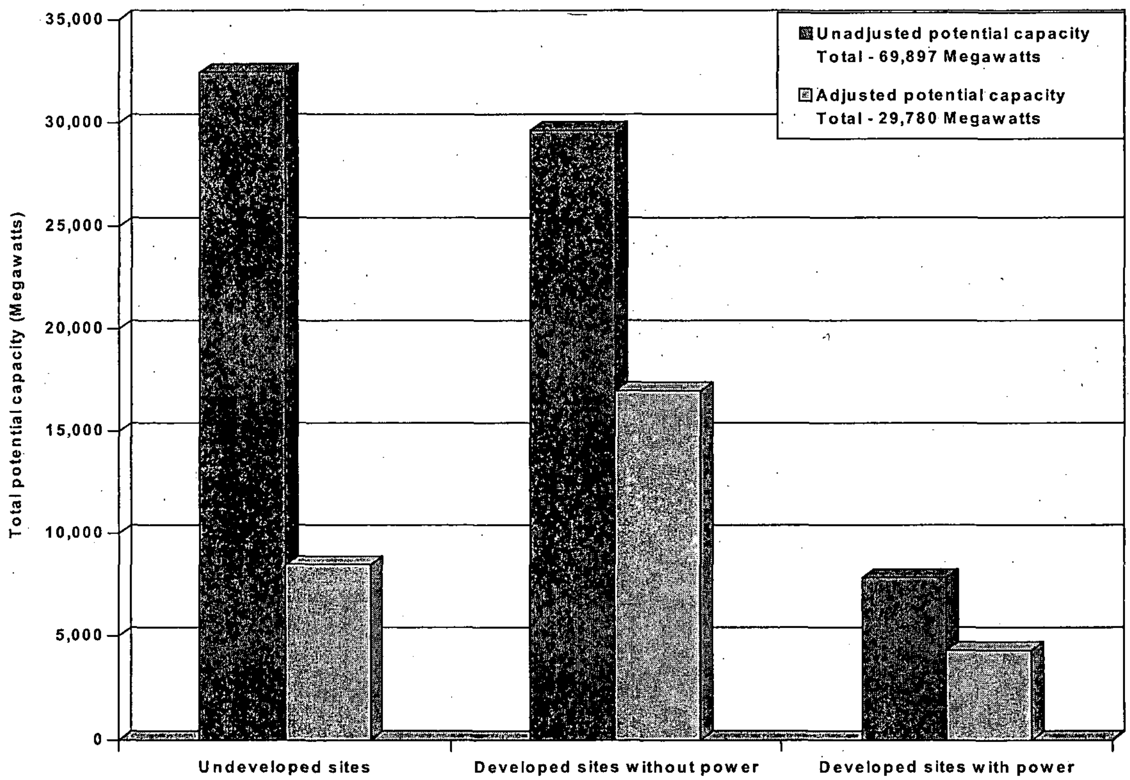


**Figure 6.** Total undeveloped hydropower capacity by site status.

Table 5 identifies the percent of the original undeveloped hydropower capacity that remains after HES is applied. Louisiana has the greatest percentage (89%) of the undeveloped hydropower capacity remaining for development, while Delaware and Maryland have the least remaining original capacity. Many (25) of the states have greater than 50% of the original hydropower capacity remaining for development after HES model is applied.

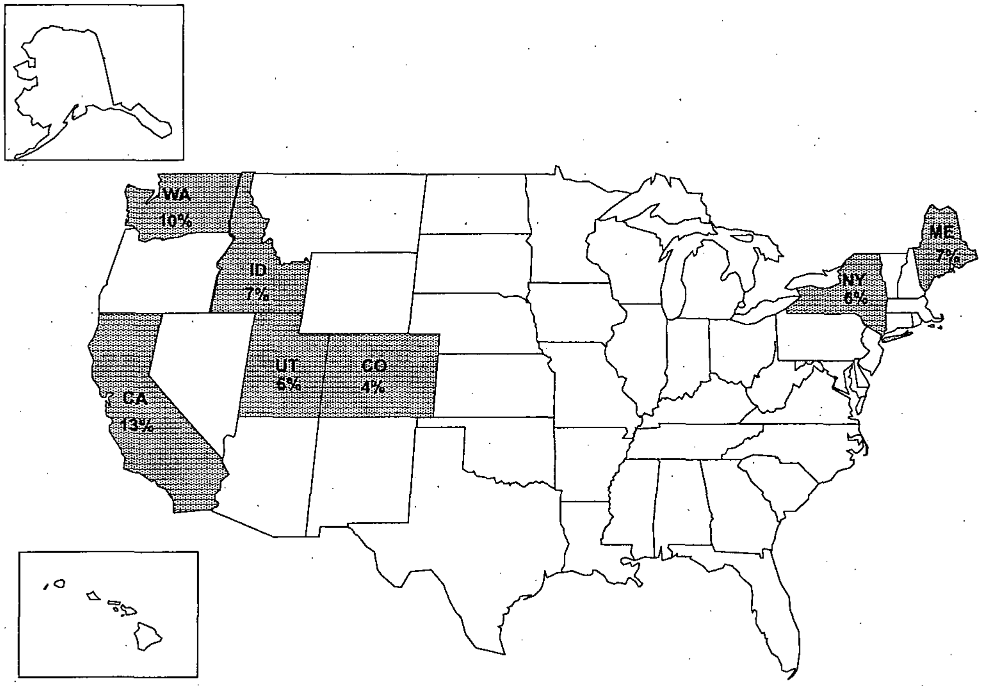


**Figure 7.** Location of the majority of hydropower sites by state, reported as a percentage of the total number of sites.

**Table 5.** The percent of the original undeveloped hydropower capacity that remains after HES is applied.

| State | Sites | Modeled Capacity (MW) | Nonmodeled Capacity (MW) | Percent of Original |
|---|---|---|---|---|
| AK | 119 | 2,158 | 4,042 | 53.39% |
| AL | 33 | 363 | 498 | 72.89% |
| AR | 61 | 737 | 1,209 | 60.96% |
| AZ | 21 | 338 | 1,810 | 18.67% |
| CA | 763 | 3,390 | 10,391 | 32.62% |
| CT | 68 | 44 | 239 | 18.41% |
| CO | 251 | 664 | 2,346 | 28.30% |
| DE | 1 | 0.02 | 0.18 | 11.11% |
| FL | 13 | 43 | 61 | 70.49% |
| GA | 62 | 612 | 1,137 | 53.83% |

**Table 5.** (continued).

| State | Sites | Modeled Capacity (MW) | Nonmodeled Capacity (MW) | Percent of Original |
|---|---|---|---|---|
| HI | 25 | 68 | 429 | 15.85% |
| IA | 79 | 305 | 455 | 67.03% |
| ID | 373 | 1,655 | 7,713 | 21.46% |
| IL | 49 | 301 | 595 | 50.59% |
| IN | 30 | 44 | 84 | 52.38% |
| KS | 18 | 83 | 153 | 54.25% |
| KY | 51 | 439 | 913 | 48.08% |
| LA | 22 | 200 | 226 | 88.50% |
| MA | 130 | 132 | 325 | 40.62% |
| MD | 36 | 30 | 229 | 13.10% |
| ME | 367 | 1,042 | 1,706 | 61.08% |
| MI | 86 | 389 | 613 | 63.46% |
| MN | 40 | 137 | 226 | 60.62% |
| MO | 29 | 323 | 697 | 46.34% |
| MS | 19 | 91 | 128 | 71.09% |
| MT | 158 | 1,014 | 3,672 | 27.61% |
| NC | 93 | 508 | 1,458 | 34.84% |
| ND | 14 | 50 | 99 | 50.51% |
| NE | 45 | 149 | 345 | 43.19% |
| NH | 97 | 32 | 116 | 27.59% |
| NJ | 12 | 9 | 11 | 81.82% |
| NM | 22 | 35 | 90 | 38.89% |
| NV | 181 | 67 | 126 | 53.17% |
| NY | 352 | 1,309 | 2,119 | 61.77% |
| OH | 43 | 183 | 242 | 75.62% |
| OK | 33 | 341 | 542 | 62.92% |
| OR | 222 | 2,245 | 3,544 | 63.35% |
| PA | 104 | 703 | 2,218 | 31.70% |
| RI | 30 | 11 | 14 | 78.57% |
| SC | 49 | 480 | 1,134 | 42.33% |
| SD | 33 | 695 | 1,123 | 61.89% |
| TN | 22 | 138 | 496 | 27.82% |

**Table 5.** (continued).

| State | Sites | Modeled Capacity (MW) | Nonmodeled Capacity (MW) | Percent of Original |
|---|---|---|---|---|
| TX | 89 | 1,018 | 1,234 | 82.50% |
| UT | 322 | 894 | 1,938 | 46.13% |
| VA | 88 | 617 | 1,250 | 49.36% |
| VT | 149 | 174 | 420 | 41.43% |
| WA | 562 | 3,414 | 7,475 | 45.67% |
| WI | 102 | 153 | 453 | 33.77% |
| WV | 37 | 1,149 | 1,925 | 59.69% |
| WY | 72 | 804 | 1,628 | 49.39% |
| Totals | 5,677 | 29,780 | 69,897 | 42.61% |

# CONCLUSIONS

The trend for hydropower development is downward because of current environmental attributes and legal and institutional constraints. After loading hydropower data for the states into HES and checking the data with the respective states, the analysis indicates that undeveloped hydropower capacity will drop by about 43%. The greatest decrease for any state is always at undeveloped sites. However, with the development of new technologies (e.g., environmentally friendly turbines, ultra-low head turbines), or changes in the energy picture (e.g., another oil crisis), hydropower production could increase.

The results of the HES are obtained in a viable, low-cost manner and can be used by developers as a preliminary means for identifying developable sites. These results provide a peerless means for identifying the undeveloped hydropower capacity essential for continued energy growth, which in turn is necessary for the continued economic strength of the United States.

Application of HES to current data significantly reduces state and regional totals for undeveloped hydropower capacity. However, an abundance of potential sites remain that are likely to be developed, given the current environmental awareness and geopolitical constraints. Strategies may need to be formulated to further assess those sites with the most potential for development.

## OBTAINING INDIVIDUAL STATE INFORMATION

The HES results for the 49 states[a] can be obtained by accessing DOE's Hydropower Program homepage on the Internet at *www.inel.gov/national/ hydropower/index.html*, writing or calling the authors, or calling the National Technical Information Service (NTIS). Hydropower Evaluation Software can be obtained by contacting the authors. Reports of DOE-sponsored projects or reports received on foreign exchange agreements can be ordered from Oak Ridge, Tennessee. Reports are available in paper, microfiche, computer disks, and magnetic tape formats.

**Telephone Orders.** (703) 487-4650. NTIS sales desk and customer services are available between 8:30 a.m. and 5:00 p.m., Eastern Standard Time.

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**For Help Tracing an Order.** Call (703)487-4650 and request the customer service option.

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[a] Delaware was not included because of few hydropower resources.

## ADDITIONAL HYDROPOWER EVALUATION SOFTWARE INFORMATION

Additional information concerning HES can be obtained by contacting Alison Conner, Jim Francfort, or Ben Rinehart at the addresses provided below. Copies of the software and the User's Manual may also be obtained from these individuals.

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# Appendix A
# Basic Site Data

# Appendix A
# Basic Site Data

The INEEL obtained the basic site data for each of the undeveloped sites from FERC's Hydropower Resource Assessment database. The following data fields were copied into HES from the FERC database for each site. The names used are the actual structural names assigned to each field in the database. (Note: "_" is used in dBASE as a separator character.)

**PROJNUM.** The number assigned to each project by FERC. When a PROJNUM is not assigned for a project, the user is strongly encouraged to provide a pseudo number (see HES User's Manual).

**PLANT_NM.** Name of the project.

**STREAM.** Name of the stream where the project is located.

**STATE_NM.** Name of the state where the project is located.

**LAT_U.** The latitude of the site.

**LONG_U.** The longitude of the site.

**CLASS_C.** The owner class code:

C = Cooperative

F = Federal

I = Industrial

M = Municipal and other nonfederal

P = Private utility

R = Private nonutility.

**OWNER_NM.** Name of the project owner.

**KWRATE_P.** The estimated potential nameplate rating (kW) of the project assigned by the Hydropower Resource Assessment database. This is not the current capacity at a developed site. It is the undeveloped capacity at a site or the additional capacity of a site that already has power generation capability.

**GEN_AA_P.** The potential Average Annual Generation (MWh) of a site estimated by Hydropower Resource Assessment database. This is not the current average annual generation at a developed site but the undeveloped capacity average annual generation at a site or the additional average annual generation of a site that already has power generation capability.

**UNITYP_P.** Type of unit:

C = Conventional

R = Reversible

Z = Missing.

**PLANTTYP.** The project type or type of operation:

CMB = Combined conventional and reversible units

DIV = Gravity diversion (powerhouse on different stream)

PDV = Pumped diversion (one-way pumped storage)

PMP = Pure (recycled) pump storage

RES = Reservoir only

ROR = Run-of-river (dam 10 ft high with minimal storage)

RRG = Reregulating

STG = Storage, conventional (dam > 10 ft high with significant storage)

TID = Tidal conventional hydropower.

**STATUS_C.** Project status code:

DJ = Disclaimer of FERC jurisdiction

EA = Exemption applied for

FA = Federally authorized

FR = Federally recommended

LE = License exception

LJ = Lack of FERC jurisdiction

MA = FERC major license application

MO = FERC major license outstanding

NA = FERC minor license application

NO = FERC minor license outstanding

PA = FERC preliminary permit application

PO = FERC preliminary permit outstanding

XX = No status

YO = FERC minor part license outstanding

ZZ = Missing.

**BASIN_NM.** The river basin where the project is located.

**CNTY_NM.** The county where the project is located.

Not all of the above 15 variables are present for each site in the Hydropower Resource Assessment database, and the information the database provided was not always accurate. Various state agencies and INEEL personnel reviewed the information in an effort to ensure the accuracy of the site information.

ATTACHMENT D1
GEOTHERMAL ENERGY ASSOCIATION
"ALL ABOUT GEOTHERMAL ENERGY – BASICS"
(NO DATE)

# Geothermal Energy Association

# "All about Geothermal Energy – Basics"

# (no date)

## ALL ABOUT GEOTHERMAL ENERGY - BASICS



**What is geothermal energy?**
Geothermal energy is defined as heat from the Earth. It is a clean, renewable resource that provides energy in the United States and around the world. It is considered a renewable resource because the heat emanating from the interior of the Earth is essentially limitless. The heat continuously flowing from the Earth's interior is estimated to be equivalent to 42 million megawatts of power.(1) The interior of the Earth is expected to remain extremely hot for billions of year to come, ensuring an inexhaustible flow of heat.

**What are the different ways in which geothermal energy can be used?**
Geothermal energy can be used for electricity production, for direct use purposes, and for home heating efficiency (through geothermal heat pumps).

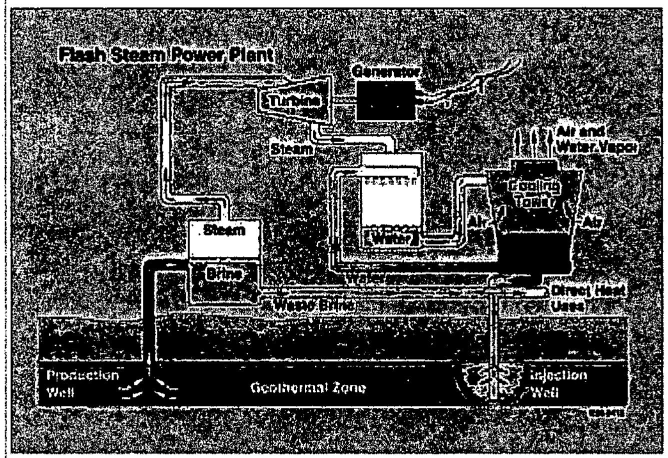
**Geothermal electricity**: To develop electricity from geothermal resources, wells are drilled into the natural hot water or steam, known as a geothermal reservoir. The reservoir collects many meters below the groundwater table. Wells bring the geothermal liquid to the surface, where it is converted at a power plant into electricity (see below for more information about the different types of geothermal electricity production).

**Direct Use**: Direct use applications utilize geothermal heat without first converting it to electricity, such as for space heating and cooling, food preparation, industrial processes, etc. People have been taking advantage of direct use applications for centuries, with documentation of early uses tracing back to ancient Roman times.

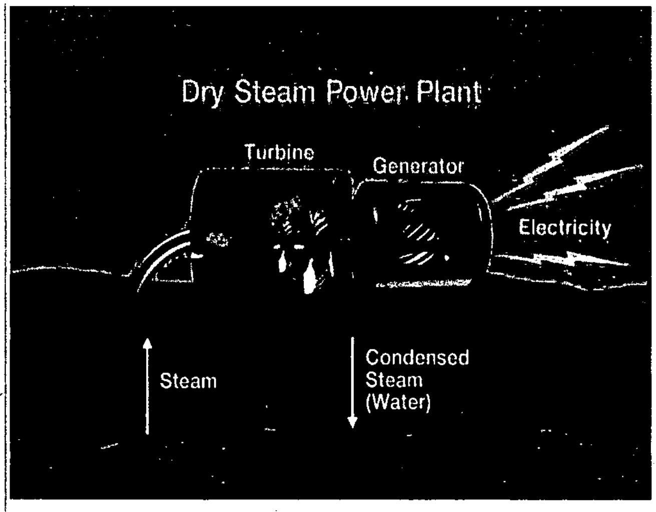
**Geothermal Heat Pumps (GHPs)**: Geothermal heat pumps are devices that take advantage of the relatively constant temperature of the Earth's interior, using it as a source and sink of heat for both heating and cooling. When cooling, heat is extracted from the space and dissipated into the Earth; when heating, heat is extracted from the Earth and pumped into the space. Geothermal heat pumps can be used anywhere on Earth, and are considered by the EPA to be one of the most efficient heating and cooling systems available. For more information about GHPs, please visit www.geo-exchange.org.

**What more can you tell me about geothermal electric power plants?**
There are four widely used types of geothermal power plants, and three types that are more experimental at this time.

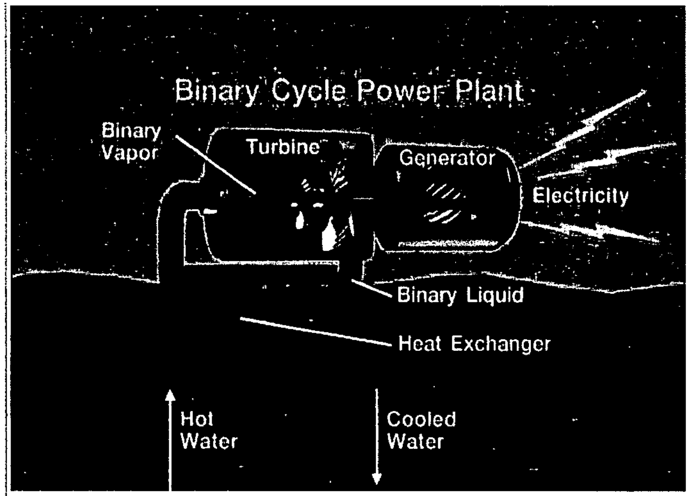
1) **Flash Power Plant**: Geothermal steam is separated in a surface vessel (steam separator) and delivered to the turbine, and the turbine powers a generator.




2) **Dry Steam Power Plant**: steam directly from the geothermal reservoir runs the turbines that power the generator, and no separation is necessary because wells only produce steam. The image below is a more simplified version than the image above.




3) **Binary Power Plant**: Recent advances in geothermal technology have made possible the economic production of electricity from lower temperature geothermal resources, at 100o C (212o F) to 150o C (302 o F). Known as binary geothermal plants, these facilities reduce geothermal energy's already low emission rate to near zero. In the binary process, the geothermal water heats another liquid, such as isobutane, that boils at a lower temperature than water. The two liquids are kept completely separate through the use of a heat exchanger used to transfer the heat energy from the geothermal water to the "working-fluid." The secondary fluid vaporizes into gaseous vapor and (like steam) the force of the expanding vapor turns the turbines that power the generators.




4) **Flash/Binary Combined Cycle**: This type of plant, which uses a combination of flash and binary technology, has been used effectively to take advantage of the benefits of both technologies. In this type of plant, the flashed steam is first converted to electricity with a backpressure steam turbine, and the low-pressure steam exiting the backpressure turbine is condensed in a binary system.

For more information about the above four types of power plants, access GEA's Environmental Guide.

5) **Enhanced Geothermal System or Hot Dry Rock** (not commercial): Producing electricity from hot dry rock requires fracturing hot rocks, pumping water into and out of the hot rock, and generating electricity. Research applications of this technology are being pursued in the US, France, Australia, and elsewhere. They are not yet economically viable or even near-commercial.

6) **Kalina System**: A small demonstration powerplant using the "Kalina" cycle operated as part of Iceland's Husavik GeoHeat Project. The Kalina cycle uses an ammonia-water mixed working fluid that claims higher efficiency. This system is not considered commercial and reports on the demonstration are not available.

7) **Rankine Cycle System**: The U.S. Department of Energy is proposing to demonstrate a remote geothermal power system at Chena Hot Springs in Alaska using the Rankine Cycle. In this system, a compressor/motor module is expected to be converted into a turbogenerator by simply reversing the flow direction. This is a demonstration project, and this system is not considered commercial. (For more information about the Chena Hot Springs Project, click here)

**What is a baseload resource?**

A baseload resource operates most efficiently at a relatively constant level of generation and is not limited by changes in weather patterns or other factors. Geothermal relies on a readily available, constant source of heat for generation, and is therefore considered a baseload resource. Other resources such as coal, oil, and natural gas are also considered baseload resources.

Because some renewable energy sources can only operate under favorable weather conditions, they are often considered to be limited in their ability to meet the looming large-scale power needs of the twenty-first century. Geothermal, however, has the potential to provide reliable sources of electricity while still offering significantly lower emissions levels than fossil fuel sources and avoiding problems of radioactive waste disposal.

**What is "availability factor" and "capacity factor"?**

Availability factor is measured as the number of hours that a power plant is available to produce power divided by the total hours in a set time period, usually a yea. Geothermal's availability factor is about 95 percent. This means that geothermal electric-power plants are available for generation 95 percent of any given time, based on decades of observations by plant operators.(2)

While availability factor measures a plant's potential for use, capacity factor measures the amount of real time during which a facility is used. To understand availability and capacity factor, consider the analogy of a working car. When a car is not in use, but is free from defects and available to be used, we may speak of the car's availability factor. When the car is actually being driven, we may speak of the car's capacity factor. Geothermal's capacity factor ranges from 89 to 97 percent, depending upon the type of geothermal system in place.

**Where can I find more detailed information about geothermal energy?**

The Geothermal Energy Association (GEA) has recently produced several updated, comprehensive documents on the issues of cost, employment, and the environment, all of which can be found at the GEA website. The environmental paper also includes more detailed basic information about geothermal energy. Click below to access the following links:

**Factors Affecting Cost of Geothermal Power Development**
**Geothermal Industry Employment - Survey Results and Analysis September 2005**
**A Guide to Geothermal Energy & The Environment**

If you are looking for a current update about geothermal energy, renewable energy, and global warming issues in the U.S., the world, and in our nation's capitol, take a look at GEA's latest Update.

For the truths behind common geothermal myths, take a look at our Mythbusters section.

For the list of useful links with more information and resources related to geothermal energy, click here.

(1)Energy and Geosciences Institute, University of Utah. Prepared by the U.S. Geothermal Industry for the Renewable Energy Task Force (1997), Briefing on Geothermal Energy. Washington, D.C.
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Geothermal Energy Association - Washington, DC - USA

# U.S. Department of Energy
# Energy Efficiency and Renewable Energy
# Geothermal Technologies Program

# "Geothermal Power Plants"

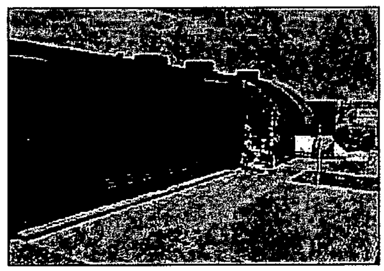
## January 2006

Geothermal Basics
Geothermal Resource Map
Research & Development
R&D Successes
Applications
Power Plants
Direct Use
Heat Pumps
Impacts
Laws & Standards

Printable Version

EERE Information Center

# Geothermal Power Plants



Geothermal power plant in the Imperial Valley, California.

There are three geothermal power plant technologies being used to convert hydrothermal fluids to electricity. The conversion technologies are dry steam, flash, and binary cycle. The type of conversion used depends on the state of the fluid (whether steam or water) and its temperature. Dry steam power plants systems were the first type of geothermal power generation plants built. They use the steam from the geothermal reservoir as it comes from wells, and route it directly through turbine/generator units to produce electricity. Flash steam plants are the most common type of geothermal power generation plants in operation today. They use water at temperatures greater than 360°F (182°C) that is pumped under high pressure to the generation equipment at the surface. Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units.

**U.S. Geothermal Power Plants**

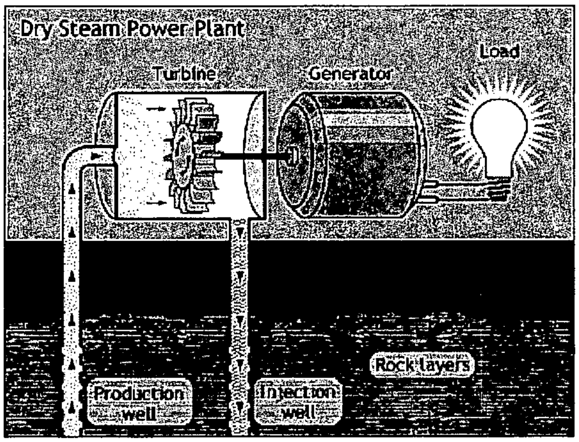
**Power plant photographs**

- Casa Diablo
- Navy 1
- The Geysers
- Hawaii
- Honey Lake
- Imperial Valley
- Nevada
- Utah

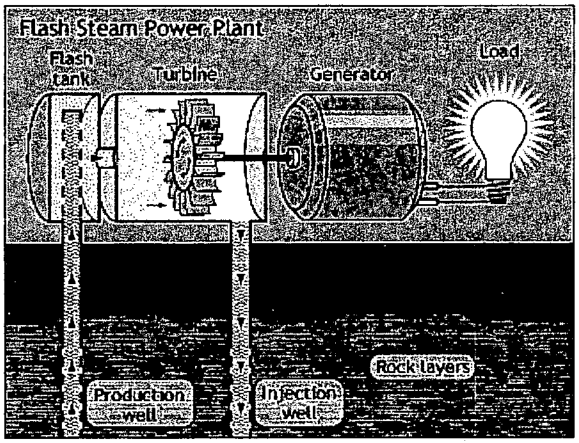
**Dry Steam Power Plants**

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels!) This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904, and is still very effective. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal power. These plants emit only excess steam and very minor amounts of gases.

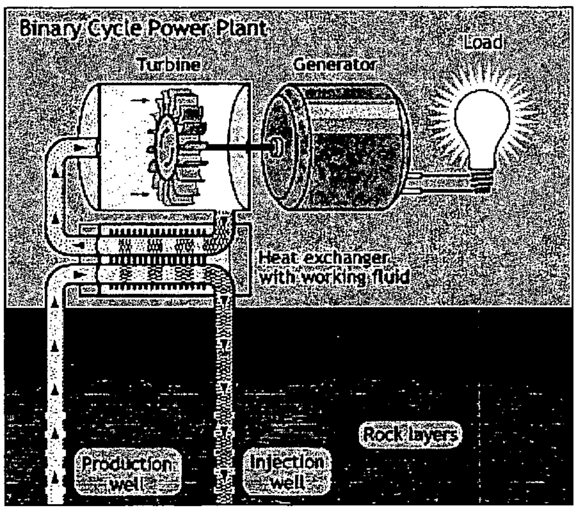
Dry steam power plants at The Geysers in California.




**Flash Steam Power Plants**
Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank to extract even more energy.




**Binary-Cycle Power Plants**
Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.




## The Future of Geothermal Electricity
Steam and hot water reservoirs are just a small part of the geothermal resource. The Earth's magma and hot dry rock will provide cheap, clean, and almost unlimited energy as soon as we develop the technology to use them. In the meantime, because they're so abundant, moderate-temperature sites running binary-cycle power plants will be the most common electricity producers.

Before geothermal electricity can be considered a key element of the U.S. energy infrastructure, it must become cost-competitive with traditional forms of energy. The U.S. Department of Energy is working with the geothermal industry to achieve $0.03 to $0.05 per kilowatt-hour. We believe the result will be about 15,000 megawatts of new capacity within the next decade.

## DOE Support

The U.S. Department of Energy recognizes the strategic value of geothermal electricity, and supports its development in several ways through its Geothermal Technology Development Program. First, it works with Congress to ensure support for geothermal energy and renewables in general. Second, it sponsors millions of dollars in research and development at national laboratories and universities. Investigators are working on issues in exploration, geochemistry, drilling, resource usage, and equipment operation. Third, through its GeoPowering the West initiative, it works with state and local officials and other stakeholders to identify and overcome regulatory and institutional barriers to geothermal power development.

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Content Last Updated: 01/19/2006

ATTACHMENT D3
U.S. DEPARTMENT OF ENERGY
ENERGY EFFICIENCY AND RENEWABLE ENERGY
GEOTHERMAL TECHNOLOGIES PROGRAM
"U.S. GEOTHERMAL RESOURCE MAP"
JANUARY 2006

# U.S. Department of Energy
# Energy Efficiency and Renewable Energy
# Geothermal Technologies Program

# "U.S. Geothermal Resource Map"

## January 2006

# U.S. Geothermal Resource Map

The geothermal resources map of the United States below shows the estimated subterranean temperatures at a depth of 6 kilometers. To determine the Earth's internal temperature at any depth below the capabilities of normal well drilling, multiple data sets are synthesized. The data used for this figure are: thermal conductivity, thickness of sedimentary rock, geothermal gradient, heat flow, and surface temperature.

ATTACHMENT E1
REPP-CREST
"WHAT CAN A DASH OF BIOMASS DO"
(NO DATE)

# REPP-CREST

# "What Can a Dash of Biomass Do?"

## (no date)

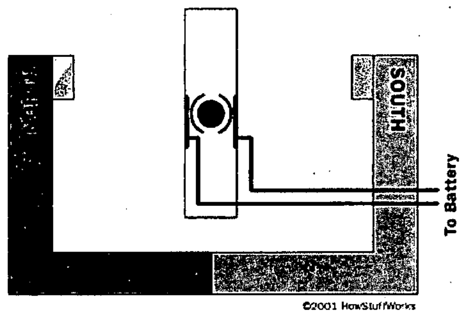
# What Can A Dash of Biomass Do?

Biomass can be used in a variety of energy conversion processes in order to yield power, heat, steam and fuel.

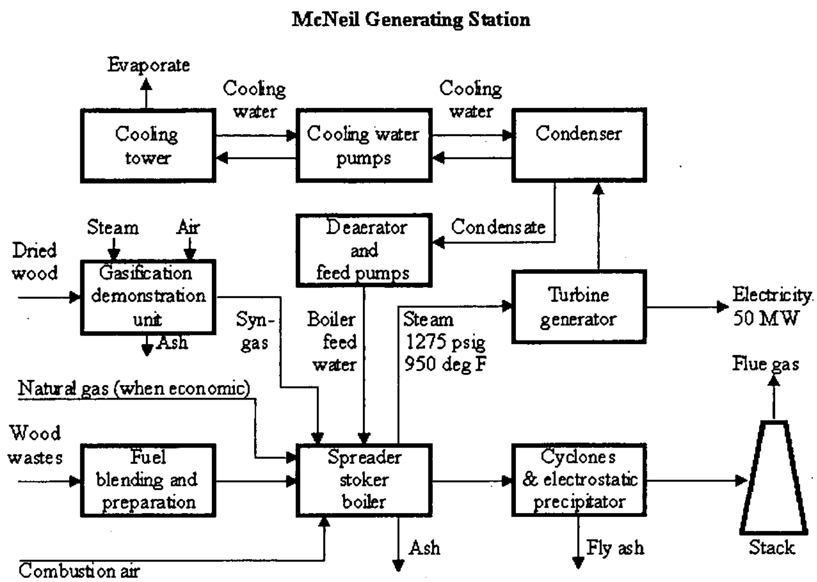
## Power

Biopower can be generated any number of ways, which are detailed in Chapter 4 of this report. Most biopower is generated through a co-firing method or with a traditional steam turbine. In any system, a turbine is stimulated, either by steam or gas. The turbine is connected to a generator which contains magnets which are positioned to ensure repellance, meaning the polar opposites are unable to attract to one another. When callibrated correctly the magnets inside the generator generate a magnetic field. A conductor rod will be passed through the magnetic field, causing electrons in the conductor rod will flow freely thereby creating an electrical current.

REPP
1612 K Street, NW
Suite 202
Washington, DC 20006




The conducting rod is metal, often copper, wound into tight coils to maximize the amount of electricity created. The ends of the coils are connected to an outside transmission station and eventually fed to the grid [1]. Below is a flow chart of the McNeil Generating System in Burlington, Vermont; one of the oldest online biomass generating power plants in the country. It was founded in 1986 and uses woodchips as its primary fuel.

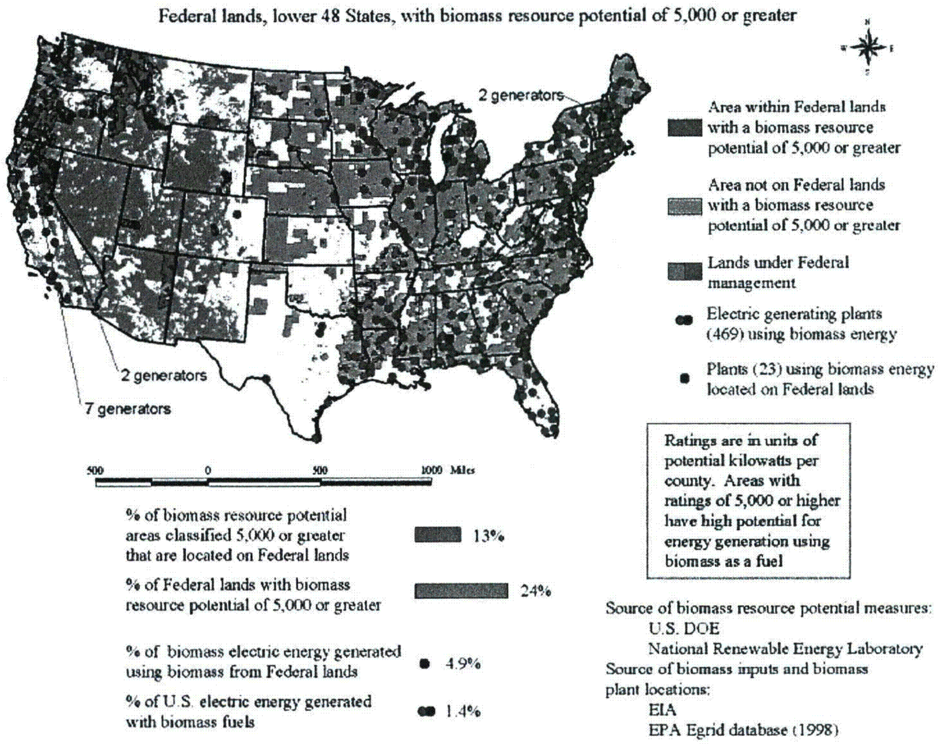



According to the Energy Efficiency and Renewable Energy Office of the Department of Energy, today's biopower plants have a combined capacity of 10.3 gigawatts. With the average home requiring 3 to 4 Kw, today's biopower plants generate enough electricity to supply over 34 million homes with electricity. Astonishingly, this is only 1.4% of our nation's energy capacity [2]! Biomass is expected to supply up to 30% of our nation's power by 2020 [3].

Back to Top

## Heat and Steam

The same power plants that produce power also yield useful steam and heat which can be used to heat residential and commercial buildings. The process of capturing the heat and the steam that is released from the process is called combined-heat-and-power or CHP. Taking advantage of these products can improve the efficiency of the operation by over 35%. Pulp and paper mills in the Southeast, Northeast and Great Lakes region of the U.S. already generate power, steam and heat from biomass. Finland hosts CHP operations that heat homes and businesses. Below is a map of the United States which shows where biomass can hope to be harvested to aid in one of the energy sectors.




Back to Top

## Traditional Heat

Of course, biomass such as wood in fireplaces and kilns also heat homes and provide energy for cooking. Biomass is the oldest known source of renewable energy—humans have been using it since we discovered fire—and it has high energy content. The energy content of dry biomass ranges from 7,000 Btu/lb for straws to 8,500 Btu/lb for wood [4]. Below is a chart that lists the heat content of different types of biomass, as supplied by the Energy Information Administration. For perspective, it takes about 10,000 Btu to cook a meal. Alternatively, one gallon of gasoline is equivalent to 124,884 btu.

Table B6. Average Heat Content of Selected Biomass Fuels

| Fuel Type | Heat Content | Units |
|---|---|---|
| Agricultural Byproducts | 8.248 | Million Btu/Short Ton |
| Black Liquor | 11.759 | Million Btu/Short Ton |
| Digester Gas | 0.619 | Million Btu/Thousand Cubic Feet |
| Landfill Gas | 0.490 | Million Btu/Thousand Cubic Feet |
| Methane | 0.941 | Million Btu/Thousand Cubic Feet |
| Municipal Solid Waste | 9.945 | Million Btu/Short Ton |
| Paper Pellets | 13.029 | Million Btu/Short Ton |
| Peat | 8.000 | Million Btu/Short Ton |
| Railroad Ties | 12.618 | Million Btu/Short Ton |
| Sludge Waste | 7.512 | Million Btu/Short Ton |
| Sludge Wood | 10.071 | Million Btu/Short Ton |
| Solid Byproducts | 25.830 | Million Btu/Short Ton |
| Spent Sulfite Liquor | 12.720 | Million Btu/Short Ton |
| Tires | 26.865 | Million Btu/Short Ton |
| Utility Poles | 12.500 | Million Btu/Short Ton |
| Waste Alcohol | 3.800 | Million Btu/Barrel |

| | | |
|---|---|---|
| Wood/Wood Waste | 9.961 | Million Btu/Short Ton |

Source: Energy Information Administration, Form EIA-860B (1999), "Annual Electric Generator Report - Nonutility 1999."

Back to Top

## Fuel

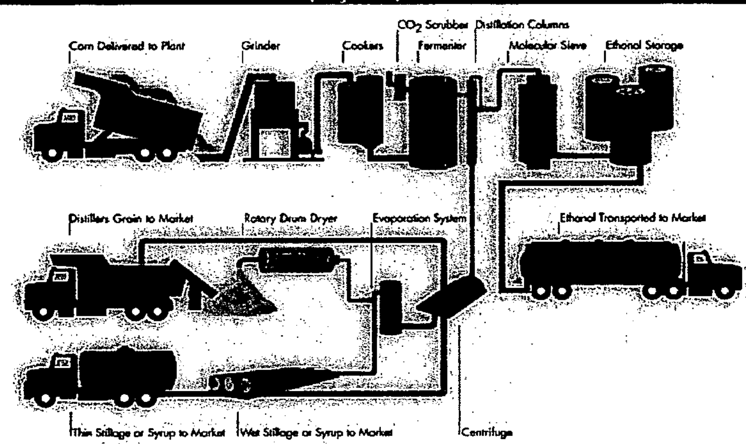
Solid biomass can also be converted into liquid fuels that power cars, engines including those in diesel generators, and even industrial operations. Methanol, ethanol, biofuel and biodiesel can all be created from biomass. Methanol is a wood alcohol which is not as efficient as gasoline as a fuel and is mostly used in antifreeze and in the production of other chemicals, such as formaldehyde [5]. For more information on methanol, visit the Methanol Institute.

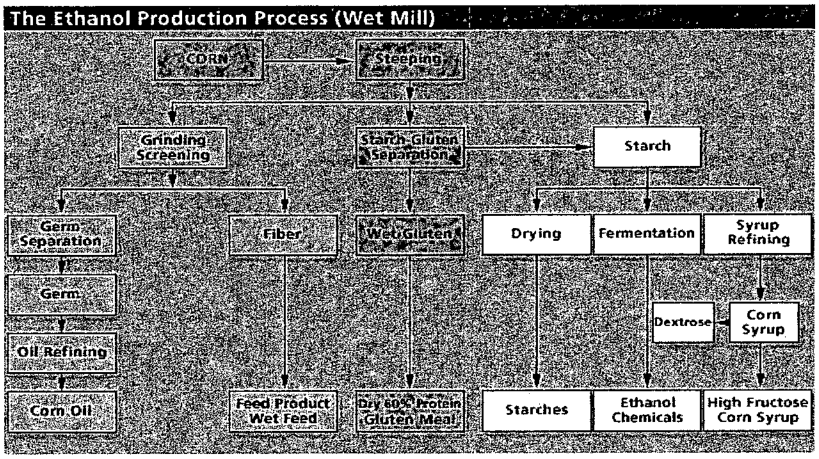
Ethanol, or ethyl alcohol, is a clear, colorless, flammable oxygenated fuel currently added as a gasoline additive in 30 states to increase octane and lower tailpipe greenhouse gas emissions [6]. It is biodegradable and water soluble. Ethanol (which comes from cellulosic biomass such as corn) is produced through fermentation at either a dry mill or at a wet mill, both displayed below. The dry mill process is simpler than the wet mill process. The wet mill breaks the corn into its components and processes each separately. In addition to ethanol, both processes also create distiller's grain, which is fed to farm animals.

Up to 24% ethanol can be added to gasoline before engine modifications are necessary. A blend known as E85, which is 85% ethanol and 15% gasoline, can be used to power flexible fuel vehicles (FFVs). Many cars on the market today are already built to run on E85. Brazil has had much success converting nearly all of its vehicles to run on E85 made from sugar. It even announced that it would stop importing oil by the end of 2006 [7].

Ethanol has a better environmental profile than gasoline as measured at both the production facility and the tailpipe. Ethanol production plants produce less carbon dioxide, methane and particulates than gasoline refineries, which help meet clean air standards. A blend of 10% ethanol, or E10, yields a 26% reduction in greenhouse gases when compared to gasoline alone [8]. The Senate version of The Energy Policy Act of 2005 includes an ethanol provision that would boost ethanol production to 8 billion gallons from the current level of 3.9 billion gallons by 2012 [9]. For more information on ethanol, please see visit the Renewable Fuels Association website.

**The Ethanol Production Process (Dry Mill)**






Both Diagrams courtesy of the Renewable Fuels Association, Production Processes

Biodiesel is the result of combining alcohol (including ethanol) with oil extracted from soybeans, rapeseed, animal fats, or other biomass. Biodiesel is an American-made fuel that can be produced from any fat or vegetable oil, such as soybean oil often sold as 2% (B2) or 10% (B10) blends with diesel. "Concerns that biodiesel can't perform or flow well in adverse weather are based on myths," according to Kelly Strebig, a research engineer for the University of Minnesota Center for Diesel Research at Minneapolis, Minnesota [10]. Biodiesel performs very well in cold climates and is being used in airport snowplows and school buses according to an article a Missouri paper. It also burns much cleaner than traditional diesel, making it more environmentally friendly. Seen below are two liters of biodiesel. Some biodiesel companies are even contracting with restaurants to make biodiesel from their used vegetable oils.

Back to Top

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[3] "Economic Analysis Highlights Major Economic Impact of 8 Billion Gallon RFS." May 23, 2005. Press Release of the Renewable Fuels Association. Available Online at www.ethanolrfa.org. June 20, 2005.

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[6] "Economic Analysis Highlights Major Economic Impact of 8 Billion Gallon RFS." May 23, 2005. Press Release of the Renewable Fuels Association, in reference to the footnote listed below. Available Online at www.ethanolrfa.org. June 20, 2005

[7] Jim Landers. "Ethanol's Sweet Allure." The Dallas Morning News. June 10, 2005.

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[11] Environmental News Network. www.enn.com

ATTACHMENT E2
STATE OF OREGON
RENEWABLE RESOURCES
"BIOMASS ENERGY: COST OF PRODUCTION"
(NO DATE)

# State of Oregon
# Renewable Resources

# "Biomass Energy: Cost of Production"

## (no date)

Renewable Resources



## Biomass Energy: Cost of Production

### Combustion and Gasification Facilities

Using conventional combustion technology without cogeneration, the estimated cost to generate electricity from biomass ranges from 5.2 to 6.7 cents per kilowatt-hour in Oregon and the Pacific Northwest. Actual costs would vary depending on financing, location, system design and fuel cost. In the future, new gasification technologies may lower the cost of generating electric power from waste wood and other biomass fuels. In contrast, the estimated cost of generating electricity from a new natural gas-fired, combined-cycle power plant is 2.8 cents per kilowatt-hour.

For biomass-fueled power plants, reliance on variable supplies of forest and agricultural residues means that a continuous supply of fuel may be uncertain. Generation of electric power requires large quantities of biomass. Fuel transportation, storage and handling costs are a significant part of the costs of biomass energy production. One strategy to deal with fuel supply uncertainty is to design the facility to handle multiple biomass fuel types. Future expansion of the biomass power market may require the development of a feedstock supply system based on large-scale production of biomass fuel from energy crops.

Heat is a byproduct of producing electric power using biomass. Steam produced in a biomass-fired boiler can both generate electric power and supply industrial process heat. Cogeneration is the combined production of electricity and process heat. In a cogeneration power plant, sale of steam to an industrial user can offset the cost of producing electric power from biomass.

### Biogas Facilities

Naturally-occurring anaerobic digestion in solid waste landfills produces methane, which can be used to generate electricity. In Oregon, generating electricity from landfill gas is cost-competitive with natural gas power generation. The estimated cost is 2.9 to 3.6 cents per kilowatt-hour. Sale of power generated from landfill gas can offset the cost of equipment needed otherwise to collect and flare methane produced in landfills.

At wastewater treatment plants that use anaerobic digesters as part of the treatment system, methane is a by-product of the treatment process. Wastewater treatment plants can use digester gas to generate electricity and offset the cost of buying power from the local utility. Because treatment plants receive revenue for treating wastewater, these plants have a negative feedstock cost for power generation from their methane gas.

The estimated cost of producing electric power from anaerobic digestion of animal manure is 3.7 to 5.4 cents per kilowatt-hour. Digester technology can be part of an integrated facility that produces electricity and heat, eliminates waste disposal and odor problems and helps to protect the environment.

The cost of a farm-site manure digester depends on local site conditions and the number of animals on the farm. A plug-flow digester designed to process the manure of 500 dairy cows will have capital costs in the range of $230,000 to $260,000. Electricity and heat generated from digester gas reduce farm energy costs. Liquid and fiber digester residues have value as fertilizers and soil amendments. The costs of building and operating the digester can be recovered from sales of these products and from energy cost savings.

Dairy farm runoff presents an environmental hazard from poorly managed animal manure. Runoff can pollute local streams and spread disease. Anaerobic digestion protects surface streams from contamination because the process destroys harmful microorganisms that are carried in manure. Although it is expensive to construct a manure digester, there is also a cost for alternative manure management and cleanup measures that produce no income for the dairy operator.

### Ethanol Production

The cost of producing ethanol varies with the cost of the feedstock used and the scale of production. Approximately 85 percent of ethanol production capacity in the United States relies on corn feedstock. The cost of producing ethanol from corn is estimated to be about $1.10 per gallon. Although there is currently no commercial production of ethanol from cellulosic feedstocks such as agricultural wastes, grasses and wood, the estimated production cost using these feedstocks is $1.15 to $1.43 per gallon.

ATTACHMENT E3
U.S. DEPARTMENT OF AGRICULTURE AND U.S. DEPARTMENT OF ENERGY
"BIOMASS AS A FEEDSTOCK FOR A BIOENERGY AND BIOPRODUCTS INDUSTRY: THE TECHNICAL FEASIBILITY FOR A BILLION-TON ANNUAL SUPPLY"
APRIL 2005

# U.S. Department of Agriculture and U.S. Department of Energy

# Joint Study

# "Biomass as Feedstock for A Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply"

**ORNL/TM-2005/66**

**April 2005**

# Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

April 2005

U.S. Department of Energy

U.S. Department of Agriculture

# 2. The Biomass Feedstock Resource Base

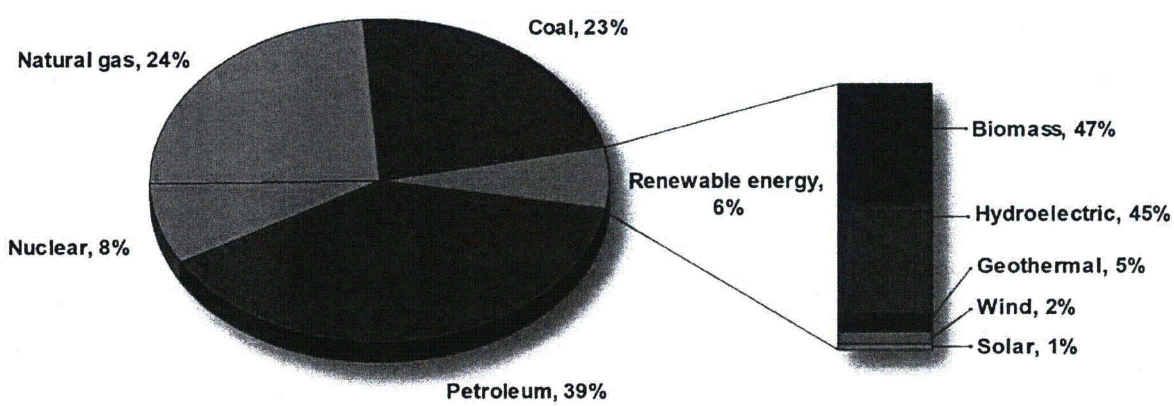
## 2.1 Land Resources for Biomass Production

The land base of the United States encompasses nearly 2,263 million acres, including the 369 million acres of land in Alaska and Hawaii. About 33 percent of the land area is classified as forest land, 26 percent as grassland pasture and range, 20 percent as cropland, 8 percent as special uses (e.g., public facilities), and 13 percent as miscellaneous uses such as urban areas, swamps, and deserts (Vesterby and Krupa, 2001; Alig et al., 2003). About one-half of this land has some potential for growing biomass. This percentage is nearly 60 percent without Alaska and Hawaii.

Currently, slightly more than 75 percent of biomass consumption in the United States (about 142 million dry tons) comes from forestlands. The remainder (about 48 million dry tons), which includes biobased products, biofuels and some residue biomass, comes from cropland.

## 2.2 Biomass Feedstock Consumption

In 2003, biomass contributed nearly 2.9 quadrillion BTU (quad) to the nation's energy supply, nearly 3 percent of total U.S. energy consumption of about 98 quads (EIA, 2004a). At 47 percent of total renewable energy consumption, biomass is the single largest renewable energy resource, recently surpassing hydropower (Figure 2). More than 50 percent




| Biomass Consumption | Million dry tons/year |
|---|---|
| Forest products industry | |
| Wood residues | 44 |
| Pulping liquors | 52 |
| Urban wood and food & other process residues | 35 |
| Fuelwood (residential/commercial & electric utilities) | 35 |
| Biofuels | 18 |
| Bioproducts | 6 |
| **Total** | **190** |

- Forestlands and agricultural lands contribute 190 million dry tons of biomass - 3% of America's current energy consumption.

Source: EIA, 2004a & b

Figure 2: Summary of biomass resource consumption

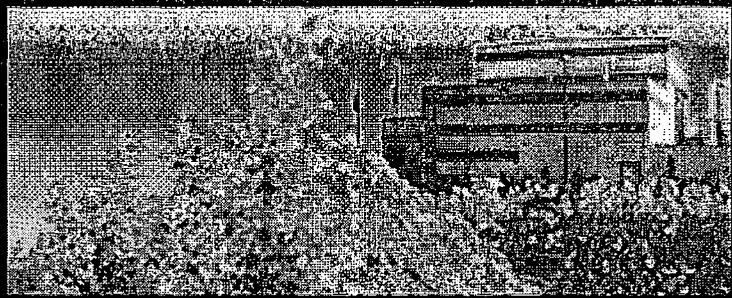
ATTACHMENT E4
U.S. DEPARTMENT OF ENERGY
ENERGY EFFICIENCY AND RENEWABLE ENERGY
BIOPOWER FACT SHEET
"BIOMASS COFIRING: A RENEWABLE ALTERNATIVE FOR UTILITIES"
JUNE 2000

# U.S. Department of Energy
# Energy Efficiency and Renewable Energy

# Biopower Fact Sheet
# "Biomass Cofiring: A Renewable Alternative for Utilities"
# DOE/GO-102000-1055

## June 2000

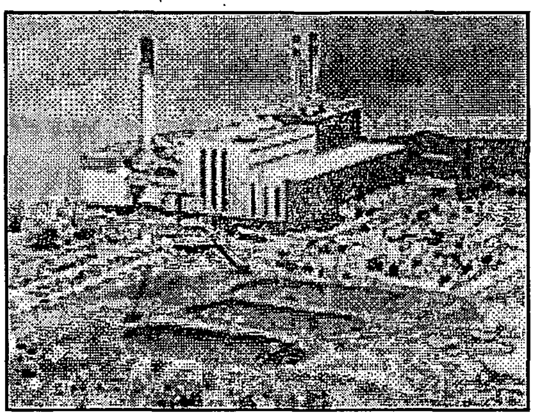
# Biomass Cofiring: A Renewable Alternative for Utilities



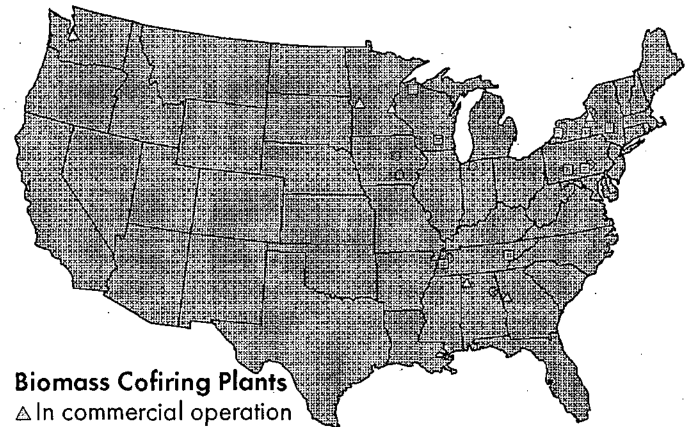
## Biomass Cofiring

Cofiring is a near term, low-cost option for efficiently and cleanly converting biomass to electricity by adding biomass as a partial substitute fuel in high-efficiency coal boilers. It has been demonstrated, tested, and proved in all boiler types commonly used by electric utilities. There is little or no loss in total boiler efficiency after adjusting combustion output for the new fuel mixture. This implies that biomass combustion efficiency to electricity would be close to 33%-37% when cofired with coal. Extensive demonstrations and tests also confirmed that biomass energy can provide as much as 15% of the total energy input with only feed intake system and burner modifications. The opportunities for biomass cofiring are great because large scale coal-powered boilers represent 310 gigawatts of generating capacity. Cofiring biomass with coal offers several environmental benefits. Cofiring reduces emissions of carbon dioxide, a greenhouse gas that can contribute to the global warming effect (see picture on the reverse side). Also, biomass contains significantly less sulfur than most coal. This means that cofiring will reduce emissions of sulfurous gases such as sulfur dioxide that will then reduce acid rain. Early test results with woody biomass cofiring showed a reduction potential as great as 30% in oxides of nitrogen, which can cause smog and ozone pollution.

During the 1990s, electric utilities across the country implemented biomass cofiring demonstrations and commercial operations. Five power plants started the year 2000 regularly cofiring coal with wood residue products. Another plant closed in 1998 after 10 years of operating successfully with biomass. Five additional plants were planning tests in the year 2000. More than 10 years of experience produced information that is now available on the technical and economic performance of cofiring biomass with coal.



The Dunkirk Power Station will use hybrid willow grown by New York farmers to generate renewable electricity.




## Economic Considerations

Cofiring economics depends on location, power plant type, and the availability of low-cost biomass fuels. A typical cofiring installation includes modifications to the fuel-handling and storage systems and possibly the burner to accommodate biomass. Costs can increase significantly if wood needs to be dried, size needs to be reduced, or the boiler requires a separate feeder. Retrofit costs range from $150 to $300 per kilowatt (kW) of biomass generation in pulverized coal boilers. Cyclone boilers offer the lowest cost opportunities, as low as $50 per kW.

Fuel supply is the most important cost factor. Costs for biomass fuels depend on many factors such as climate, closeness to population centers, and the presence of industries that handle and dispose of wood. Low price, low shipping cost, and dependable supply are paramount. Usually the cost of biomass fuels must be equal to or less than the cost of coal per unit of heat for cofiring to be economically successful. Some utilities reduce fuel costs by cofiring with biomass; the Tennessee Valley Authority, for example, estimates that it will save $1.5 million per year in fuel costs cofiring with biomass at its Colbert plant.

## Technical Challenges

Several technical questions about fuel feed, boiler chemistry, and ash deposition and disposal have been raised and are approaching resolution. Losses in boiler efficiency caused by cofiring are small and are usually due to high moisture content in the biomass fuels. A consensus

ATTACHMENT E5
U.S. DEPARTMENT OF ENERGY
ENERGY INFORMATION ADMINSTRATION
FORECASTS
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# U.S. Department of Energy
# Energy Information Administration

# Forecasts
# "Biomass for Electricity Generation"

## November 2002

# Biomass for Electricity Generation

by Zia Haq

This paper examines issues affecting the uses of biomass for electricity generation. The methodology used in the National Energy Modeling System to account for various types of biomass is discussed, and the underlying assumptions are explained. The Energy Information Administration's estimation of biomass resources shows that there are 590 million wet tons of biomass available in the United States on an annual basis; 20 million wet tons (enough to supply about 3 gigawatts of capacity) are available today at prices of $1.25 per million Btu or less. The average price of coal to electric utilities in 2001 was $1.23 per million Btu.

## Introduction

The U.S. economy uses biomass-based materials as a source of energy in many ways. Wood and agricultural residues are burned as a fuel for cogeneration of steam and electricity in the industrial sector. Biomass is used for power generation in the electricity sector and for space heating in residential and commercial buildings. Biomass can be converted to a liquid form for use as a transportation fuel, and research is being conducted on the production of fuels and chemicals from biomass. Biomass materials can also be used directly in the manufacture of a variety of products.

In the electricity sector, biomass is used for power generation. The Energy Information Administration (EIA), in its *Annual Energy Outlook 2002 (AEO2002)* reference case,[1] projects that biomass will generate 15.3 billion kilowatthours of electricity, or 0.3 percent of the projected 5,476 billion kilowatthours of total generation, in 2020. In scenarios that reflect the impact of a 20-percent renewable portfolio standard (RPS)[2] and in scenarios that assume carbon dioxide emission reduction require- ments based on the Kyoto Protocol,[3] electricity generation from biomass is projected to increase substantially. Therefore, it is critical to evaluate the practical limits and challenges faced by the U.S. biomass industry. This paper examines the range of costs, resource availability, regional variations, and other issues pertaining to biomass use for electricity generation. The methodology by which the National Energy Modeling System (NEMS) accounts for various types of biomass is discussed, and the underlying assumptions are explained.

A major challenge in forecasting biomass energy growth is estimating resource potential. EIA has compiled available biomass resource estimates from Oak Ridge National Laboratory (ORNL),[4] Antares Group, Inc.,[5] and the U.S. Department of Agriculture (USDA).[6] This paper discusses how these data are used for forecasting purposes and the implications of the resulting forecasts, focusing on biomass used in grid-connected electricity generation applications.

## Background

Biomass has played a relatively small role in terms of the overall U.S. energy picture, supplying 3.2 quadrillion Btu of energy out of a total of 98.5 quadrillion Btu in 2000.[7] The vast majority of it is used in the pulp and paper industries, where residues from production processes are combusted to produce steam and electricity. The industrial cogeneration sector consumed almost 2.0 quadrillion Btu of biomass in 2000. Outside the pulp and paper industries, only a small amount of biomass is used to produce electricity. There are power plants that combust biomass exclusively to generate electricity and facilities that mix biomass with coal (biomass co-firing plants). The electricity generation sector (excluding cogenerators) consumed about

0.7 quadrillion Btu of biomass in 2000. The remaining 0.5 quadrillion Btu of biomass was consumed in the residential and commercial sectors in the form of wood consumption for heating buildings. To put these numbers in perspective, the electricity generation sector consumed 20.5 quadrillion Btu of coal and 6.5 quadrillion Btu of natural gas in 2000.[8]

Biomass played a significant role among renewables in 2000, however, providing 48 percent of the energy coming from all renewable sources. In EIA's *AEO2002* reference case projection, growth in demand for biomass is expected to be modest. In the *AEO2002* high renewables case projection, the demand for biomass is higher than in the reference case due to assumptions of reduced initial capital cost[9] and increased supply. In aggressive RPS cases,[10] the demand for biomass is much higher than projected even in the high renewables case.

Among many reasons for increased biomass utilization in those cases, environmental benefits are the most important. Compared with coal, biomass feedstocks have lower levels of sulfur or sulfur compounds.[11] Therefore, substitution of biomass for coal in power plants has the effect of reducing sulfur dioxide ($SO_2$) emissions. Demonstration tests have shown that biomass co-firing with coal[12] can also lead to lower nitrogen oxide ($NO_x$) emissions. Perhaps the most significant environmental benefit of biomass, however, is a potential reduction in carbon dioxide ($CO_2$) emissions.

A closed-loop process is defined as a process in which power is generated using feedstocks that are grown specifically for the purpose of energy production. Many varieties of energy crops are being considered, including hybrid willow, switchgrass, and hybrid poplar. If biomass is utilized in a closed-loop process, the entire process (planting, harvesting, transportation, and conversion to electricity) can be considered to be a small but positive net emitter of $CO_2$. It is not precisely a net zero emission process in a life-cycle sense, because there are $CO_2$ emissions associated with the harvesting, transportation, and feed preparation operations (such as moisture reduction, size reduction, and removal of impurities). However, those emissions are not the result of combustion of biomass but result instead from fuel consumption (mostly petroleum and natural gas) for harvesting, transportation, and feed preparation operations.

Although biomass-based generation is assumed to yield no net emissions of $CO_2$ because of the sequestration of biomass during the planting cycle, there are environmental impacts. Wood contains sulfur and nitrogen, which yield $SO_2$ and $NO_x$ in the combustion process. However, the rate of emissions is significantly lower than that of coal-based generation. For example, per kilowatthour generated, biomass integrated gasification combined-cycle (BIGCC) generating plants can significantly reduce particulate emissions (by a factor of 4.5) in comparison with coal-based electricity generation processes.[13] $NO_x$ emissions can be reduced by a factor of about 6 for dedicated BIGCC plants compared with average pulverized coal-fired plants.[14]

## Biomass Technologies for Electricity Generation

Both dedicated biomass and biomass co-firing are used in the electricity generation sector. New dedicated biomass capacity is represented in NEMS as BIGCC technology. It is assumed that hot gas filtration will be used for gas cleanup purposes in this technology. Hot gas cleanup technology is relatively new, and the U.S. Department of Energy (DOE) and many industrial partners are conducting tests to demonstrate the technology. The alternative to hot gas cleaning is low-temperature gas cleaning. In low-temperature cleaning the gas is quenched with water, and particulates are removed in a series of cyclone vessels. There are advantages and disadvantages associated with both processes.

The advantages of cold gas cleaning are that it is commercially available, the capital cost is relatively low, and the systems are easier to operate than hot gas cleanup systems. The disadvantages of cold gas cleanup are that the cooling process, the cold gas cleanup system, and fuel gas recompression systems reduce the overall process efficiency by up to 10 percent. The gas turbines downstream of the gasifier require the gas at high temperatures and pressure, and therefore the gas that has just undergone cooling for cleanup purposes must be repressurized and reheated in order to conform to gas turbine inlet specifications. The advantages of the newer hot gas cleanup technology are that it allows the process to be operated at higher efficiencies and it generates less waste water than the cold gas cleanup processes. The disadvantages of the hot gas cleanup technology are that operational experience is limited, it has higher costs, and it adds complexity to the process; however, it is considered to be the technologically more advanced choice for new dedicated biomass plants.

The McNeil Generating Station demonstration project in Burlington, Vermont, is an example of a biomass gasification plant. It has a capacity of 50 megawatts and supplies electricity to the residents of the City of Burlington. This is an existing wood combustion facility whose feedstock is waste wood from nearby forestry operations, including forest thinnings and discarded wood pallets. To this existing wood combustion facility a low-pressure wood gasifier has been added that is capable of converting 200 tons per day of wood chips into fuel gas. The fuel gas, fed directly into the existing boiler (Figure 1) augments the McNeil Station's capacity by an additional 12 megawatts. The system was designed and constructed in 1998 and attained fully operational status in August 2000.

In addition to the Vermont project, DOE has funded five new advanced biomass gasification research and development projects beginning in 2001. Emery Recycling in Salt Lake City, Utah, will test new IGCC and integrated gasification and fuel cell (IGFC) concepts based on a new gasifier that uses segregated municipal solid waste, animal waste, and agricultural residues. Sebesta Blomberg in Roseville, Minnesota, has begun a project on an atmospheric gasifier with gas turbine at a malting facility, using barley residues and corn stover. Alliant Energy in Lansing, Iowa, is developing a new combined-cycle concept that involves a fluidized-bed pyrolyzer and uses corn stover as a feedstock. United Technologies Research Center in East Hartford, Connecticut, has begun a project that will test a biomass gasifier coupled with an aero-derivative turbine with fuel cell and steam turbine options, using clean wood residues and natural gas as feedstocks. Carolina Power and Light in Raleigh, North Carolina, will develop a biomass gasification process that will produce a reburning fuel stream for utility boilers, using clean wood residues. After completion of research and development tests, these projects are candidates for commercialization over the next few years.[15]

Biomass co-firing involves combining biomass material with coal in existing coal-fired boilers. Coal-fired boilers can handle a pre-mixed combination of coal and biomass in which the biomass is combined with the coal in the feed lot and fed through an existing coal feed system. Alternatively, boilers can be retrofitted with a separate feed system for the biomass such that the biomass and coal actually mix inside the boiler.

Table 1 shows the power plants that currently are co-firing with biomass on a commercial basis. The portion of biomass consumed varies from less than 1 percent to about 8 percent of total heat input, with two exceptions: Excel Energy's Bay Front plant in Ashland, Wisconsin, and Tacoma Steam Plant Number 2, owned by Tacoma Public Utilities.

The Bay Front Station can generate electricity using coal, wood, shredded rubber, and natural gas. Experience has shown that it is better to operate units 1 and 2 on 100 percent coal during periods of high load and on 100 percent biomass during off-peak periods. A blending of coal and biomass can cause ash fouling and slagging problems. Therefore, the heat input from biomass averages about 40 percent in this plant.[16]

Tacoma Public Utilities is a municipal utility that provides water, electricity, and rail services. Tacoma Steam Plant uses a fluidized-bed combustor that can co-fire wood, refuse-derived fuel, and coal. The plant runs for only as many hours as necessary to burn the refuse-derived fuel it receives. The City of Tacoma Refuse Utility has modified its resource recovery facility to produce refuse-derived fuel. The generating plant is paid $5.50 per ton to accept the refuse-derived fuel from the Refuse Utility. A memorandum of understanding between the Refuse Utility and Tacoma Public Utilities commits the latter to burn the refuse-derived fuel for electricity generation. Coal is the most expensive fuel for the plant, making it desirable to burn as much biomass as possible.[17] The fuel mix varies from season to season, depending on the availability of biomass feedstocks. The cost of renovating the steam plant to co-fire the biomass fuel was about $45 million. Washington State's Department of Ecology provided a grant of $15 million to partially offset the renovation costs.

Biomass for electricity generation is treated in four ways in NEMS: (1) new dedicated biomass or biomass gasification, (2) existing and new plants that co-fire biomass with coal, (3) existing plants that combust biomass directly in an open-loop process,[18] and (4) biomass use in industrial cogeneration applications. Existing biomass plants are accounted for using information such as on-line years, efficiencies, heat rates, and retirement dates, obtained through EIA surveys of the electricity generation sector.

## Description of Biomass Supply Curves

The biomass fuel price is calculated from regional supply curves, which are an input to the model. The raw data for the supply schedules are available at the State or county level. These are aggregated to form the regional supply schedule by North American Electric Reliability Council (NERC) region. Supply schedules are aggregated for four fuel types: agricultural residues, energy crops, forestry residues, and urban wood waste/mill residues. Table 2 shows the biomass supply available in the United States. The data in Table 2 are based on survey and modeling work by ORNL, the USDA, and Antares Group, Inc. Table 2 represents the maximum supply available in the various regions at a price of $5 per million Btu.[19] A brief description of each type of biomass is provided below:

- *Agricultural residues* are generated after each harvesting cycle of commodity crops. A portion of the remaining stalks and biomass material left on the ground can be collected and used for energy generation purposes. Residues of wheat straw and corn stover[20] are included in the biomass supply schedule used in NEMS. Wheat straw and corn stover make up the majority of crop residues.

- *Energy crops* are produced solely or primarily for use as feedstocks in energy generation processes. Energy crops includes hybrid poplar,[21] hybrid willow,[22] and switchgrass,[23] grown on cropland acres currently cropped, idled, or in pasture, and in the Conservation Reserve Program (CRP).[24]

- *Forestry residues* are the biomass material remaining in forests that have been harvested for timber. Timber harvesting operations do not extract all biomass material, because only timber of certain quality is usable in processing facilities. Therefore, the residual material after a timber harvest is potentially available for energy generation purposes. Forestry residues are composed of logging residues, rough rotten salvageable dead wood, and excess small pole trees.

- *Urban wood waste/mill residues* are waste woods from manufacturing operations that would otherwise be landfilled. The urban wood waste/mill residue category includes primary mill residues and urban wood such as pallets, construction waste, and demolition debris, which are not otherwise used.

By 2020, the United States is estimated to have a maximum of 7.1 quadrillion Btu of biomass available at prices of $5 per million Btu or lower. Agricultural residues, forestry residues, and urban wood waste/mill residues are currently available. EIA also assumes that energy crops can become available on a commercial basis beginning in 2010. By 2020, the four biomass types are projected to be fairly evenly divided, with agricultural residues providing most of the supply and urban wood waste/mill residues providing the least amount at the high end of the supply curves.

Figure 2 shows the variation in the resource as a function of price. A relatively small portion of the supply is available at $1 per million Btu or less. Feedstock cost is a contributing factor that keeps the growth of biomass-based electricity generation at low levels under *AEO2002* reference case conditions. The available low-cost feedstock (<$1 per million Btu) is almost exclusively urban wood waste and mill residues. This category of biomass continues to be the only significant resource available at prices up to about $2 per million Btu. At that price level, agricultural residues become viable as a second source of biomass. Energy crops and forestry residues begin to make significant contributions at prices around $2.30 per million Btu or higher. A brief description of the methodology by which the supply curves are derived is provided below. Table 3 shows the biomass quantities, expressed in various units, that are projected to be available at different price levels.

### Agricultural Residue Supply Curve

The underlying assumption behind the agricultural residue supply curve is that after each harvesting cycle of agricultural crops, a portion of the stalks can be collected and used for energy production. Agricultural residues cannot be completely extracted, because some of them have to remain in the soil to maintain soil quality (i.e., for erosion control, carbon content, and long-term productivity). It is assumed that 30 to 40 percent of the residues could be removed from the soil, depending on the State. In terms of acreage, the most important agricultural commodity crops being planted in the United States are listed in Table 4. Corn, wheat, and soybeans represent about 70 percent of total cropland harvested.

The agricultural residue supply curve used in NEMS incorporates only the residues available from corn stover and wheat straws. While this may appear to understate the agricultural residues that are potentially available for energy production, there are compelling reasons for excluding other types of commodity crops. In the case of hay, the whole crop is harvested and fed to livestock; therefore, it is assumed that there would be no useful amount of residue available. An attempt has been made to produce alfalfa, pellet the leaves using adhesive materials, and use the stems as biomass. The processing costs were too high, however, and there was no market for alfalfa pellets in the United States. In the case of tobacco the whole plant is used, leaving little or no residue. Residue from soybeans is relatively small and tends to deteriorate rapidly in the field, making it unsuitable for collection and energy extraction. Barley, oats, rice, and rye are produced in relatively small geographical areas and thus are not likely to have an impact on the national biomass supply curve.

The procedure for estimating the agricultural residue supply curve is as follows. Data on the quantities of corn and wheat produced in each State are available from the USDA.[25] From the harvested quantities of corn and wheat grain, a certain amount must be subtracted, representing the amount that the farmer needs to leave on the soil in order to maintain organic matter and prevent erosion. The quantity of residue that must remain depends on the crop type and rotation, soil type, weather conditions, and the tillage system. ORNL is currently preparing detailed estimates of how much residue needs to remain on the soil, taking into consideration these factors. For NEMS, only State-wide average yields and soil carbon needs using a reduced till practice (somewhat similar to mulch till and continuous crop rotations) are being considered.

The price of corn stover and wheat straw includes three components: the cost of collecting the residues, a transportation cost for transporting the material from the farm gate to the energy conversion facility, and a premium paid to farmers to encourage participation. For each harvest operation, a list of needed equipment is determined. Using standard engineering estimates consistent with those used by the USDA, the time per acre required to complete each operation and the cost per hour of using each piece of equipment are calculated.

Both the premiums to farmers and the transportation costs are based on current market practices. Several companies purchase corn stover or wheat straw to produce bedding, insulating materials, particle board, paper, and chemicals. These firms typically pay $10 to $15 per dry ton ($0.58 to $0.87 per million Btu) to farmers to compensate for any lost nutrient or environmental penalties (such as land erosion) that result from harvesting the residues. Studies have shown that transporting giant round bales of switchgrass costs $5 to $15 per dry ton ($0.29 to $0.87 per million Btu) for distances of less than 50 miles. Because agricultural residue bales would be of similar size, weight, and density as switchgrass bales, it is assumed that the cost of transporting bales from the farm gate to the energy conversion facility would be $10 per dry ton ($0.58 per million Btu). It is assumed by ORNL that the premium that would have to be paid to farmers would amount to $10 per dry ton ($0.58 per million Btu), for a total premium and transportation cost of $20 per dry ton ($1.16 per million Btu).

**Energy Crop Supply Curve**

Energy crops are not currently being commercially grown in the United States. Demonstration programs are underway with DOE funding in Iowa and New York, including IES Utilities Inc.'s biomass co-firing project at its Ottumwa Station plant in Iowa, for which there are plans to produce 200,000 tons of switchgrass harvested from 40,000 to 50,000 acres of land; and NRG's Dunkirk Station at Dunkirk, New York, where willow from 400 acres of farmland is being co-fired with coal. Therefore, the energy crop supply curve in NEMS represents future resources that could be more profitable at different market prices for farmers to plant in place of existing uses of cropland. An important assumption is that energy crops will not become commercially available until 2010.

The energy crop supply curve prepared by ORNL for EIA has three components: hybrid poplar, hybrid willow, and switchgrass. ORNL uses a model called the Policy Analysis System (POLYSYS) to estimate the quantities of energy crops that could be produced at various prices. POLYSYS is an agricultural sector model that forecasts the production of major agricultural crops. In addition, it has a livestock sector and food, feed, industrial, and export demand functions. POLYSYS was developed and is maintained by the

Agricultural Policy Analysis Center at the University of Tennessee and is also used by the USDA Economic Research Service to conduct economic and policy analysis. The underlying assumption in the POLYSYS model is that a farmer will plant and harvest energy crops only if the crop can be sold at a price that assures a profit higher than the profit made by producing conventional agricultural crops on the same piece of land. POLYSYS captures the interaction between energy crops and conventional crops when land is switched from conventional crops to energy crop production. As a joint project between USDA and DOE, POLYSYS has been modified to include dedicated energy crops. POLYSYS uses the 1999 USDA crop and livestock projection as a baseline and can be used to estimate deviations from that baseline.

POLYSYS considers the availability of four types of cropland in the United States: acreage that is currently being planted with traditional crops, idled acreage, acreage in pasture, and acreage in the CRP. The model assumes that energy crop production will be limited to areas that are climatically suited for their production, thus excluding all States in the Rocky Mountain and Western Plains regions. The rationale for these exclusions is that there is a natural rain gradient in the United States, as a result of which land to the west of the gradient generally requires irrigation for crop production, which may have significant environmental penalties. Irrigation has been excluded as a viable management practice for energy crop production. All land east of the rain gradient has been included in POLYSYS, but land to the west has been excluded. Future genetic improvements in energy crops could, however, extend this range.

A POLYSYS model run using assumptions that optimize the yield of biomass was used for NEMS.[26] These assumptions apply only to the acreage under CRP programs and not to acreage currently planted, in pasture, or idle. Different management practices are assumed for CRP and non-CRP acres, because the CRP acres are among the most environmentally sensitive cropland and because CRP is explicitly an environmental program.

Energy crop yields in the supply curve vary within and between States and are based on field trial data and expert opinion. Table 5 shows the energy crop yield assumptions that have been used for POLYSYS. The variation in yields is due to differences in weather and soil conditions across the country. The lowest yields are assumed to be in the Northern Plains and the highest in the heart of the corn belt, as is the pattern observed with traditional crops. In addition, POLYSYS assumes that different varieties of switchgrass, hybrid poplar, and willow are produced in different parts of the country, with different yield assumptions. Energy crop production costs are estimated using the same full-cost accounting approach that is used by USDA to estimate the cost of producing conventional crops.[27] The approach includes both fixed costs (such as equipment) and variable costs (such as labor, fuel, seed, and fertilizers).

Switchgrass stands are assumed to remain in production for 10 years before replanting, to be harvested annually, and to be delivered as large round bales. The plants can regenerate, and the same plant can continue to produce switchgrass for up to 10 years. It is assumed that new switchgrass varieties will have been developed after 10 years, and that it will be financially beneficial to plow under the existing switchgrass stand and replant with a new variety. Once established, a switchgrass field could be maintained in perpetuity, but the advantages of new, higher yield varieties would warrant periodic replanting.

Hybrid poplars are assumed to be planted at spacings of 8 feet by 10 feet (545 trees per acre) and to be harvested after 6, 8, and 10 years of growth in the Pacific Northwest, southern United States, and northern United States, respectively. Harvesting is assumed to be by custom operation, and the product is assumed to be delivered as whole tree chips.

Willow production is assumed only in the northern United States. Willows can technically be grown throughout the entire eastern United States, but limited research has been done for areas outside the Northeast and North Central regions. Willows are produced in a coppice system with a replant every 22 years. They are planted in 2 x 3 double rows (6,200 trees per acre) with first harvest in year 4 and subsequent harvests every 3 years for a total of 7 harvests. Willow is delivered as whole tree chips.

In terms of product quality, hybrid poplar and willow contain about 45 to 50 percent moisture when harvested. The trees would typically be fed into a wood chipper, which generally would provide chips between 0.5 and 1 inch square and less than 0.25 inch thick. Switchgrass is harvested at about 15 percent moisture, baled, and generally ground in a tub grinder before use.

It is assumed in POLYSYS that energy crops are produced if they generate a profit equal to or greater than those earned for existing agricultural uses of cropland. Energy crops compete for land not only with existing uses but also with each other. Under the assumed yields and management practices, switchgrass dominates the biomass supply curve due to higher average yields and lower average production costs than hybrid poplar or willow. POLYSYS provides an estimate of the farm-gate price. To that price, an average transportation cost of $10 per dry ton (1997 dollars) is added to determine the plant-gate price.

**Forestry Residue Supply Curve**

The forestry residue supply curve was derived on the basis of work done by the USDA Forest Service (USDA-FS) and ORNL. The ORNL estimate of the availability of forestry residues is based on a 1984 USDA-FS study by McQuillan et al.,[28] which analyzed several types of data, including forestry inventory, logging and chipping costs, hauling distances and costs, stocking densities, wood types, slope, and equipment operability constraints. The McQuillan study is the only such analysis with national coverage. More recent studies exist, but they are local or regional in scope. The fundamental approach used in the McQuillan study still remains valid.

The input data were used to estimate regional supply schedules for softwood and hardwood chips for 1983 and to provide projections for 1990, 2010, and 2030. The USDA-FS study used estimates of "recoverability factors" that reduced the size of the inventory. Recoverability is used to account for the accessibility of the resource (i.e., existence of roads), whether the resource occurs in stands that are available, and how much of the resource can be retrieved (taking into account gathering problems with small pieces, breakage, etc.). The original data for the study came from a national inventory of "waste wood," which was defined as logging residues, rough rotten salvable wood, excess sapling, and small pole trees.

The forestry residue supply curve used in NEMS is based on the 1984 USDA-FS analysis and a 1994 ORNL study by Turhollow and Cohn,[29] which was revised in 1995 by Decision Analysis Corporation under contract to EIA.[30] The amount of waste wood available has been updated using the most recent USDA-FS inventory data. Other adjustments to reflect the availability of waste wood include (1) the exclusion of sapling and small pole trees, (2) changes to the recoverability factors, (3) the addition of a nominal stumpage fee, and (4) conversion from 1980 dollars to 1998 dollars based on an index of agricultural prices paid. The modifications were implemented by ORNL, based on the following rationale:

1. Saplings as a source of waste wood generally do not become available below costs of $6 per million Btu (1998 dollars). Because of the relatively high cost of recovering sapling waste wood, it was excluded from the updated supply curves. The USDA-FS defines polewood as trees with greater than 5 inch dbh (diameter breast high) but smaller than saw timber trees. Although large quantities of pole trees become available at costs of about $3.60 per million Btu (1998 dollars) or higher, the polewood has potential to grow into future pulpwood or future saw timber inventory and, therefore, is not likely to be harvested by the forest products industry.

2. The recoverability factor is a resource reduction factor that takes into account three site-specific considerations: retrieval efficiency due to technology or equipment, site accessibility or existence of roads, and steepness of slopes. In modifying the recoverability factors, ORNL did not change the retrieval efficiency assumptions from those in the USDA-FS study (i.e., 50 percent of inventory is assumed to be recoverable); however, ORNL's changes to the site access and steep slope factors reduced the inventory of softwood and hardwood that could potentially be recovered to 54 percent and 43 percent of the existing inventory, respectively. ORNL assumed that cable or helicopter logging would be necessary on steep slopes, and that in either situation it would not be economical to haul out much of the low-value wood, such as cull or branches.

3. For live cull, sound dead wood, and logging residues a stumpage fee of $2 per dry ton was assumed. The stumpage fee represents a cost to acquire the materials, based on data that was provided to ORNL by USDA's Southern Research Station.

4. ORNL subtracted the cost of transporting forestry residues from collection sites to power plants. Therefore, the ORNL data for forestry residues represent the supply schedule at the collection point (i.e., at the edge of the forest). EIA assumes a transportation cost from the collection point to the power plant of $10

per dry ton, which is added to the forestry residue supply curve from ORNL. This constant transportation cost is applied to all regions in all years for agricultural residues, forestry residues, and energy crops.

The spatial distribution of agricultural residues, energy crops, and forestry residues varies considerably. Transportation costs are dependent on spatial distribution and on the quantity needed by a facility.[31] Therefore, the estimation of transportation costs is highly problematic for these resources. For example, the estimated transportation cost for supplying switchgrass to hypothetical facilities in Tennessee varies by 50 percent among facilities of the same size and increases on average by 30 percent when the facility demand changes from 100,000 dry tons per year to 630,000 dry tons per year. Similar or even larger variations can be expected with agricultural residues, because less is removed per acre at harvest, and thus the hauling distances would have to be greater to supply a given quantity of feedstock. There are also regional differences that result from differences in road regulations and labor costs.

Estimating transportation costs for forestry residues is especially difficult, because they vary significantly depending on whether the chips are hauled on primary or secondary roads. There are no national studies that have examined the variations in transportation costs for different feedstocks, different regions, and different facility demands. For this reason, a uniform transportation cost of $10 per dry ton was assumed. The transportation cost for urban wood waste/mill residues, which are point sources of biomass, is calculated somewhat differently, as described below.

**Urban Wood Waste and Mill Residue Supply Curve**

Most of the residues in this category are waste wood from manufacturing operations and wood that would otherwise be landfilled. Antares Group, Inc., performed this analysis for EIA. Antares estimated the State-by-State available supplies of urban wood waste and mill residues. Urban wood waste is further broken down into wood yard trimmings, construction residues, demolition residues, and other waste wood, including discarded consumer wood products. The mill residues are further broken down into bark residues and wood residues, both from primary mills. When available, State-level data from existing reports were used to construct supply curves of urban wood waste and mill residues. When published State-level data were not available, quantities were estimated by disaggregating reported national quantities. The disaggregation from national to State-level data was done by using accepted "indicators" (such as housing start data) that are correlated with residue generation.

The cost at which these residues can be obtained was estimated using processing costs, State-specific landfill tipping fees, and transportation costs. If a residue is typically landfilled, it was assumed that a 50-percent reduction in tipping fees would be offered at a waste collection facility as an incentive for people to take their wood waste to the collection facility instead of a landfill. The maximum distance beyond which transporting the residues would become prohibitive was assumed to be 100 miles from a potential biopower site. Costs were estimated for each residue type for hauling distances of 25, 50, 75, and 100 miles.

An important assumption in this analysis, made by Antares, was that urban wood waste and mill residues would be considered to be available only if they are not currently being used for other productive purposes. In other words, it was assumed that if urban wood waste and mill residues are currently being used for any purpose, it would not be economically attractive to divert them to electricity generation at any price.

Table 6 shows representative characteristics for different subcategories of urban wood waste and mill residues. The collection and processing costs are obtained from the available literature. While these are average collection and processing costs, the actual costs are expected to range from $0 to $8 per wet ton for mill residues and from $10 to $14 per wet ton for urban residues. A transportation cost is added to the collection and processing costs. The total expenditure in local transportation costs in 1996 was reported to be $122 billion (in 1996 dollars).[32] Local trucking accounted for 506 billion ton-miles in 1996.[33] This implies a national average local freight charge of about $0.24 per ton-mile (1996 dollars). For distances of 50, 75, and 100 miles around a co-firing facility, this would translate to transportation costs of $12, $18, and $24 per dry ton ($0.70, $1.05, and $1.40 per million Btu), respectively.

The national average was converted to State averages using transportation price indexes for different geographical areas. For pallets, construction debris, and demolition debris, a particular State's major urban-based transportation indexes were used. For primary mill residues, the State's lowest transportation index was used to reflect the more rural nature of the location of wood processing centers. A supply curve for urban wood waste and mill residues was constructed using this methodology.

**Supply Curve Uncertainties**

Although a significant amount of effort has gone into estimating the available quantities of biomass supply, the following uncertainties still are associated with the numbers:

- Perhaps the most significant uncertainty is the value of competing uses of biomass materials. For example, the mulch market consumes large amounts of waste biomass material. Different qualities of mulch are available at different prices. How much mulch and other biomass-derived materials can be diverted from their current markets into electricity generation and the prices at which such reallocations might take place are not well understood.

- In agricultural waste, the significant uncertainty is in the impact of biomass removal on soil quality. A general consensus in the farming community that more agricultural residues need to be left on the soil to maintain soil quality could result in significant losses of biomass for electric power generation purposes.

- In forestry residues, the unknown factor is the impact of changes in forest fire prevention policies on biomass availability. A policy whereby the vegetation in forests is reduced to minimize the potential for forest fires could significantly increase the quantity of forestry residues available.

- Similarly, while the amount of material that is recycled from municipal solid waste streams has steadily grown, it is generally recognized that a significant portion of the municipal solid waste stream is still landfilled. An aggressive attempt to recycle more of the municipal solid waste stream might translate into less available biomass for electricity generation.

Given these uncertainties, the current supply curves represent our best understanding of the availability of biomass at this point in time. Responses of the biomass, solid waste, agricultural waste, and forestry communities to market changes will determine the ultimate availability of biomass materials in the United States.

## Implementation in NEMS

NEMS represents both dedicated biomass (BIGCC) and biomass co-firing plants for new capacity. BIGCC is treated in the same way as any other generation option in NEMS. In addition to the supply curves, which provide feedstock costs, NEMS needs the following BIGCC-specific inputs in order to generate the biomass forecast: capital cost, operating and maintenance cost (fixed and variable), project life, production tax credits, and heat rate. Table 7 shows the overnight capital costs assumed for BIGCC projects in the *AEO2002* reference case. BIGCC plants are assumed to have a 4-year construction lead time. Therefore, for projects initiated in 2001, the earliest time that a plant could come on line would be 2005. The BIGCC capital cost assumption in the reference case is derived from a 1997 estimate published by DOE and the Electric Power Research Institute.[34] The DOE/EPRI costs are adjusted upward to take into account greater uncertainties concerning the costs for the gasification portion of the plant as opposed to the gas conditioning/power generation portion of the plant. EIA assumptions are used in place of the published values for interest during construction and contingency costs. Figure 3 shows the capital costs used in NEMS for biomass, compared with the costs used for several other technologies. BIGCC, at $1,536 per kilowatt, has a relatively high capital cost in comparison with coal- and natural-gas-based generation technologies. BIGCC capital costs are higher than coal IGCC capital costs mainly as a result of the need for additional feed preparation equipment. Capital costs are assumed to decline over time as more units are built.

Biomass co-firing is represented in NEMS by assuming that coal-fired capacity can be retrofitted for biomass co-firing at levels up to 5 percent on a heat input basis. It is assumed that, for such low levels of co-firing, no additional capital or operating and maintenance costs would be incurred. The biomass would be commingled with coal, and the mixture would be fed into the boiler through the existing coal feed system. Therefore, no new capital expenditure would be required. The existing coal feedlot operators would be able to manage the tasks of mixing biomass and coal without the need for additional labor.

It is also assumed that the biomass co-firing limits will vary by region (Table 8). The regional limits are based on the availability of biomass and of coal-fired capacity. These are the maximum upper bounds on biomass co-firing. NEMS chooses lower levels of co-firing, depending on the other generation options available in each region. It has been suggested, based on demonstration-scale tests, that biomass co-firing could be carried out at higher levels by incurring an incremental capital cost.[35] Incorporation of this capability into NEMS is currently being investigated.

## NEMS Projections

*AEO2002* Reference Case

Figure 4 shows the *AEO2002* reference case projection for biomass use in electricity generation. Biomass continues to be the largest nonhydroelectric renewable technology throughout the forecast horizon, growing from a capacity of about 6.7 gigawatts in 2000 to about 10.4 gigawatts by 2020, including dedicated biomass and industrial cogeneration (Table 9).[36] In comparison, wind capacity, which has a much lower utilization rate than biomass, is projected to grow from about 2.4 gigawatts in 2000 to 9.1 gigawatts in 2020. Similarly, generation from biomass grows from 38.0 billion kilowatthours in 2000 to 64.3 billion kilowatthours by 2020 (Table 10).

### *AEO2002* High Renewables Case

*AEO2002* also includes a high renewables case that assumes more favorable cost and performance characteristics for nonhydroelectric renewable energy technologies, including biomass, than are assumed in the reference case. The assumptions in the high renewables case include lower capital costs, lower operating and maintenance costs, and increased availability of biomass fuel supplies. Capital costs are assumed to be similar to those in the publication *Renewable Energy Technology Characterizations*.[37] The costs are about 3 percent lower than those assumed in the reference case in the early years of the forecast period due to more optimistic assumptions about the costs for the gasification portion of the plant. In addition, it is assumed that operation and maintenance costs would be 14 percent lower than in the reference case, also based on the same document. The biomass supplies are increased by 10 percent at each step of the supply curve. Fossil and nuclear technology assumptions remain unchanged from those in the reference case.

The basic trends in the high renewables case are similar to those in the reference case, but biomass capacity increases to 12.3 gigawatts by 2020 instead of 10.4 gigawatts in the reference case (Table 9). Generation from biomass plants increases to 76.0 billion kilowatthours by 2020, as compared with 64.3 billion kilowatthours in the reference case (Table 10).

### 10% and 20% RPS Cases

EIA has analyzed the impact of imposing 10-percent and 20-percent renewable portfolio standards by 2020.[38] The 10% RPS case assumed that a legislatively mandated nationwide RPS would require 10 percent of the Nation's electricity to be generated from nonhydroelectric renewable energy sources in 2020 and beyond. Similarly, the 20% RPS case assumed that a legislatively mandated nationwide RPS would require 20 percent of the Nation's electricity to be generated from nonhydroelectric renewable energy sources in 2020 and beyond. The RPS cases assumed the same $NO_x$ and $SO_2$ caps as mandated by the Clean Air Act Amendments of 1990, which is the assumption made in the *AEO2002* reference case.

The biomass supply curves used for the RPS cases are the same as those used for the *AEO2002* reference case. The emissions caps are applied only to the electricity generation sector (excluding cogenerators) and are assumed to cover emissions from both utility-owned and independently owned electric power plants. In the 20% RPS case, as a result of the assumed nationwide legislative mandate, renewables are projected to enter the market much more rapidly than in the reference case (Tables 9 and 10). Figure 5 shows projected biomass consumption in the different cases. In the 20% RPS case, dedicated biomass is projected to provide 3.8 quadrillion Btu of energy for electricity generation by 2020. An additional 0.7 quadrillion Btu of biomass energy is projected to be consumed for co-firing and as ethanol derived from cellulose. Ethanol from cellulose utilizes biomass from the same supply curve as dedicated biomass and biomass co-firing, and thus the three biomass applications compete with each other for their respective feedstocks.

The growth of biomass generation depends on the level of renewables required by the RPS. A low RPS requirement (such as 10 percent or less by 2020) would first be met by wind, which is more economical than biomass. In addition, biomass co-firing with coal is sensitive to the growth of other electricity generation technologies. In general, biomass co-firing with coal is more economical than biomass gasification; however, it is less economical than biomass gasification in scenarios where large amounts of coal-fired capacity are projected to be retired, such as cases which assume that U.S. emission reduction targets under the Kyoto Protocol will be met exclusively through reductions in domestic carbon dioxide emissions. In the 20% RPS case, biomass gasification grows substantially by 2020, and this translates into a large demand for biomass feedstocks, which increases the feedstock cost for co-firing, making the use of biomass for co-firing uneconomical relative to biomass gasification.

The projected growth of biomass consumption in the 20% RPS case raises the question of whether or not there would be sufficient land to sustain the required level of biomass production. An analysis of the results of the 20% RPS case shows that there would be a requirement for approximately 9.6 to 14.4 million acres of land devoted to energy crops by 2020, depending on the yield obtained.[39] There were 932 million acres of land in U.S. farms and ranches in 1997. The acreage devoted to farms and ranches has been declining steadily since the 1950s, at a rate of about 4.9 million acres per year.[40] It is possible to grow biomass energy crops on CRP lands. Under the Farm Security and Rural Investment Act of 2002, signed into law on May 13, 2002, the acreage that can be enrolled in the CRP has been increased to 39.2 million acres. Therefore, in the 20% RPS case, if all the energy crops were planted on CRP land, approximately 24 percent to 37 percent of the CRP land would have to be devoted to energy crop production by 2020. Land use for biomass-based energy consumption is not expected to conflict with land requirements for crop production, because the land requirements for energy crops are far smaller and less than the land that has been removed from agricultural production as a result of improvements in farm productivity.

## Conclusion

EIA's estimation of biomass resources shows that there are 590 million wet tons (equivalent to 413 million dry tons) of biomass available in the United States on an annual basis. Historically, biomass consumption for energy use has remained at low levels, although it is the largest nonhydroelectric renewable source of electricity in the United States (considering both industrial cogeneration from biomass and electricity sector generation). The main impediment has been the cost of obtaining the feedstock. Of the estimated total resource of 590 million wet tons, only 20 million wet tons (equivalent to 14 million dry tons, or enough to supply about 3 gigawatts of capacity) is available today at prices up to $1.25 per million Btu.

Biomass use for power generation is not projected to increase substantially by 2020 in the *AEO2002* reference case because of the cost of biomass relative to the costs of other fuels and the higher capital costs relative to those for coal- or natural-gas-fired capacity. Slightly more growth is projected in the high renewables case, but the difference from the reference case projection is relatively small. In the 20% RPS case, significantly more use of biomass for electricity generation is projected than in the reference case, because electric utilities would be required to generate a portion of their power from renewable resources, including biomass.



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# Florida Public Service Commission and Department of Environmental Protection

# "An Assessment of Renewable Generating Technologies for Florida"

**January 2003**

# An Assessment of Renewable Electric Generating Technologies for Florida

PREPARED BY THE

Florida Public Service Commission and the
Department of Environmental Protection

JANUARY 2003

## Cost Considerations of Renewable Resources

Renewable fueled generating technologies ultimately must compete with traditional generating technologies to sustain themselves as a viable alternative resource. Presently, renewable technologies are, for the most part, more expensive than the incremental generating unit that would be built to serve electric customers. Due to advances in jet engine technologies, the electric industry's preferred generating technology to serve peak load is a natural gas fired combustion turbine generator operating in a simple cycle mode. When a more base loaded type generator is needed the simple cycle can be connected to a heat recovery unit to capture the high temperature exhaust gases from the turbine, which in turn produces steam that is also used to produce electricity. While natural gas is the preferred fuel for these kinds of machines, oil and coal that have been converted into a gas can also be used as fuels.

Proponents of renewable technologies point out that renewables have certain desirable characteristics which may not always be appropriately captured by bottom line production costs. They cite the modular nature of many technologies, the fact that renewables do not use coal, oil, natural gas, or nuclear fuels, and that fuel input costs are either negligible or have less volatility than fossil based fuels. On the other hand, some renewables have characteristics which may diminish their economic value. Intermittent resources like solar and wind are sometimes harder to incorporate into reserve requirements. Some renewables that are remote from load centers may require transmission upgrades to get the energy to customers and there may be line losses associated with moving the power. Finally, while distributed resources can be helpful for certain aspects of distribution stability, power quality must be maintained.

Chapter III provides a discussion of the various life cycle cost estimates for renewable resources.

## Environmental Considerations of Renewable Resources

Many people assume that by definition renewable resources are "cleaner" or have less environmental impacts than non-renewable resources. Such assertions should be carefully examined. All energy infrastructure has some kind of impacts. The challenge is to evaluate the relative seriousness of various impacts and how to best mitigate them. For example, windmills have no air emissions associated with combustion processes, but where they are sited has generated controversy on the aesthetic issues associated with their construction.[7] Likewise, MSW facilities, while deemed renewable by definition in this statute, often are opposed because of the combustion process involved in producing electricity. The air emission profile for a MSW facility would look more similar to a conventional fossil fueled unit depending on the vintage of the unit. Here again, this report discusses the environmental characteristics of various renewable technologies, but does not attempt to assign a single, unidimensional ranking in terms of their qualitative impacts on the environment.

An emission profile of regulated air emissions was established for Florida's current "fleet" of renewable resource electrical generators, and is presented in Figure 4. It should be noted that this chart reflects actual data reported during the year 2001, for existing Florida generating units

[7] "Cape Cod: Twisting in the Wind," *Public Utilities Fortnightly*, May 15, 2002, Vol. 140, No. 10.

One conclusion which can be reached, is that most of Florida's current fleet of electrical generating units constructed primarily for the purpose of combusting renewable fuels are at least as clean, with respect to regulated emissions, as Florida's existing coal- and oil-fired units (which includes grandfathered units). However, combined cycle natural gas-fired units clearly emit the lowest amount of air pollutants per MWh generated of all existing carbon-based fuels. Modern natural gas-fired combined cycle power plants emit nearly no sulfur dioxide and about 3 parts per million of nitrogen oxides.

Concerning thermal emissions, each of the above types of generating units (whether fossil or renewable fuel-fired) is responsible for heat being emitted to the air and, in some cases, water bodies. Additionally, modern units of each type are typically designed as zero discharge facilities, implying that no wastewater streams exist. Older units, however, represent a source of wastewater discharges.

The waste streams to land associated with each technology can also vary. As a general rule, waste streams are higher for solid fuels than liquid fuels, with gaseous fuels having nearly no ash. For example, the quantities of ash generated from the combustion of MSW and RDF are typically double that of coal combustion. Ash generated from the combustion of coal is roughly equivalent to that of bagasse, wood or bark, per MWh of electricity produced. Comparably speaking, fuels such as petcoke and oil generate very low quantities of ash (perhaps five percent that of coal), while the generation of ash from the combustion of natural gas and landfill gas is essentially zero.[8]

Figures 4 and 5 do not include carbon dioxide emissions because carbon dioxide is currently not a regulated pollutant in the U.S. Nevertheless, many scientists, and perhaps a majority of scientists, believe that carbon dioxide emissions are the principal anthropogenic contributor to global warming. There are active discussions nationally and internationally regarding whether or not carbon dioxide emissions should be regulated. Indeed, the U.S. has agreed to voluntarily monitor and report the annual inventory of carbon dioxide emissions. To this end, the U.S. Environmental Protection Agency publishes an annual report entitled *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

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[8] For additional information regarding waste streams see the U.S. Environmental Protection Agency's Report to Congress dated March, 1999 entitled *Wastes from the Combustion of Fossil Fuels Volume 2 – Methods, Findings, and Recommendations.*

Black and Veatch provided Table 10 which lists typical ranges of performance and costs for a facility directly burning 2,000 tons of waste per day.

**TABLE 10**

**PRODUCTION COSTS FOR 50 MW MSW Generator**

| | |
|---|---|
| Plant Capacity | 50 MW |
| Net Plant Heat Rate | 16,000 Btu per kWh |
| MSW tons per day | 2,000 |
| Capacity Factor | 60 to 80 percent |
| Capital Cost | \$2,500 to \$4,600 per kW |
| Fixed O&M | \$100 to \$175 per kWyear |
| Variable O&M | \$25 to \$50 per MWh |
| Levelized Cost | 3.5 to 15.3* cents per kWh |

*This assumes a \$25 per ton tipping fee. Information presented by Integrated Waste Services Association indicates that for Florida plants a \$50 per ton fee is more typical and thus production costs could be closer to 2¢.*

Questionnaire responses were received from the representatives of 12 operating direct combustion MSW generators within Florida, as well as one potential site. Net summer plant capacity ratings of the units ranged from 10 MW to 75.5 MW. Most questionnaires indicated that it is technically feasible to dispatch the unit. However, several cited contract provisions which currently prevent the unit from being dispatched, or make it uneconomical for the generator to do so. Only one of the responses included cost data, citing a \$6,500 per kW capital cost. Performance data is comparable to the Black and Veatch data above. Heat rates for the units ranged from 13,300 to 18,000 Btu per kWh, with capacity factors of between 78 and 95 percent. MSW plants have negative fuel costs in that they are paid to take waste materials. Each respective municipality pays a tipping fee to the generator to deliver MSW. One response provided a fuel cost of negative \$4.23 per Mbtu, indicating a tipping fee is received by the generator from the municipality.

## Landfill Gas

Landfill gas is one of the more mature options for obtaining energy from municipal wastes. Many landfill sites within Florida already have gas collection technology installed in order to meet Federal Clean Air and New Source Performance Standards. Energy Developments, Ltd., stated that for every 1 million tons of municipal solid waste in a landfill, enough gas is produced to fuel approximately 1 MW of generating capacity, yielding about 8,500 MWhs.[22] The capital costs for landfill gas projects is dependent on site characteristics, the conversion technology used, and the extent of the collection systems already in place. However, according to Black and Veatch, the payback period for landfill gas sites is often between 2 and 5 years. Capacity factors can vary greatly depending on the technology used to convert the landfill gas into electricity. Data provided by workshop participants and on questionnaire responses indicates that landfill gas projects are not available for utility dispatch.

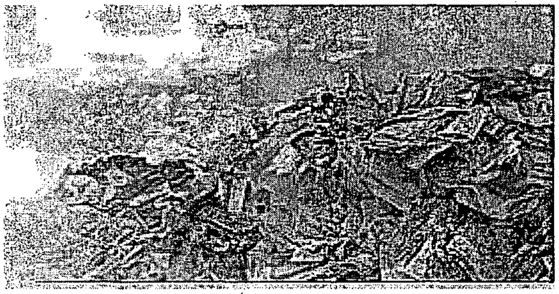
[22] David R. Wentworth, Energy Developments, Ltd., *Landfill Gas to Electricity Development in the State of Florida.* Presentation at the FPSC Staff Renewable Assessment.

# U.S. Environmental Protection Agency

# "Electricity from Municipal Solid Waste"

## November 2006

# Electricity from Municipal Solid Waste



Municipal solid waste (MSW) refers to the stream of garbage collected through community sanitation services. Medical wastes from hospitals and items that can be recycled are generally excluded from MSW used to generate electricity. Paper and yard wastes account for the largest share of the municipal waste stream,[1] and much of this can be recycled directly or composted.

**Environmental Impacts of:**

- **Natural Gas**
- **Coal**
- **Oil**
- **Hydroelectricity**
- **Non-Hydro Renewable**
- **Nuclear Energy**

Currently, over 30 percent of MSW generated in the United States is recycled annually. While not producing this waste in the first place is the preferred management strategy for this material, recycling is preferred over any method of disposal. The majority of MSW that is not recycled is typically sent to landfills after it is collected. As an alternative, MSW can be directly combusted in waste-to-energy facilities to generate electricity. Because no new fuel sources are used other than the waste that would otherwise be sent to landfills, MSW is often considered a renewable power source. Although MSW consists mainly of renewable resources such as food, paper, and wood products, it also includes nonrenewable materials derived from fossil fuels, such as tires and plastics.

At the power plant, MSW is unloaded from collection trucks and shredded or processed to ease handling. Recyclable materials are separated out, and the remaining waste is fed into a combustion chamber to be burned. The heat released from burning the MSW is used to produce steam, which turns a steam turbine to generate electricity.

The United States has about 89[2] operational MSW-fired power generation plants, generating approximately 2,500 megawatts, or about 0.3 percent of total national power generation. However, because construction costs of new plants have increased, economic factors have limited new construction.

## Environmental Impacts

Although power plants are regulated by both federal and state laws to protect human health and the environment, there is a wide variation of environmental impacts associated with power generation technologies. The purpose of the following section is to give consumers a better idea of the specific air, water, land, and solid waste impacts associated with MSW-fired electricity generation.

## Air Emissions Impacts

Burning MSW produces nitrogen oxides and sulfur dioxide as well as trace amounts of toxic pollutants, such as mercury compounds and dioxins. Although MSW power plants do emit carbon dioxide, the primary greenhouse gas, the biomass-derived portion is considered to be part of the Earth's natural carbon cycle. The plants and trees that make up the paper, food, and other biogenic waste remove carbon dioxide from the air while they are growing, which is returned to the air when this material is burned. In contrast, when fossil fuels (or products derived from them such as plastics) are burned, they release carbon dioxide that has not been part of the Earth's atmosphere for a very long time (i.e., within a human time scale).

The average air emission rates in the United States from municipal solid waste-fired generation are: 2988 lbs/MWh of carbon dioxide, (it is estimated that the fossil fuel-derived portion of carbon dioxide emissions represent approximately one-third of the total carbon emissions) 0.8 lbs/MWh of sulfur dioxide, and 5.4 lbs/MWh of nitrogen oxides.[3]

The variation in the composition of MSW affects the emissions impact. For example, if MSW containing batteries and tires are burned, toxic materials can be released into the air. A variety of air pollution control technologies are used to reduce toxic air pollutants from MSW power plants.

There can be significant greenhouse gas reduction benefits from recycling and source reduction when compared to other management options. Note also that over 1.6 million ton of ferrous and non-ferrous metals, plastics, glass and combustion ash are recycled annually.[4]

## Water Resource Use

Power plants that burn MSW are normally smaller than fossil fuel power plants but typically require a similar amount of water per unit of electricity generated. When water is removed from a lake or river, fish and other aquatic life can be killed, affecting those animals and people who depend on these resources.

## Water Discharges

Similar to fossil fuel power plants, MSW power plants discharge used water. Pollutants build up in the water used in the power plant boiler and cooling system. In addition, the cooling water is considerably warmer when it is discharged than when it was taken. These water pollutants and the higher temperature of the discharged water can upon its release negatively affect water quality and aquatic life. This discharge usually requires a permit and is monitored. For more information about these regulations, visit EPA's Office of Water Web site.

## Solid Waste Generation

The combustion of MSW reduces MSW waste streams, reducing the creation of new landfills. MSW combustion creates a solid waste called ash, which can contain any of the elements that were originally present in the waste. MSW power plants reduce the need for landfill capacity because disposal of MSW ash requires less land area than does unprocessed MSW. However, because ash and other residues from MSW operations may contain toxic materials, the power plant wastes must be tested regularly to assure that the wastes are safely disposed to prevent toxic substances from migrating into ground-water supplies. Under current regulations, MSW ash must be sampled and analyzed regularly to determine whether it is hazardous or not.[5] Hazardous ash must be managed and disposed of as hazardous waste. Depending on state and local restrictions, non-hazardous ash may be disposed of in a MSW landfill or recycled for use in roads, parking lots, or daily covering for sanitary landfills.

## Land Resource Use

MSW power plants, much like fossil fuel power plants, require land for equipment and fuel storage. The non-hazardous ash residue from the burning of MSW is typically deposited in landfills.

## Fuel Reserves

U.S. residents, businesses, and institutions produced more than 229 million tons of MSW in 2001, which is equivalent to approximately 4.4 pounds of waste per person per day. In 2001, 33.6 million tons (14.7 per cent) of MSW were combusted.[6]

1. U.S. EPA, Office of Solid Waste, *Basic Facts*.
2. A Look at Waste-to-Energy/Maria Zannes, IWSA; presented at the NAWTEC Fall 2004 Meeting, Columbia University, NYC.
3. U.S. EPA, *Compilation of Air Pollutant Emission Factors (AP-42)*.
4. Kiser, Jonathan V. L., Recycling and Waste-to-Energy: The Ongoing Compatibility Success Story, EXIT Disclaimer *MSW Management*, May/June 2003.
5. U.S. EPA, Office of Solid Waste, *MSW Disposal*.
6. Municipal Solid Waste in the United States: 2001 Facts and Figures. EPA530-S--011.

ATTACHMENT G1
RTI INTERNATIONAL
"BEYOND-THE-FLOOR ANALYSIS FOR EXISTING AND NEW COAL- AND OIL-FIRED ELECTRIC UTILITY STEAM GENERATING UNITS NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS"
DECEMBER 2003

# RTI International

# "Beyond-the-Floor Analysis for Existing and New Coal- and Oil-Fired Electric Utility Steam Generating Units National Emission Standards for Hazardous Air Pollutants"

## December 2003

RTI INTERNATIONAL | **Memorandum**

TO: Bill Maxwell, U.S. Environmental Protection Agency, OAQPS (C439-01)

FROM: Jeffrey Cole, RTI International

DATE: December 2003

SUBJECT: Beyond-the-floor analysis for existing and new coal- and oil-fired electric utility steam generating units national emission standards for hazardous air pollutants

This memorandum describes the development of the beyond-the-floor analysis for existing and new coal- and oil-fired electric utility steam-generating units National Emission Standard for Hazardous Air Pollutants (NESHAP). In this memorandum, we considered available regulatory options (i.e., technologies or work practices) that were more stringent than the MACT floor level of control for each of the different subcategories that make up the Electric Utility source category.

**OUTLINE**

## 1.0 INTRODUCTION

As discussed in the memorandum entitled "MACT Floor Analysis for Coal- and Oil-Fired Electric Utility Steam-Generating Units National Emission Standards for Hazardous Air Pollutants," the EPA chose to set MACT for mercury (Hg) from existing and new coal-fired electric utility steam-generating units and nickel (Ni) from existing and new oil-fired electric utility steam-generating units. Therefore, this discussion addresses beyond-the-floor control options for existing or new units.

## 2.0 BEYOND-THE-FLOOR OPTIONS FOR EXISTING COAL- AND OIL-FIRED ELECTRIC UTILITY STEAM GENERATING UNITS

In order to determine possible beyond-the-floor control options for existing units, we analyzed all available emissions data on air pollution control devices (APCD) that are currently utilized or experimental (both full-size and pilot-scale). The following are the possible beyond-the-floor control options for existing units.

### 2.1 Coal-fired Units

Conventional PM controls (electrostatic precipitators [ESP] and fabric filters) generally do not remove the vapor-phase HAP (i.e., elemental Hg, hydrochloric acid [HCl], and hydrogen fluoride [HF]) from coal-fired unit emissions. This is because these controls do not effectively capture gaseous pollutants. Two technologies that possibly could be used to further reduce the amount of vapor-phase HAP emitted from utilities are sorbent injection and selective catalytic reduction (SCR).[1]

**2.1.1 Sorbent injection.** Due to their multiple internal pores and high specific surface area, sorbents have the potential to improve the removal of Hg (mostly through the capture of elemental mercury ($Hg^0$; sorbents will also remove $Hg^{++}$) as well as other gaseous pollutants that are carried with combustion fine particulates in all coal-fired subcategories (except for integrated gasification combined cycle [IGCC] units because of their lack of external PM control device).

The extent of the potential Hg removal is dependent on: (1) efficient distribution of the sorbent (e.g., activated carbon) in the flue gas; (2) the amount of sorbent needed to achieve a specific level of Hg removal, which will vary depending on the fuel being burned; (3) the amount of chlorine (Cl) present in the fuel; and (4) the type of PM control device (e.g., at a given sorbent feed rate, a fabric filter provides more Hg control than an ESP because of the additional adsorption that occurs on the bags of the fabric filter because of the increased gas contact time).

Sorbents can be introduced by two basic methods: by channeling flue gas through a bed of sorbent or by direct sorbent injection. Sorbent bed designs consist of fixed-sorbent filter beds, moving beds, or fluidized sorbent filter beds. With direct sorbent injection, after sorbent is introduced into the flue gas, it adsorbs Hg and other contaminants and is captured downstream in an existing or sorbent-specific PM control device. The types of sorbent that may be viable in sorbent injection include two basic types of activated carbon (AC; regular and impregnated) as well as other carbon (mixed with other sorbents) and noncarbon sorbents.

Activated carbon is a specialized form of carbon produced by pyrolyzing coal or various hard, vegetative materials (e.g., wood) to remove volatile material. The resulting carbon-based material (char) then undergoes a steam or chemical activation process to produce an AC that contains multiple internal pores and has a very high specific surface area. With this internal pore structure, the AC can adsorb a broad range of contaminants. Various studies, shown in Table 1, have shown good to excellent Hg removal with the injection of AC (particularly on bituminous-fired units); however, other studies (also shown in Table 1) have not shown good Hg removal (particularly on subbituminous- and lignite-fired units). The Hg removal performance of AC injection seems to be highly dependent on coal rank and composition (i.e., Hg and Cl content of the coal) and specific utility plant configuration (e.g., sequencing of APCD equipment). Further, little long-term data are available.

Chemically impregnated AC is AC that has been supplemented with chemicals to improve its Hg removal. The Hg in the flue gas reacts with the chemical that is bound to the AC, and the resulting compound is removed by the PM control device. Typical impregnants for AC are chlorine, sulfur, and iodide. Chemically impregnated AC has shown enhanced Hg removal over regular AC. Chemically impregnated AC requires smaller rates of carbon injection than does regular AC for equivalent Hg removals. The required carbon-to-mercury mass ratio may be reduced by a factor of from 3 to 10 with the chemically impregnated AC.[2] The cost per mass unit of impregnated AC may, however, be significantly greater than that of unmodified AC.

Other commercially available sorbent materials are Sorbalit™ (a mixture of lime with additives and 3 to 5 percent AC) and Darco FGD (an AC derived from lignite).[2] Zeolites constitute another category of sorbent. There are naturally occurring mineral zeolites, in addition to commercially available synthetic zeolites. Both types contain large surface areas and have a good potential for Hg removal.

The AC test data available to EPA, representing full-scale electric utility units, consists of tests taken at four sites. The sites had initial baseline tests conducted without AC injection in 2001, and parametric tests and long-term test programs conducted in 2002 and 2003 after installation of AC injection. The test sites' sampling description, coal type, control device configuration, and total Hg removal (both the maximum Hg removal during each test and average Hg removal during the entire test period) are listed in Table 1. Even though these tests were taken over an extended period of time, the summary data available show that there appears to be variability in Hg removal results between the maximum Hg removal during each test and the average Hg removal during the entire test period at a given site.

Although AC, chemically impregnated AC, and other sorbents show potential for improving Hg removal over what is achieved with conventional PM and $SO_2$ controls, this technology is not currently available on a commercial basis and has not been installed, except on a demonstration basis, on any electric utility unit in the United States to date. Further, limited long-term data (e.g., longer than a few days) are available to indicate the performance of this technology on all representative coal ranks or on a significant number of different power plant configurations. Therefore, these technologies do not provide a viable basis for either establishing or going beyond the floor.

**2.1.2 Selective catalytic reduction (SCR).** The SCR test data available to EPA, representing full-scale electric utility units, consists of tests taken at four sites in 2001, two of the original four sites were then retested in 2002, and finally two additional sites were tested in 2002, for a total of eight sets of data. The test sites' coal type, control device configuration, and total Hg removal (with SCR turned off and SCR operating) are listed in Table 2. The data suggests that, although designed as a nitrogen oxides ($NO_x$) control technology, the SCR has ability to transform certain species of Hg into other speciated forms that are easier for conventional PM and $SO_2$ controls to capture. The transformation of Hg species can be seen most prominently when an SCR is operating at a site with a PM control device and a wet FGD control device or a site with only a single particulate (venturi) scrubber. The Hg emitted during combustion, which would (in the absence of the SCR) tend to remain as $Hg^0$, is oxidized to $Hg^{++}$. The highly soluble oxidized Hg is then removed by the wet FGD or particulate (venturi) scrubber. However, this Hg reduction effect has been observed in limited stack testing on bituminous coal-fired sites (S2 and S4), and results on a subbituminous coal-fired site have not been uniformly successful.[3] Sites S1 and S3 showed only minimal Hg oxidation across the SCR. To EPA's knowledge, no commercial-scale, lignite-fired, SCR-equipped unit has been tested to date, though it is entirely possible that greater Hg removal would result when applied to a lignite-fired unit. Similarly, SCR has not yet been tested on all types of coal sources as well as on blends of coal. It should be noted that these tests were of short-term nature and the maximum Hg removal seen may not represent the long-term average observed even at a given site. Also, the data show that SCR does not lead to increased Hg oxidation and removal in all cases on all coal ranks.

In summary, sorbent injection has not been sufficiently demonstrated in practice, nor have long-term economic considerations (e.g., carbon availability, waste disposal issues, and required permitting for new waste landfill and sludge ponds) been evaluated to allow sorbent injection to be considered viable as a beyond-the-floor option. With regard to the use of SCR, there is inadequate effectiveness information on which to base a beyond-the-floor standard.

**Table 1. Full-scale Activated Carbon Injection Emission Tests at Coal-fired Electric Utility Sites**

| Test site, Location | Description of test plan | Coal type | Control device | Maximum Hg removal during each test | Average Hg removal during the entire test period |
|---|---|---|---|---|---|
| Alabama Power, Gaston[4] | Long-term tests over 10 days, constant conditions, are scheduled for 2002-2003. | Bituminous | Hot-side ESP; COHPAC FF | S-CEM: <br>• 90% | S-CEM: <br>• 78% <br>Ontario-Hydro: <br>• 90% total <br>• 86% oxidized <br>• >98% elemental |
| WE Energies, Pleasant Prairie[5] | Long-term tests over 10 days, constant conditions. *Note: The S-CEM removal efficiencies shown here averages and maximums taken over (1) three days with an average injection rate of 1.6 lbs/MMacf, (2) four days with an average injection rate of 3.7 lbs/MMacf and (3), five days with an average injection rate of 11.3 lbs/MMacf.* | Powder River Basin Subbituminous | Cold-side ESP, SCA | S-CEM: <br>• 49%, 61%, and 70% | S-CEM: <br>• 47%, 57%, and 66% <br>Ontario-Hydro: <br>• 72.9% total <br>• 74.5% oxidized <br>• 70.7% elemental |
| PG&E NEG Salem Harbor Station[3] | Parametric tests and long-term tests in Spring 2002. | Bituminous | Cold-side ESP; SNCR | 280-290F: 68%, 70% <br>298-306F: 67%, 75%, 78% <br>322-327F: 65%, 85%, 85% <br>343-347F: 25%, 45% | 280-290F: 69% <br>298-306F: 73% <br>322-327F: 78% <br>343-347F: 35% |
| PG&E NEG Brayton Point Station[6] | Parametric tests and long-term tests in Fall 2002. | Bituminous | 2 Cold-side ESP, in series with combined SCA | Hg capture varied based on sorbent and operating conditions. | S-CEM: <br>• 62% |

COHPAC - combination of an upstream electrostatic precipitator followed by a high air-to cloth ratio fabric filter

SCA - Specific Collection Area

S-CEM - Semi-Continuous Emissions Monitor

Ontario Hydro - Ontario Hydro speciated mercury analysis method

SNCR - Selective Non-Catalytic Reduction

**Table 2. Full-scale SCR Emission Tests at Coal-fired Electric Utility Sites[7]**

| Site | Coal | Year sampled | PM Control | SO2 Control | Total Hg removal, % (w/SCR off: w/SCR on) |
|---|---|---|---|---|---|
| S1 | Powder River Basin Subbituminous | 2001 | ESP | None | 60 / 78 |
| S2 | Ohio Bituminous | 2001 | ESP | Wet FGD | 51 / 88 |
| S2* | Ohio Bituminous | 2002 | ESP | Wet FGD | NA / 84 |
| S3 | Pennsylvania Bituminous | 2001 | ESP | None | 16 / 13 |
| S4 | Kentucky Bituminous | 2001 | Particulate (Venturi) Scrubber | None | 46 / 90 |
| S4* | Kentucky Bituminous | 2002 | Particulate (Venturi) Scrubber | None | 44 / 91 |
| S5 | West Virginia Bituminous | 2002 | ESP | Wet FGD | 51 / 91 |
| S6 | Kentucky & West Virginia Bituminous | 2002 | ESP | None | No data currently available |

* Retest

NA - Not analyzed with SCR off.

## 2.2 IGCC Units

Integrated gasification combined cycle units are specialized units in which coal is first converted into synthetic coal gas. In this conversion process, the carbon in the coal reacts with water to produce hydrogen gas and carbon monoxide (CO). The synthetic coal gas (syngas) is then combusted in a combustion turbine, which drives an electric generator. Hot gases from the combustion turbine then pass through a waste heat boiler to produce steam. This steam is fed to a steam turbine connected to a second electric generator. Because of their design, IGCC units have no external APCD. Therefore, we believe the best potential way of reducing Hg emissions from existing IGCC units is to remove Hg from the syngas before combustion. An existing industrial IGCC unit has demonstrated a process, using sulfur-impregnated AC carbon beds, that has proven to yield 90 to 95 percent Hg removal from the coal syngas.[8] This technology could potentially be adapted to the electric utility IGCC units.

To our knowledge, neither of the two existing IGCC units have run tests of this type of carbon bed, fuel cleaning, device. Because of concerns about the costs involved and because existing IGCC units utilize older technology, it is not clear if using sulfur-impregnated AC carbon beds would be effective on the particular syngas burned in these units.

### 2.3 Coal Refuse-fired Units

Coal refuse units (i.e., 99 percent of their heat input supplied by burning coal refuse) are located adjacent to old coal mine refuse piles. The units are specially designed to burn this high-ash silt. All of the 13 coal refuse-fired units existing in 1999 are equipped with fluidized bed combustors (FBC); 10 of these 13 units inject limestone as a sorbent for $SO_2$ control, and 4 of these 13 units are equipped with SCR for $NO_x$ control. The only two coal refuse-fired units on which performance tests were conducted in response to the ICR are the MACT floor facilities for the coal-refuse fired subcategory.

To our knowledge, there are no currently available technologies that could be used as beyond-the-floor options for coal refuse units.

### 2.4 Oil-fired Units

The only emission control technology that we are aware of to consider as a beyond-the-floor option for existing oil-fired units is fabric filtration. Fabric filters have been shown in pilot-scale testing to be more effective at reducing Ni emissions than an ESP. However, the use of fabric filters on oil-fired units is also known to be problematic due to the prevalence of the "sticky" PM emitted from such units, which sticks to the fabric and creates a fire safety hazard. No existing oil-fired units are known to employ fabric filters as their PM control. Because of this, fabric filters are not considered to be a viable beyond-the-floor option for oil-fired units.

## 3.0 BEYOND-THE-FLOOR OPTIONS FOR NEW COAL- AND OIL-FIRED ELECTRIC UTILITY STEAM GENERATING UNITS

Once the MACT floor determinations were done for new units in each subcategory (by fuel type), EPA considered various regulatory options more stringent than the MACT floor level of control (i.e., additional technologies or other work practices that could result in lower emissions) for the different subcategories. Due to the technical complexities of controlling Hg and Ni emissions from the sources affected by this rule, we have not been able to determine whether (identified) potential beyond-the-floor options are available.. The following describes the possible beyond-the-floor options of which we are aware for new units.

### 3.1 Coal-fired Units

As discussed in Section 2 of this memorandum, two technologies that possibly could be used to further reduce the amount of vapor phase Hg emitted from utilities are sorbent injection and SCR. However, as explained in Section 2, sorbent injection is not available on a commercial basis and has not been demonstrated on a utility unit operating at full capacity over an extended period of time. Similarly, SCR has not shown the same change-in-speciation effect on Hg emissions on all types of coal sources (and among different seams within a coal rank).

### 3.2 IGCC Units

Because of their design, IGCC units have no external APCD controls. Therefore, as is explained in Section 2 of this memorandum, the best potential way of improving Hg removal from IGCC units is to remove the Hg from the syngas before combustion. Based on published information regarding the industrial IGCC unit noted in Section 2, EPA believes that a 90 percent reduction in Hg emissions is possible from new IGCC units based on the use of carbon bed technology. Therefore, we believe that proposing a 90 percent Hg reduction based on the use of carbon bed technology as a beyond-the-floor level for new IGCC units is reasonable.

### 3.3 Coal Refuse-fired Units

Existing coal refuse-fired units utilizing 100 percent coal refuse, all of which utilize FBC technology, have demonstrated the best Hg control of any emissions-tested electric utility unit in the industry based on the electric utilities information collection request (ICR).

### 3.4 Oil-fired Units

There has not been a new oil-fired unit constructed in the United States since 1981. As discussed in Section 2 of this memorandum, if a new oil-fired unit is constructed, the only technology that would offer emissions control better than the proposed new MACT limits for emission control is the use of fabric filtration; however, fabric filtration is not presently considered to be a viable control option for oil-fired units because of the prevalence of the "sticky" PM emitted from these units, which sticks to the fabric and creates a fire safety hazard.

## REFERENCES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2. New Jersey Mercury Task Force. "Volume 1: Executive Summary and Recommendations." pp. 50-52. December 2001.

3. Srivastava, Ravi K. "Current and Emerging Mercury Control Technologies." Western Mercury Workshop, April 21-22, 2003, Denver, CO.

4. "Final Site Report for: E.C. Gaston Unit 3: Sorbent Injection into a Cold-Side ESP for Mercury Control" prepared by ADA Environmental Solutions, Report No. 41005R11, May 2003, pp. 31-32.

5. "Final Site Report for: Pleasant Prairie Power Plant Unit 2: Sorbent Injection into a Cold-Side ESP for Mercury Control" prepared by ADA Environmental Solutions, Report No. 41005R12, May 2003, pp. 27-28.

6. Durham, M. "Update on Full-Scale Activated Carbon Injection for Control of Mercury Emissions." Presentation slide show given by ADA Environmental Solutions to Utility MACT Working Group, August 8, 2002. Docket A-92-55, Item No. II-E-81.

7. Laudal, D., P. Chu, L. Brickett, C.W. Lee. "Effect of SCR on mercury Speciation for Coal-fired Power Plants." Presentation by Energy & Environmental Research Center (EERC) University of North Dakota.

8. Rutkowski, M.G., M.G. Klett, and R.C. Maxwell. "The Cost of Mercury Removal from Coal-Based IGCC Relative to a PC Plant." Gasification Technologies 2002 Symposium, October 27-30, 2002, San Francisco, CA. Docket A-92-55, Item No. II-I-23.

ATTACHMENT G2
U.S. DEPARTMENT OF ENERGY
ENERGY EFFICIENCY AND RENEWABLE ENERGY
"NET GENERATION BY ENERGY SOURCE BY TYPE OF PRODUCER"
OCTOBER 2006

# U.S. Department of Energy
# Energy Information Administration

# "Net Generation by Energy Source by Type of Producer"

## October 2006

# Net Generation by Energy Source by Type of Producer

*Electric Power Annual with data for 2005*
*Report Released: October 4, 2006*
*Next Release Date: October 2007*

Table 1.1 xls pdf format

Table 1.1. Net Generation by Energy Source by Type of Producer, 1994 through 2005
(Thousand Megawatthours)

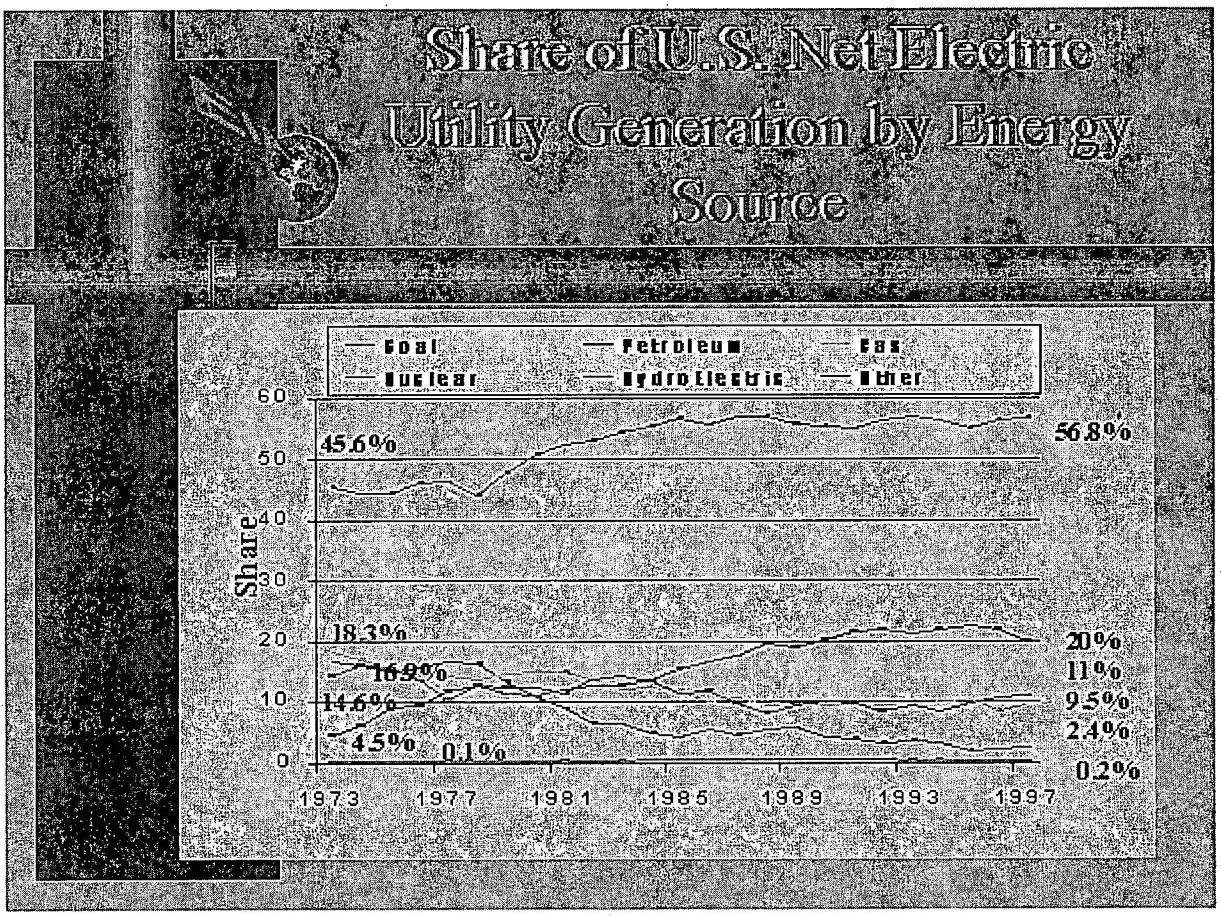
| Period | Coal[1] | Petroleum [2] | Natural Gas | Other Gases[3] | Nuclear | Hydroelectric Conventional[4] | Other Renewables[5] | Hydroelectric Pumped Storage[6] | Other [7] | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total (All Sectors)** | | | | | | | | | | |
| 1994 | 1,690,694 | 105,901 | 460,219 | 13,319 | 640,440 | 260,126 | 76,535 | -3,378 | 3,667 | 3,247,522 |
| 1995 | 1,709,426 | 74,554 | 496,058 | 13,870 | 673,402 | 310,833 | 73,965 | -2,725 | 4,104 | 3,353,487 |
| 1996 | 1,795,196 | 81,411 | 455,056 | 14,356 | 674,729 | 347,162 | 75,796 | -3,088 | 3,571 | 3,444,188 |
| 1997 | 1,845,016 | 92,555 | 479,399 | 13,351 | 628,644 | 356,453 | 77,183 | -4,040 | 3,612 | 3,492,172 |
| 1998 | 1,873,516 | 128,800 | 531,257 | 13,492 | 673,702 | 323,336 | 77,088 | -4,467 | 3,571 | 3,620,295 |
| 1999 | 1,881,087 | 118,061 | 556,396 | 14,126 | 728,254 | 319,536 | 79,423 | -6,097 | 4,024 | 3,694,810 |
| 2000 | 1,966,265 | 111,221 | 601,038 | 13,955 | 753,893 | 275,573 | 80,906 | -5,539 | 4,794 | 3,802,105 |
| 2001 | 1,903,956 | 124,880 | 639,129 | 9,039 | 768,826 | 216,961 | 77,985 | -8,823 | 4,690 | 3,736,644 |
| 2002 | 1,933,130 | 94,567 | 691,006 | 11,463 | 780,064 | 264,329 | 86,922 | -8,743 | 5,714 | 3,858,452 |
| 2003 | 1,973,737 | 119,406 | 649,908 | 15,600 | 763,733 | 275,806 | 87,410 | -8,535 | 6,121 | 3,883,185 |
| 2004 | 1,978,620 | 120,646 | 708,979 | 16,766 | 788,528 | 268,417 | 90,408 | -8,488 | 6,679 | 3,970,555 |
| 2005 | 2,013,179 | 122,522 | 757,974 | 16,317 | 781,986 | 269,587 | 94,932 | -6,558 | 4,749 | 4,054,688 |
| **Electricity Generators, Electric Utilities** | | | | | | | | | | |
| 1994 | 1,635,493 | 91,039 | 291,115 | -- | 640,440 | 247,071 | 8,933 | -3,378 | -- | 2,910,712 |
| 1995 | 1,652,914 | 60,844 | 307,306 | -- | 673,402 | 296,378 | 6,409 | -2,725 | -- | 2,994,529 |
| 1996 | 1,737,453 | 67,346 | 262,730 | -- | 674,729 | 331,058 | 7,214 | -3,088 | -- | 3,077,442 |
| 1997 | 1,787,806 | 77,753 | 283,625 | -- | 628,644 | 341,273 | 7,462 | -4,040 | -- | 3,122,523 |
| 1998 | 1,807,480 | 110,158 | 309,222 | -- | 673,702 | 308,844 | 7,206 | -4,441 | -- | 3,212,171 |
| 1999 | 1,767,679 | 86,929 | 296,381 | -- | 725,036 | 299,914 | 3,716 | -5,982 | -- | 3,173,674 |
| 2000 | 1,696,619 | 72,180 | 290,715 | -- | 705,433 | 253,155 | 2,241 | -4,960 | -- | 3,015,383 |

ATTACHMENT G3
U.S. DEPARTMENT OF ENERGY
ENERGY INFORMATION ADMINISTRATION
“SHARE OF US NET ELECTIC UTILITY GENERATION BY ENERGY SOURCE”
(NO DATE)

# U.S. Department of Energy
# Energy Information Administration

# “Share of U.S. Net Electric Utility Generation by Energy Source”

## (no date)




Slide 27 of 30

- Electric Utilities used petroleum for 17 percent of electric generation in 1973. During the 1973 oil embargo petroleum prices soared while its availability was labeled as questionable, thus began a long-term decline in the use of petroleum as a fuel for electric generation.
- Petroleum-fired electric plants produced only 2 percent of electric generation in 1997 -- due to increased use of nuclear, gas-fired and coal-fired electric generation.
- A rapid growth of nuclear electricity generation was slowed by the 1979 accident at the Three Mile Island nuclear power plant. No new orders for nuclear reactors were made after 1978.
- Electric utility generation by nuclear reactors has improved significantly. The national capacity factor-below 65 percent in the 1970's and 1980's-has surpassed 70 percent since 1991, achieving 76 percent in 1996.

Source: Nuclear portion of domestic electricity: Energy Information Administration, Annual Energy Review 1997, DOE/EIA-0384(97). (Washington, DC, July 1998), Table 8.3; Reactor performance: Annual Energy Outlook 1998, DOE/EIA-0383(98), (Washington, DC-December 1997), p 54; Form EIA-759, "Monthly Power Plant Report."

ATTACHMENT G4
U.S. DEPARTMENT OF ENERGY
ENERGY INFORMATION ADMINSTRATION
"SUMMARY STATISTICS: RECEIPTS AND COST OF FOSSIL FUELS FOR THE ELECTRIC POWER INDUSTRY BY SECTOR, BTUS"
OCTOBER 2006

# U.S. Department of Energy
# Energy Information Administration

# "Summary Statistics: Receipts and Cost of Fossil Fuels for the Electric Power Industry by Sector, BTUs"

## October 2006

# Summary Statistics: Receipts and Cost of Fossil Fuels for the Electric Power Industry by Sector, Btus

*Electric Power Monthly with data for October 2006*
*Report Released: January 12, 2007*
*Next Release Date: Mid-February 2007*

**Table ES2.b. xls format Electric Power Monthly**

**Table ES2.b. Summary Statistics: Receipts and Cost of Fossil Fuels for the Electric Power Industry by Sector, Btus, 2006 and 2005**

| | September | | | | | | Year-to-Date | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total (All Sectors)** | | | | | | | | | | |
| **Items** | **Receipts (billion Btu)** | | **Cost (dollars/million Btu)** | | **Number of Plants [1]** | | **Receipts** | | **Cost** | |
| | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** |
| Coal[2] | 1,753,632 | 1,784,392 | 1.72 | 1.6 | 464 | 472 | 15,826,758 | 15,469,407 | 1.69 | 1.53 |
| Petroleum Liquids [3] | 34,735 | 95,228 | 8.14 | 9.09 | 311 | 409 | 330,138 | 676,562 | 8.88 | 7.03 |
| Petroleum Coke | 17,443 | 17,905 | 1.38 | 1.11 | 25 | 30 | 157,089 | 160,050 | 1.29 | 1.09 |
| Natural Gas[4] | 599,686 | 599,696 | 6.22 | 10.63 | 830 | 864 | 5,355,872 | 5,018,753 | 7 | 7.53 |
| Fossil Fuels | 2,405,496 | 2,497,220 | 2.93 | 4.05 | 1,140 | 1,180 | 21,669,856 | 21,324,771 | 3.11 | 3.11 |
| **Electric Utilities** | | | | | | | | | | |
| **Items** | **Receipts (billion Btu)** | | **Cost (dollars/million Btu)** | | **Number of Plants** | | **Receipts** | | **Cost** | |
| | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** |
| Coal[2] | 1,337,707 | 1,343,424 | 1.71 | 1.61 | 310 | 315 | 12,150,627 | 11,850,474 | 1.69 | 1.52 |
| Petroleum Liquids[3] | 26,425 | 55,340 | 7.94 | 8.5 | 203 | 250 | 219,057 | 401,539 | 8.4 | 6.66 |
| Petroleum Coke | 9,478 | 9,427 | 1.5 | 1.26 | 10 | 11 | 80,398 | 77,990 | 1.44 | 1.27 |
| Natural Gas[4] | 196,723 | 182,295 | 6.83 | 10.81 | 317 | 306 | 1,790,453 | 1,453,607 | 7.38 | 7.72 |
| Fossil Fuels | 1,570,334 | 1,590,486 | 2.45 | 2.9 | 515 | 511 | 14,240,534 | 13,783,611 | 2.5 | 2.32 |
| **Independent Power Producers** | | | | | | | | | | |
| **Items** | **Receipts (billion Btu)** | | **Cost (dollars/million Btu)** | | **Number of Plants** | | **Receipts** | | **Cost** | |
| | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** | **Sep-06** | **Sep-05** |
| Coal[2] | 387,198 | 412,078 | 1.73 | 1.55 | 129 | 129 | 3,431,615 | 3,355,251 | 1.69 | 1.55 |

ATTACHMENT H1
BREAKTHROUGH TECHNOLOGIES INSTITUTE
"FUEL CELLS 2000 PROJECTS DATABASE"
NOVEMBER 2000

# Breakthrough Technologies Institute

# "Fuel Cells 2000 Projects Database"

# November 2000

Use the Binocular Icon in Acrobat Reader to Search this Document

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# Worldwide Fuel Cell Installations

| Fuel cell Manufacturer | Project Partners | Fuel cell | Location | Building | Start date | Status | Fuel used | Picture | Comments / Contact Information |
|---|---|---|---|---|---|---|---|---|---|
| Acumentrics Corporation | U.S.Department of Defense, the National Park Service, Electric Power Research Institute, First Energy | 5 kW tubular SOFC beta unit | Cleveland, Ohio | Cuyahoga Valley National Park Environmental Education Center | May 2005 | Ongoing | | | Will be operated in grid parallel mode with additional capability to operate in independent island mode to meet critical needs of the educational facility during power loss. Will add another 5 kW unit in the spring of 2006 to bring total installed capacity to 10 kW. |
| Acumentrics Corporation | Sumitomo Corporation, Nippon Steel Corporation | 5 kW tubular SOFC | Japan | Nippon Steel Corporation's Yawata Laboratories | Shipped Jan. 2005 | | Natural gas | | |
| Acumentrics Corporation | US Army Corp of Engineers Construction and Engineering Research Laboratory (CERL), Fuel Cell Test and Evaluation Center (FCTec), SOFCo EFS Holdings LLC | Two 5 kW tubular SOFC CHP units | Sheridan, Wyoming | Big Goose Ranger Station in Bighorn National Forest | Jul. 2005 | Ongoing | Propane | | Provides power to two cabins, an office/shop, five trailers and drinking and wastewater pumping systems. Recycled heat provides heat to one cabin. The fuel cell and station will be shut down for six months during cold weather. |
| Acumentrics | SOFCo EFS Holdings LLC | 10 kW tubular SOFC | Ohio | | Announced Aug. 2005 | | Commercial 2007 Certified Diesel fuel | | Completed a 500-hour demonstration using the SOFC along with a diesel reformer. Funded by Ohio's Third Frontier Program to demonstrate a sulfur-tolerant SOFC. |
| Acumentrics Corporation | US Department of Energy National Energy Technology Laboratory (NETL), University of Alaska-Fairbanks, Ohio Department of Development, SOFCo EFS Holdings LLC | 5 kW tubular SOFC | Idaho Falls, Idaho | NETL's Idaho National Engineering and Environmental Laboratory | Jun. 2005 | | 2007 Certified Diesel and Syntroleum diesel | | Three-day demonstration using the SOFC with a catalytic partial oxidation (CPOX) diesel reformer. The fuel cell will be transferred to the US Department of Energy's Arctic Energy Technology Development Laboratory at the University of Alaska, Fairbanks for 18 months of testing using natural gas. |
| Acumentrics Corporation | National Park Service, University of Alaska-Fairbanks | 5 kW tubular SOFC | Seward, Alaska | Exit Glacier Nature Center in Kenai Fjords National Park | May 2004 | | Propane | | Provides power and heat to the nature center year-round. |
| Acumentrics Corporation | ChevronTexaco Technology Ventures | Five 2 kW tubular BB-SOFC 2000 units | Houston, Texas | | Shipped Jan. 2003 | | | | |
| Acumentrics Corporation | ChevronTexaco Technology Ventures | 2 kW tubular BB-SOFC 2000 | Houston, Texas | | Shipped Oct 2002 | | | | |
| American Fuel Cell Corp. | EPRIGEN, Inc. | Sixteen 3 kW Alpha Residential Power | Various locations | | | | Natural gas | | For alpha testing. US DoD Climate Chang Fuel Cell Program grant ($48,000) |

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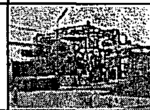
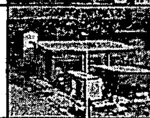
| | | Generation (RPG) units | | | | | | | |
| Ansaldo Fuel Cells Spa | MTU-CFC Solutions, IZAR, FhG Umsicht, CESPA, Z.A.E., OVM, University Genova, ASM, Nitra, Technip, E.ON | "MW-sized" MCFC fuel cell plant | Italy | | Planned | | Biogas | | BICEPS project--Biogas Integrated Concepts. |
| Ansaldo Fuel Cells Spa | Marmara Research Centre | 500 kW hybrid plant MCFC/Gas Turbine | Turkey | | Planned plant start-up Spring 2006 | Planned, undergoing site preparations | NATO F76 Diesel oil | | MCFC-NAV project. Prototype of diesel-fueled MCFC for naval applications |
| Ansaldo Fuel Cells Spa | FN Spa (site owner) | 125 kW hybrid plant MCFC/Gas Turbine | Bosco Marengo, Italy | FN Spa, outdoor site | Jun. 2005 | Operational | Natural gas |  | TECNODEMO project. 3,000 operational hours achieved by Oct. 2005. |
| Ansaldo Fuel Cells Spa | Iberdrola, ENEA, Balcke | Series 2tW, 500 kW hybrid plant MCFC/Gas Turbine | Guadalix, Spain | | Dec. 2004 | Plant improvements ongoing after first operational run | Natural gas |  | FOAK project. First of the "Series 2TW" |
| Ansaldo Fuel Cells Spa | ENEL | 100 kW MCFC | Milan, Italy | ENEL site | 1998-1999 | Completed | Natural gas |  | Proof of Concept |
| Ansaldo Fuel Cells Spa | IBERDROLA | 100 kW MCFC | Guadalix, Spain | IBERDROLA stack test and conditioning facility | 1999 | Completed | Natural gas | | |
| Apollo Energy Systems Inc. | Hydrolec, Inc | 10 kW Apollo alkaline fuel cell w/ 12 kW lead-cobalt battery | Ft. Lauderdale, Florida | | 2002 | In production | | | Contract to supply 2,000 Apollo power plants per month to Hydrolec, Inc. for power back up and elevator systems around the world; starting in 2002. Contract worth $223 million. |
| Astris Energi Inc. | Electronic Machining srl (El.Ma), Energie Rinnovabili Italia srl (ERI) | Alkaline fuel cells | Rovereto, Italy | Astris Energi site | Sale announced Aug. 2005 | Planned | | | Order for fuel cells, test equipment and an E8 generator. Will be used to demonstrate Astris' fuel cell technology to potential clients and partners. Success during this trial may lead to 24 mountain shelter projects and a demonstration in Isera, Italy. |
| Ballard | US Department of Defense, LOGANEnergy | Two AirGen 1 kW PEM units | Ayer, Massachusetts | Fort Devens office security hut | Planned | Contract awarded Jun. 2005 | Hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. The fuel cells will be installed in a stand-by power support role at the security hut of the main office facility. |
| Ballard | Government of Canada, National Research Council, MGE UPS Systems | NexaRM | Vancouver, Canada | National Research Council's Institute for Fuel Cell Innovation | Planned | | | | Will serve as a backup power source for uninterruptible power supply (UPS). Part of Canada's h2 Early Adopters Program (h2EA) |
| Ballard | Government of Canada, Bell Canada | NexaRM | Canada | Bell Canada backup power site | Planned | | | | Part of Canada's h2 Early Adopters Program (h2EA) |
| Ballard | Government of Canada, University of Toronto at Mississauga. MGE UPS Systems | NexaRM | Mississauga, Canada | University of Toronto at Mississauga | Planned | | | | Will provide critical backup power for server room applications at the University. Part of Canada's h2 Early Adopters Program (h2EA) |
| Ballard | Nippon Oil | Nine 1 kW PEM | Japan | Four houses | Aug. 2005 | | Coil oil | | World's first coil oil-fueled |

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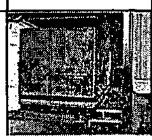
| | | units | | and 5 multi-family residences | | | | | fuel cell demonstration. |
| Ballard | Tokyo Gas | 1 kW MK1030 PEM fuel cell | Tokyo, Japan | Prime Minister's residence | Apr. 2005 | | Natural gas | | Co-generation unit--provides electricity and reuses waste heat. |
| Ballard | Tokyo Gas | One-hundred 1 kW Lifuel PEM units | Various locations, Japan | Residential | Installed by Jun. 2005 | | | | |
| Ballard | Osaka Gas | Twenty-eight PEM units | Japan | Residential | Installations begin Aug. 2005 | | | | Part of the first stage of the "Large-Scale Demonstration Project of Stationary Fuel Cells" |
| Ballard | Nippon Oil | 1 kW PEM | Yokohama, Japan | Nippon Oil's Yokohama Oil Refinery | Apr. 2004 | | Kerosene | | |
| Ballard | Keiyo Gas | 1 kW PEM | Chiba, Japan | | 2004 | | | | Field test. |
| Ballard | Osaka Gas | PEM-"semi commercial unit, type-2" | Japan | | Shipped Jan. 2004 | | | | Cogeneration system for field testing. |
| Ballard | Tokyo Gas | 1 kW PEM | Yokohama, Japan | Tokyo Gas employee's residence | Unknown | Mar. 2003 | |  | Cogeneration units. Ten-month test operation. |
| Ballard | Japan Gas Association | 1 kW PEM | Tobitakyu, Japan | Kajima Technical Research Institute | Feb. 2003 | | | | Japan Gas Assoc. Phase 2 test of residential PEM fuel cells of different manufacturers. |
| Ballard | EnBW | 250 kW PEM | Mingolsheim, Germany | Spa bath | Sep. 2002 | One-year demonstration | Natural gas |  | Logged 6,000 hours of operation at 75% efficiency with utilization of waste heat. Part of EDISon (Intelligent Energy Distribution System) program. |
| Ballard | EUS GmbH, AEG SVS Power Supply Systems GmbH, E.ON Engineering GmbH, MVV Energie AG, University of Dortmund | 250 kW stationary PEM generator CHP with micro-turbine | Oberhausen, Germany | Fraunhofer Institute for Environmental Safety and Energy Engineering | Jun. 2002 | Ongoing | Natural gas |  | "PEM-Oberhausen" project http://www.pem-oberhausen.de/englisch/index.html |
| Ballard | Japan Gas Association | 1 kW PEM | Tokyo and Osaka, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | | | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of operation in Phase I testing, 8,000 hours scheduled in Phase 2 using fuel cells of different manufacturers. |
| Ballard | | 250 kW stationary PEM generator | Tomakomai, Japan | Nishimachi Sewage Treatment Center | Jul. 2001 | Nov. 2002 | Methane gas from anaerobic digester | | |
| Ballard | Nippon Telegraph and Telephone (NTT) | 250 kW PEM stationary generator | Tokyo, Japan | NTT's Musashino Research and Development Center | Mar. 2001 | May 2003 | Town gas |  | Cogeneration system incorporating an adsorption chiller for air conditioning. Operated for 5,026 hours. |

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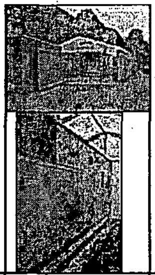
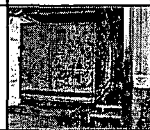
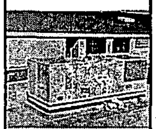
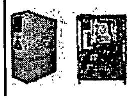
| Ballard | Promocell , University of Liege | 220 kW PEM stationary generator | Liege, Belgium | University of Liege | 2001 | Ongoing | Natural gas |  | Provides power to the university campus and heats the university swimming pool. |
| Ballard | | 250 kW stationary PEM generator | Tomakomai, Japan | Nishimachi Sewage Treatment Center | 2001 | Ongoing | Methane gas from anaerobic digester | | |
| Ballard | Bewag AG | 250 kW PEM | Berlin, Germany | Bewag's Fuel Cell Innovation Park | Jun. 2000 | Ongoing | Natural gas | | Provides power to the park. |
| Ballard | Bewag, Hamburgische Electrizitäts-Werke AG, EDF, PreussenElektra AG, VEAG Vereinigte Energiewerke AG | 250 kW PEM stationary generator | Berlin, Germany | Bewag's Treptow heating plant | Jun. 2000 | Ongoing | Natural gas |  | Five-year demonstration project. Being tested by a consortium of European electric companies led by Bewag, the largest supplier of power and heat in Berlin. |
| Ballard | Nippon Telegraph and Telephone (NTT) | 250 kW PEM stationary generator | Tokyo, Japan | NTT research lab | Nov. 2000 | Ended May 2003 | Town gas |  | Cogeneration system incorporating an adsorption chiller for air conditioning. Operated for 5,026 hours. |
| Ballard | Elektra Birseck Muenchenstein (EBM) | 250 kW PEM stationary generator | Basel, Switzerland | EBM corporate headquarters | 2000 | | Natural gas |  | |
| Ballard | Cinergy Technology Inc. | 250 kW PEM stationary generator | Crane, Indiana | Crane Naval Surface Warfare Center | Sept. 1999 | Ended 2001 | Natural gas |   | First 250 kW PEM fuel cell generator in the world to enter field testing. Provided heat and power during the two-year evaluation. |
| Bharat Heavy Electricals Ltd. (BHEL) | | 50 kW PAFC power plant (two 25 kW stacks) | India | BHEL testing facility | | 2000 | By-product hydrogen from a chlor-alkali factory | | In-house design, operated for 500 hours. |
| 3rennstoffzellente :hnik GmbH (ZBT) | VNG, Stadtwerke Chemnitz, DBI Gas und Umweltechnik, Bergakademie Frieberg, Schalt und Regeltechnik | 4 kW Inhouse 4000 PEM CHP | Chemnitz, Germany | Chemnitz Botanical Garden | Jun. 2005 | | Natural gas | | Part of DemoCell project conducted by German Company, VNG. Provides heat and power, with excess fed to the local utility grid. |
| Ceramic Fuel Cells Ltd. (CFCL) | szencorp | 1 kW Micro-CHP SOFC | South Melbourne, Australia | szencorp's revamped commercial building | Planned | | Natural gas | | Two-year installation, with possible extension. To be installed in a certified "green building". |
| Ceramic Fuel Cells Ltd. (CFCL) | GippsTAFE | 1 kW Micro-CHP SOFC | Chadstone, Australia | Energy and Telecommunications Training Australia (ETTA) office at GippsTAFE's Chadstone campus | Announced Apr. 2005 | | Natural gas | | Three-month field trial, trial may be extended. |
| Ceramic Fuel Cells Ltd. (CFCL) | EWE, VNG AG | 1 kW Micro-CHP SOFC | Brandenburg, Germany | | Installation planned in early 2006 | | Natural gas |  | Combined heat and power. CFCL and EWE have signed an agreement to develop a fuel cell- |

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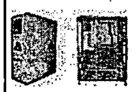
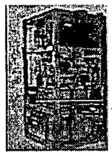
| | | | | | | | | | powered CHP unit for the residential market. |
| Ceramic Fuel Cells Ltd. (CFCL) | Powerco | 1 kW Micro-CHP SOFC | State of Tasmania, New Zealand | | Announced 2005 | To be delivered | Natural gas | | Combined heat and power |
| Ceramic Fuel Cells Ltd. (CFCL) | Powerco | 1 kW Micro-CHP SOFC | Wellington, New Zealand | Industrial Research Limited site | Aug. 2005 | | Natural gas | | Combined heat and power. |
| Ceramic Fuel Cells Ltd. (CFCL) | EWE | 1 kW Micro-CHP SOFC | Oldenburg, Germany | | Installation planned in late 2005 | | Natural gas |  | Combined heat and power. CFCL and EWE have signed an agreement to develop a fuel cell-powered CHP unit for the residential market. |
| Dais Analytic | Hamburg Gas Consult, Wingas, Technische Werke Ludwigshafen, European Fuel Cell GmBH, | Two 3 kW PEM Alpha units | Ludwigshafen, Germany | Test house | First unit installed Aug. 1999, second unit installed May 2000 | | Natural gas |  | Provided combined heat and power. Incorporated in ""House of the Future, Prototype 1" demonstrator. Preliminary prototypes were installed at Verbundnetz AG in Machern, Germany, Mar. 1999. |
| Dais Analytic | Hamburg Gas Consult, European Fuel Cell GmBH | PEM | Kassel, Germany | | 2000 | | | | |
| Dais Analytic | Hamburg Gas Consult, European Fuel Cell GmBH | PEM | Hannover, Germany | | 2000 | | | | |
| Dais Analytic | Hamburg Gas Consult, European Fuel Cell GmBH | 3 kW PEM | Hamburg, Germany | | 1999 | | | | |
| Dais Analytic | Hamburg Gas Consult, VNG | Alpha PEM CHP | Leipzig, Germany | Apartment | Aug. 1999 | | | | |
| DCH Technologies | | 5 kW PEM | | Unspecified global natural gas utility | Shipped Mar. 2002 | | Natural gas | | |
| DCH Technologies | Con Edison Co. of New York | 5 kW Enable Fuel Cell system | New York | Con Edison | Shipped May 2002 | | Hydrogen or natural gas | | Con Edison to test and validate the system, then place the fuel cell with targeted customers for evaluation as a power quality and/or peak shaving system. Company no longer in business. |
| European Fuel Cell GmbH | siGEN, Berwickshire Housing Association (BHA), Scottish Power, Scottish Enterprise, Baxi Group | 1.5 kW PEM Home Energy Center Micro-CHP | Eyemouth, UK (Scotland) | Residential | Sept. 2005 | One-year trial | Natural gas | | First residential fuel cell micro-CHP unit demonstrated in the UK. Will supply power and heat. European Fuel Cell plans about 100 installations at various European locations. |
| European Fuel Cell GmbH | EnBW | 1.5 kW PEM beta prototype | Germany | Residential | | | | | First European Fuel Cell GmbH unit to be tested at an operational site. |
| Fuel Cell Technologies (FCT) | University of Toronto | Four 5 kW SOFC units | Mississauga, Canada | 12-unit student townhouse block at the University of Toronto-Mississauga | Jul. 2005 | | Natural gas | | The four fuel cells will be connected to form a "mini-grid". The units will provide power and co-generated heat. Sponsored by Technology Partnerships Canada h2 Early Adopters Program. |
| Fuel Cell Technologies (FCT) | US Army Construction Engineering Research Laboratory (CERL), Fuel Cell Test and Evaluation Center (FCTec) Siemens Power | 5 kW SOFC CHP | Ft. Meade, Maryland | Maintenance and repair facility at Fort Meade | To be delivered to Ft. Meade in Jun. 2005 after testing at FCTec in Apr.-May 2005 | One-year demonstration | Natural gas | | |

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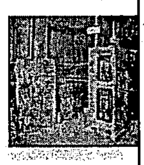
| | Generation, Inc | | | | | | | | |
| Fuel Cell Technologies (FCT) | Canadian Centre for Housing Technology, Natural Resources Canada | 5 kW SOFC | Kingston, Canada | Demonstration residential unit at the Canadian Centre for Housing Technology | Mar. 2005 | Installed | Natural gas | | Improved system with gas-powered heat-up to allow starting without an additional electrical power source. The inverter, which converts fuel cell energy to AC power used by most household appliances, was redesigned to satisfy residential standards. |
| Fuel Cell Technologies (FCT) | Federal University Itajuba | 5 kW SOFC | Itajuba, Brazil | Federal University-Itajuba | Shipped Mar. 2005 | | Natural gas | | First SOFC system tested in South America. The system will be evaluated for performance, to provide parameters to validate various SOFC modeling tools and serve as a demonstration system for Brazilian universities and energy companies. |
| Fuel Cell Technologies (FCT) | National Research Council | 5 kW SOFC | Vancouver, Canada | Institute for Fuel Cell Innovation at National Research Council | Planned, shipped Mar. 2005 | | Natural gas, methanol | | Will provide electricity to power a ground source heat pump to provide climate control for the NRC-IFCI building. Co-generated waste heat will be utilized for building services. |
| Fuel Cell Technologies (FCT) | Siemens Power Generation, Inc. | SOFC balance of plant assembly | Pittsburgh, Pennsylvania | Siemens Westinghouse Power Corporation | Planned, shipped Mar. 2005 | | | | Will be used to test Siemen's new High Power Density cells as part of a federal10-year, US$500 million program to developing innovative, low-cost ways to commercialize SOFCs that can be mass-produced at a target cost of US$400/kW. |
| Fuel Cell Technologies (FCT) | University of Liege | 5 kW tubular SOFC CHP | Liege, Belgium | University of Liege | Shipped Jun. 2005 | | | | For testing and validation. |
| Fuel Cell Technologies | Siemens Power Generation, Inc., Penn State Energy Institute, Pennsylvania Department of Conservation and Natural Resources | 5 kW SOFC | Parker Dam State Park, Pennsylvania | Parker Dam State Park Fuel Cell Pavilion | Received Dec. 2004 | Operational | Natural gas from Pennsylvania forests | | Heats cabins and administration buildings, and provides hot water for showers. |
| Fuel Cell Technologies (FCT) | University of Alaska, Fairbanks Natural Gas | 5 kW SOFC Alpha unit | Fairbanks, Alaska | Fairbanks Natural Gas site | Aug. 2003 | Operational | High pressure natural gas |  | By April 2004 the system had operated 6,158 hours. |
| Fuel Cell Technologies (FCT) | RWE | 5 kW SOFC Alpha unit | Mechernich and Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Shipped to Mechernich In Aug. 2003, relocated to Essen in Nov. 2003 | De-commissioned | Low pressure natural gas at Mechernich, high pressure natural gas at Essen |  | First tested at the RWE Lab in Mechernich, then installed at Fuel Cell Pavilion. Operated 3,541 hours. System degraded by over temperature and returned to FCT. RWE planned to upgrade to a Beta Unit. |
| Fuel Cell Technologies (FCT) | JFE Urban Development Corporation | 5 kW SOFC Alpha unit | Yokohama, Japan | JFE | Sep. 2003 | Operational | Low pressure natural gas |  | JFE will promote, sell, distribute and service FCT's SOFC products up to 50kW in the commercial and residential East Asian markets. By April 2004, had operated 1,700 hours. JFE will upgrade to a Beta unit, which can be modified for different NG |

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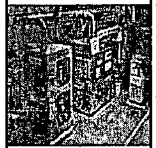
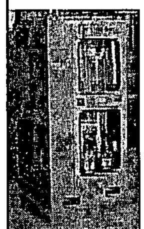
| | | | | | | | | | compositions. |
| Fuel Cell Technologies (FCT) | Ford, DTE Energy | 5 kW SOFC Alpha unit | Dearborn, Michigan | Ford's Dearborn Assembly Plant | Jul. 2003 | Testing completed | Low pressure natural gas, natural gas augmented with hydrogen gas derived from paint fume emissions |  | Part of Ford's 'Fumes-to-Fuel' System. The pilot system consumes emissions from Ford's vehicle paint shop and turns them into electrical energy and heat for the facility. By Apr. 2004 the fuel cell had operated 1,164 hours. A 50 kW system is being discussed. The 5 kW SOFC System may be relocated to Ford's Visitors center for demonstration. |
| Fuel Cell Technologies (FCT) | BC Research Inc, Methanex, NORAM Engineers & Constructors, QuestAir Technologies | 5 kW SOFC | Vancouver, Canada | BC Research Inc.'s laboratory building | Agreement signed Jun. 2003 | | Natural gas of varying NGL composition s, methanol, hydrogen, propane and heavier hydrocarbon s | | Will provide an uninterruptible power supply to BC Research's bio-assay lab. The heat and hot water output from the SOFC will also be used by the BC Research Complex. |
| Fuel Cell Technologies (FCT) | | 5 kW SOFC | Kingston, Canada | FCT research facility | | Operational | Natural gas | | |
| Fuel Cell Technologies (FCT) | U.S. Department of Energy's National Energy Technology Laboratory (NETL), Electric Power Research Institute, U.S. Environmental Protection Agency | 5 kW SOFC | Morgantown, West Virginia | NETL | Mid-2003 | | |  | NETL will conduct tests and then deliver the unit to the EPA to install the at an abandoned hardrock mine in Montana, where it will be used to provide electricity for operating instrumentation and communications equipment for environmental monitoring. |
| Fuel Cell Technologies (FCT) | Gas Technology Institute, Memphis Botanic Garden, Memphis Light, Gas and Power | 5 kW Beta 1 SOFC | Memphis, Tennessee | Memphis Botanic Garden | Prototype unit was to be delivered by Apr. 2004 | One-year demonstration project | | | Technical issues, including the inability to operate above 3 kW, arose during a 300 hour pre-delivery laboratory test. Field delivery was postponed until issues are resolved. |
| Fuel Cell Technologies (FCT) | The Presidio Trust | 5 kW SOFC system | San Francisco, California | The Presidio Trust | 2002 | | | | Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program. |
| Fuel Cell Technologies (FCT) | Hammarby Sjostad project | Two 5 kW SOFC CHP units | Stockholm, Sweden | Hammarby Sjostad project, residential units | Aug. 2002 | | Biogas | | Progressive 8,000 unit residential development project focusing on environmental concerns, largely powered by renewable energies. |
| Fuel Cell Technologies (FCT) | South Coast Air Quality Management District (SCAQMD) | Ten 5 kW SOFC CHP units | Various locations, California | Two or three units to be located at LADWP, one or two units at Sempra Utilities and one to two units at the University of California-Irvine | First delivery in 2004 | | | | Contract to provide 10 residential fuel cell units. The contract is scheduled to run though the end of 2005, during which time FCT will install, then operate and maintain the residential fuel cells for two years. |
| FuelCell Energy | Starwood Hotels & Resorts Worldwide, Inc, Alliance Star Energy | 500 kW Direct Fuel Cell (DFC) MCRC | San Francisco, California | The Westin San Francisco Airport Hotel | Planned | | | | Will supply base load power. The heat byproduct will be used to heat the hotel's indoor pool. CPUC's Self-Generation Incentive Program is expected to $1.25 million in funding. |

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| FuelCell Energy | US Department of Defense, US Department of Energy | 250 kW Direct FuelCell (DFC) MCFC | Twentynine Palms, aliforniaA | Marine Corp Air Ground Combat Center, training center | Delivery in July 2006 | Planned | | | Will improve the availability of reliable electricity to help the training center meet security requirements and cope with fluctuating power needs. |
| FuelCell Energy | Alliance Power | Two 250 kW Direct FuelCell power plants | Fontana, California | TST, Inc. | To be delivered first quarter 2006 | Planned | Natural gas | | Will replace a large burner that preheats air as part of TST's aluminum manufacturing process. |
| FuelCell Energy | South Coast Air Quality Management District (SCAQMD), California Cast Metals Association, Emergent Energy Group | Two 250 kW MCFC units | Fontana, Carson, and Rancho Dominguez, California | Metal foundries | To be delivered | Planned | | | These high temperature fuel cells will be used for metal pre-heating or other co-generation applications depending on the installation site. |
| FuelCell Energy | Select Energy Services, Eastern Connecticut State University | Four 250 kW MCFC units | Willimantic, Connecticut | Eastern Connecticut State University's central heating plant | To be installed Feb. 2006 | Planned | Natural gas | | Grid parallel operation to displace existing facility electric demand. Thermal energy from the fuel cells will be captured and used to preheat water returning to the central heating plant. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($ 1 million). |
| FuelCell Energy | Chevron Energy Solutions, US.Postal Service San Francisco Processing and Distribution Center (P&DC), Bonneville Power Administration | 250 kW DFC 300A MCFC | San Francisco, California | USPS Embarcadero Postal Center | Installed Feb. 2005 | Operational | Natural gas | | Will provide base load heat and power (grid parallel, grid independent during an outage). Funding: up to $625,000 from California's Self Generation Incentive Program .Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program. ($250,000) |
| FuelCell Energy | Alameda County, Chevron Energy Solutions | 1 MW DFC1500 MCFC (Four 250 kW units) | Dublin, California | Alameda County's Santa Rita Jail | To be installed Nov. 2005 | Planned | | | Will provide 90% of base load power, to be used in conjunction with an existing 1.18 MW solar power system. Funding: up to $1.4 million from the California Public Utilities Commission's Self Generation Incentive Program, .Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($1 million). |
| FuelCell Energy | The Korean Ministry of Commerce, Industry and Energy | 250 kW DFC300A MCFC | Kwangju, South Korea | Chosun University Hospital | Fall 2005 | Planned | | | The Korean Ministry of Commerce, Industry and Energy (MOCIE) has targeted more than 20 percent of the country's power generation to be from fuel cells. |
| FuelCell Energy | The Korean Ministry of Commerce, Industry and Energy | 250 kW DFC300A MCFC | Seoul, South Korea | Tancheon Sewage Treatment Plant | Fall 2005 | Planned | | | The Korean Ministry of Commerce, Industry and Energy (MOCIE) has targeted more than 20 percent of the country's power generation to be from fuel cells. |
| FuelCell Energy | MTU CFC Solutions GmBH, RWE Fuel Cells, Festo GmBH | 225 kW Hot Module MCFC | St. Ingbert, Germany | Festo facility | 2005 | | | | Provides heat, air conditioning and power. |

 

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| FuelCell Energy | Starwood Hotels and Resorts Worldwide Inc. | 500 kW DFC MCFC | San Diego, California | Sheraton San Diego Hotel & Marina, West Tower | Installed Sep. 2005 | | | | The Sheraton San Diego fuel cell installation including both the East and West Towers) is the largest commercial fuel cell installation in the United States. Funding of up to $1.25 million from the from the California Public Utilities Commission's (CPUC) Self-Generation Incentive Program. |
| FuelCell Energy | Alliance Power, Starwood Hotels and Resorts Worldwide Inc. | Four 250 kW DFC MCFC units | San Diego, California | Sheraton San Diego Hotel & Marina, East Tower | Summer 2004 | | | | Will supply base load electricity for the 1,044-room hotel, with heat byproduct used for the hotel's pool. Funding: up to $1.25 million from the California Public Utilities Commission's (CPUC) Self-Generation Incentive Program. |
| FuelCell Energy | PPL EnergyPlus, Pepperidge Farm | Two 250 kW DFC 300A MCFC units | Bloomfield, Connecticut | Pepperidge Farm bakery | Third quarter 2005 | Planned | | | Will provide about 20% of the facility's base load power, with the heat byproduct converted to process steam for the bakery. Funding: Connecticut Clean Energy Fund and US DoD Climate Change Fuel Cell Program $500,000) grants. |
| FuelCell Energy | Salt River Project (SRP) | 250kW DFC MCFC | Mesa, Arizona | Arizona State University East Campus | Shipped first quarter 2005 | Planned | | | The unit will feed the electricity output into SRP's local grid. |
| FuelCell Energy | RWE, City Council Ahlen, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Ahlen, Germany | Municipal wastewater treatment facility | 2005 | Planned | Sewage gas |  | Will provide combined heat and power. |
| FuelCell Energy | Marubeni Corporation, Bioenergy Co. | 250 kW DFC 300A MCFC | Tokyo, Japan | Food recycling facility at "Super Eco-Town" | *Shipment* expected in first half of 2005 | | Anaerobic digester gas | | Will provide approximately 50% of the facility's base load electricity requirement. Heat will be converted to process steam for the recycling operations. |
| FuelCell Energy | State University of New York (SUNY), New York State Energy Research and Development Authority, New York Power Authority | 250 kW MCFC CHP | Syracuse, New York | Walters Hall at SUNY's College Environmental Science and Forestry | Installed Apr. 2005 | Operational | Natural gas | | Providing electricity with waste heat used for campus hot water, space heating and/or cooling. Funding: over $2.5 million from NYPA, $1 million grant from NYSERDA, $250,000 US DoD Climate Change Fuel Cell Program. |
| FuelCell Energy | Alliance Power, Sierra Nevada Brewing Co. | ! MW DFC MCFC units (four 250 kW units) | Chico, California | Sierra Nevada Brewing Co. brewery | Installed Mar. 2005 | | Natural gas, possibly anaerobic digester gas | | Will supply electric power and heat to the brewery's production processes. Funding: 40% of eligible costs from the California Public Utilities Commission's (CPUC) Self-Generation Incentive Program. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($1 million). |
| FuelCell Energy | Marubeni Corp/Fuel Cell Japan Co., Mitsubishi Heavy Industries, | 250 kW MCFC | Osaka, Japan | Kawasaki's Akashi Works | 2005 | | | | Long-term testing and evaluation. |

 

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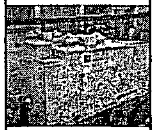
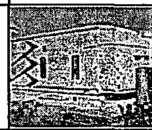
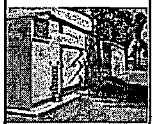
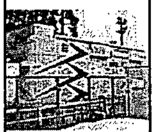
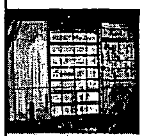
| | Kawasaki | | | | | | | | |
| FuelCell Energy | Mitsubishi Heavy Industries, Bio Energy, Co. | 250 kW MCFC power plant | Tokyo, Japan | Food waste treatment facility | Late 2004 or early 2005 | | Digester gas | | Largest food waste treatment plan in Japan. The plant treats 110 tons of garbage/day to generate digester gas. Uses a fermentation reactor and the MCFC to generate and sell electric power. |
| FuelCell Energy | Marubeni Corporation, Epson, First Energy Service Company Ltd., Seiko Epson | Two 250 kW DFC 300A MCFC units | Ina, Japan | Seiko Epson's Quartz Devise Division facilities | Apr. 2004 | Operational | Liquefied natural gas |  | Will supply power and steam. The plant also has a PAFC unit. |
| FuelCell Energy | Marubeni Corporation, City of Fukuoka | 250 kW DFC 300A MCFC | Hukuoka, Japan | Seibu Water Treatment Center | Jan. 2004 | Mar. 2005 | Digester gas |  | Supplies electricity and steam. |
| FuelCell Energy | Caterpillar Inc, City of Santa Barbara, Alliance Power | Two 250 kW. DFC MCFC units | Santa Barbara, California | El Estero Wastewater Treatment Facility | Sep. 2004 | Operational | Anaerobic digester gas (methane) |  | Provides electricity and heat for the facility's wastewater treatment system. Funding: $2.25 million from California Public Utilities Commission's (CPUC) Self-Generation Incentive Program ($500,000). .Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program. |
| FuelCell Energy | Marubeni Corporation, Japan Petroleum Exploration Co. Ltd. (JAPEX) | 250 kW DFC 300A MCFC | Nagaoka, Japan | JAPEX's Katakai natural gas gathering station | Fourth quarter 2004 | Operational | Liquefied natural gas |  | Will supply power and steam. |
| FuelCell Energy | RWE, MTU CFC Solutions GmbH, Fernwärmeversorgung Niederrhein, Stadtwerke Dinslaken | Two 250 kW DFC HotModule MCFC units | Krefeld-Fischein, Germany | Residential units | Apr. 2004 | Operational | |  | Will provide residential supply of combined heat and power in the Dinslaken area (will supply 40 homes in the winter and up to 300 during the summer). Funded by the region of NordRhein Westphalia. |
| FuelCell Energy | Vattenfall/BeWag, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Berlin, Germany | Vattenfall Europe AG's Fuel Cell Innovation Park | Sep. 2004 | Operational | Natural gas, methanol or both |  | Bi-fuel project: liquid fuel used is derived from wastes generated in the city of Berlin. Provides combined heat and power. Has logged over 4,000 operational hours. |
| FuelCell Energy | US Army Construction Engineering Research Laboratory (CERL), Fuel Cell Test and Evaluation Center (FCTec), Concurrent Technologies Corporation | 250 kW DFC 300A MCFC | Johnstown, Pennsylvania | FCTec Environmental Technologies Facility | Cooperative agreement signed Aug. 2004 | 12-month demonstration planned | Natural gas | | Will supply electricity to the facility. |
| FuelCell Energy | Ohio Cat/Caterpillar Inc, City of Westerville Electric Division, American Municipal Power Ohio | 250 kW DFC MCFC | Westerville, Ohio | Electric substation | Nov. 2004 | Operational | |  | Will feed power to 180 homes from an electric substation. Funded in part through Ohio's Third Frontier Fuel Cell Initiative. |

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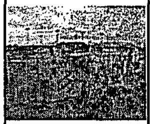
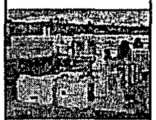
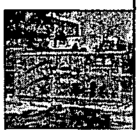
| FuelCell Energy | Quinn Power Systems Associates/Caterpillar Inc, Los Angeles County Sanitation Districts | 250 kW DFC 300A MCFC | Los Angeles, California | Palmdale Water Reclamation Plant | Nov. 2004 | Operational | Digester gas |  | The Districts, which treat about 530 million gallons of wastewater daily, are industry leaders in recovering and utilizing biogas and biomass byproducts from waste to generate electricity. Funding: $1,125,000 from the California Public Utilities Commission. |
| FuelCell Energy | Democratic National Committee | 250 kW DFC 300A MCFC | Boston, Massachusetts | Democratic National Convention | Jul. 2004 | Completed | Natural gas | | Part of a distributed generation "micro-grid" that provided electricity to support the existing grid to meet the expected additional demand of the convention. |
| FuelCell Energy | Grand Valley State University | 250 kW DFC 300A MCFC | Muskegon, Michigan | Michigan Alternative and Renewable Energy Center | Apr. 2004 | Operational | Natural gas |  | Provides electricity, heating and cooling for research space, incubator facilities, conference center and classrooms. Funding for the project, including the building and fuel cells, is provided by a $3 million grant from the Michigan Public Service Commission and bonding from the City of Muskegon. |
| FuelCell Energy | PPL EnergyPlus, Starwood Hotels & Resorts Worldwide, Inc. | 250 kW DFC 300A MCFC | Manhattan, New York | Sheraton New York Hotel & Towers | Summer 2004 | Operational | |  | The fuel cell provides about 10% of the power and hot water requirements of the 1,750 room hotel. Funding: $820,000 grant from the New York State Energy Research and Development Authority (NYSERDA). |
| FuelCell Energy | King County, CH2M Hill, Brown and Caldwell, US Environmental Protection Agency | 1 MW DFC MCFC (four 250 kW modules) | Renton, Washington | South Treatment Plant | Apr. 2004 | Two-year demonstration | Wastewater digester gas |  | Provides power to the plant. EPA is providing federal funding estimated at $12.5 million. The total value of the project is $22 million. |
| FuelCell Energy | US Department of Energy, US Army Corp of Engineers | 250 kW DFC 300A MCFC | Los Angeles, California | LADWP headquarters (John Ferraro Building) | 2003 | | Natural gas |  | Replaced a trial FuelCell Energy MCFC plant that ran from 2001-2002. Buy Down Program Recipient FY1999 US DoD Climate Change Fuel Cell Program. |
| FuelCell Energy | RWE AG, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Jul. 2003 | Operational | |  | Has logged over 22,000 operating hours. |
| FuelCell Energy | E-on, Rhoen Klinikum AG, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Bad Berka, Germany | Hospital | Oct. 2003 | Operational | |  | Provides combined heat and power. Has logged over 1,500 operating hours. |
| FuelCell Energy | EnBW/Michelin, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Karlsruhe, Germany | Michelin tire plant | Feb. 2003 | Operational | |  | Provides power, heat and process steam for tire production. Has logged over 17,000 operating hours. Funded by the Federal Ministry of Economics and Labor which financed 50% as part of the Future Investment Program. |
| FuelCell Energy | Pfalzwerke, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Gruenstadt, Germany | Gruenstadt Hospital | Jul. 2003 | Operational | | | Provides 100% of the hospital's energy needs, with excess capacity sent to the public utility system. |

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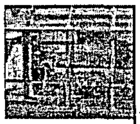
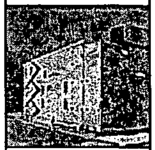
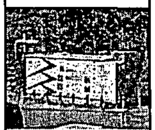
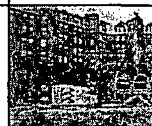
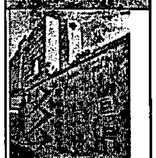
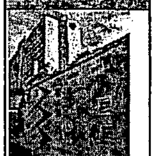
| | | | | | | | |  | Has logged over 14,000 operating hours. Funded by the Federal Ministry of Economics and Labor, which financed 50% as part of the Future Investment Program. |
| FuelCell Energy | PPL Energy Plus, Millennium Builders (a PPL subsidiary) | 250 kW DFC 300A MCFC | Toms River, New Jersey | Ocean County College | Dec. 2003 | Operational | Natural gas |  | Provides 90% of the daily power requirements for the Instructional Building, Lecture Hall and Nursing Arts Building. 20% of heating needs are also provided to the above plus the Administration Building, Library and planetarium. Funding: $827,000--New Jersey Clean Energy Program. Buy Down Recipient $250,000 FY2002 US DoD Climate Change Fuel Cell Program. |
| FuelCell Energy | PPL EnergyPlus, US Coast Guard | 250 kW DFC MCFC | Bourne, Massachusetts | US Coast Guard Air Station | May 2003 | Operational | Natural gas |  | Provides electricity to the air station, including its hangars and administrative buildings, and supplies hot water for use in the air station's barracks. Funding project came from a variety of federal, state and private sources, including the Massachusetts Renewable Energy Trust Fund. |
| FuelCell Energy | Starwood Hotels, PPL Energy Plus | 250 kW DFC 300A MCFC | Parsippany, New Jersey | Sheraton Hotel | Oct. 2003 | Operational | Natural gas |   | Provides 25% of the electric power and hot water requirements of the hotel. The New Jersey Clean Energy Program provided $860,000 in funding. |
| FuelCell Energy | Starwood Hotels, PPL Energy Plus | 250 kW DFC 300A MCFC | Edison, New Jersey | Sheraton Hotel | Aug. 2003 | Operational | Natural gas |   | Provides 25% of the electric power and hot water requirements of the hotel. The New Jersey Clean Energy Program provided $860,000 in funding. Buy Down Program Recipient FY2002 US DoD Climate Change Fuel Cell Program $250,000). |
| FuelCell Energy | Zoot Enterprises, PPL EnergyPlus | 250 kW DFC MCFC | Bozeman, Montana | Zoot Enterprises' business park | Aug. 2003 | Operational | Natural gas |  | Supplies the primary electric requirements of the building. Zoot Enterprises is installing the necessary equipment for its DFC power plants to operate independent of the electric utility grid. |
| FuelCell Energy | Connecticut Clean Energy Fund, Yale University | 250 kW DFC MCFC | New Haven, Connecticut | Yale University's archival storage facility for the Yale Peabody Museum and the Yale Environmental Science Center | Dec. 2003 | Dedicated | Natural gas |  | Provides approximately 25% of the Peabody Museum's electricity needs, with the heat being used primarily to maintain tight temperature and humidity controls at the Environmental Science Center. |

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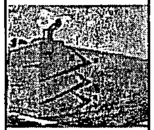
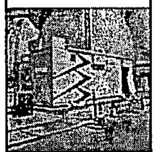
| FuelCell Energy | Harrison Mining Corporation/ AEP Ohio Coal LLC, Northwest Fuel Development Inc. | 200 kW DFC MCFC | Hopedale, Ohio | AEP Ohio Cole LLC site | Aug.-Dec. 2003 | Completed | Coal mine methane |  | Achieved 1,456 operating hours. Successfully demonstrated that coalmine methane could be used at high efficiency to produce fuel cell power. Co-funded by the U.S. Department of Energy's National Energy Technology Laboratory. |
| FuelCell Energy | Caterpillar Inc. | 250 kW DFC 300A MCFC | Peoria, Illinois | Caterpillar Technical Center | Oct. 2003 | Operational | |  | Connected to the Peoria area electricity grid, allowing Caterpillar to utilize the power plant as a demonstration unit for customers, Caterpillar dealers and development engineers. |
| FuelCell Energy | Los Angeles Department of Water and Power (LADPW), Los Angeles Department of Public Works/Bureau of Sanitation, US Army Corp of Engineers | 250 kW DFC 300 MCFC | San Pedro, California | LADWP'sTerminal Island Fuel Cell Power Plant | Sep. 2003 | Operational | Natural gas, converting to sewage digester gas (methane) during Summer 2004 |  | Provides electricity to serve about 250 households. Largely funded by LADWP's Public Benefits Program. The US Department of Defense also provided $250,000 in grant funding. (Buy Down Program). |
| FuelCell Energy | Marubeni Corporation, Kirin | 250 kW DFC 300A MCFC | Toride, Japan | Kirin Brewery | Jan. 2003 | Operational | Wastewater treatment gas |  | Supplies electricity and steam. |
| FuelCell Energy | Marubeni Corporation, City of Fukuoka | 250 kW DFC 300A MCFC | Fukuoka, Japan | Municipal wastewater treatment facility | Early 2003 | Two-year demonstration project | Digester gas |  | Supplies electricity and steam. |
| FuelCell Energy | Marubeni Corporation, Nippon Metal | 250 kW DFC 300A MCFC | Sagamihara, Japan | Nippon Metals Sagamihara Works | Fall 2003 | Operational | Natural gas | | Supplies electricity and steam. |
| FuelCell Energy | US Department of Energy's National Energy Technology Laboratory, Wabash River Energy Ltd., Global Energy Inc | 2 MW DFC 3000 MCFC | Terre Haute, Indiana | Global Energy Wabash River Energy Ltd. facility | Fourth quarter 2003 | Operational | Natural gas, coal-derived synthesis gas |   | Part of the federal Clean Coal Technology Program. Was the first plant to use a combination of coal and renewable fuels. Initial plan was to operate at the Kentucky Pioneer Energy IGCC site, but the site was moved to Wabash River to begin operation two years ahead of schedule. Funding provided by the US Department of Energy (Buy Down Program). |
| FuelCell Energy | IZAR, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Cartagena, Spain | IZAR shipyard facility | 2003 | Operational | Natural gas |  | Provides combined heat and power. Has logged over 18,000 operating hours. |
| FuelCell Energy | US Coast Guard Research and Development Center | 3 kW DMFC MCFC | Virginia Beach, VA | Cape Henry Lighthouse at U.S. Army Fort Story | Mar. 2002 | Completed | Methanol and water mixture | | Six month evaluation. Total running time of 4,090 hours. Provided heat and lighting. |
| FuelCell Energy | MTU Friedrichshafen, VSE | 250 kW MCFC | Ensdorf, Germany | Handicapped workshop | 2003 | | | | Heat and power supply. |

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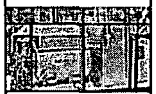
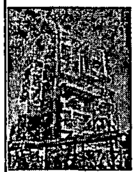
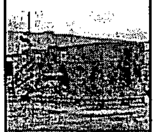
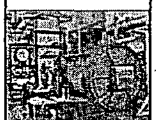
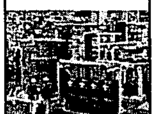
| FuelCell Energy | De Te Immobilien/ Deutsche Telekom, MTU CFC Solutions GmbH | 250 kW DFC HotModule MCFC | Munich, Germany | De Te Immobilien headquarters | Nov. 2002 | Operational | |  | Direct current backup application (telecom) and air conditioning. Has logged over 12,000 operating hours |
| FuelCell Energy | IPF KG, MTU Friedrichshafen, MTU CFC Solutions GmbH, Otto-von-guericke Clinic | 250 kW DFC HotModule MCFC | Magdeberg, Germany | Otto-von-guericke Clinic | Oct. 2002 | Operational | |  | Combined heat and power. Has logged over 19,000 operating hours. Funded by the Federal Ministry of Economics and Labor which financed 50% as part of the Future Investment Program. |
| FuelCell Energy | MTU-CFC Solutions, RWE | 250 kW MCFC HotModule | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Jan. 2002 | | |  | The system will be grid connected and will contribute to the electricity and heat supply of the adjacent Meteorit Park. |
| FuelCell Energy | Siemens Power Generation, Inc., BP, Chugach Electric Association | 200 kW DFC MCFC | Nikiski, Alaska | BP's gas-to-liquid test facility, powering administration building and warehouse | Aug. 2001 | To be installed 2003 | Natural gas |  | Funding: $4 million from BP, $2 million from the US. Department of Energy, $450,000 grant from the Cooperative Research Network of the National Rural Electric Cooperative Association. |
| FuelCell Energy | Los Angeles Department of Water and Power (LADWP), US Department of Energy, US Army Corp of Engineers | 250 kW trial MCFC plant | Los Angeles, California | LADWP headquarters (John Ferraro Building) | Aug. 2001 | Dec. 2002l | Natural gas |  | The power plant sends electricity to the City's power grid. This trial plant was replaced with permanent model in 2003. Buy Down Program Recipient FY1999 US DoD Climate Change Fuel Cell Program. |
| FuelCell Energy | Southern Company, Alabama Municipal Electric Authority (AMEA), Mercedes Benz US | 250 kW DFC MCFC | Tuscaloosa, Alabama | Mercedes Benz M-class production facility | 2001 | Completed | Natural gas |  | The plant fed the Mercedes-Benz production facility power distribution system. Also, the entire power plant was skid-mounted, making it easy to transport to different locations for demonstrations. |
| FuelCell Energy | State of Bavaria, Ferngas Nordbayern, E-on/Rhoen Klinikum AG, MTU Friedrichshafen | 250 kW DFC HotModule MCFC | Bad Neustadt, Germany | Rhoen Klinikum (medical clinic) | May 2001 | Operational | Natural gas |  | Emergency power supply and combined heat and power. Had logged over 21,000 operating hours by 2004. |
| FuelCell Energy | MTU Friedrichshafen, Stadwerke Bielefeld, BEB Erdgas-Erdol | 250 kW DFC HotModule MCFC | Bielefeld, Germany | University of Bielefeld Hospital | Feb. 2000 | 2002 | Natural gas |  | Field trial. Completed over 16,000 operating hours |
| FuelCell Energy | MTU Friedrichshafen GmbH, Elkraft A.m.b.A, Ruhrgas AG, RWE-Energie AG | HotModule MCFC | Dorsten, Germany | Ruhrgas plant | 1997 | 1998 | |  | First system demonstrator |
| FuelCell Energy | FuelCell Energy Facility Demonstration | 250 kW DFC MCFC | Danbury, Connecticut | FuelCell Energy's Facility | Feb. 1999 | Jun. 2000 | Natural gas |  | Fuel cell was grid-connected and operated for 11,800 hours delivering 11.8 million kW/hr of electricity. Excess energy was sold to the local power grid. |

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| FuelCell Energy | Los Angeles Department of Water and Power | 2 MW DFC MCFC | Santa Clara, California | Scott Receiving Station | Apr. 1996 | Mar. 1997 | |  | First full scale utility demonstration of a molten carbonate fuel cell system. Grid-connected. Operated for more than 3,600 hours. |
| Fuji Electric | | 1 kW PEM | Yokkaichi, Japan | FamilyMart chain convenience store | Announced May 2005 | Installed | | | one of Mie Prefecture's demonstration program. Half of the installation cost subsidized by the local government. It will supply electric power to 1/3 of consumption by fluorescent lamps in the store. |
| Fuji Electric | Unspecified Japanese research association | 5 MW PAFC | Japan | Unspecified Japanese research association | 2004 | | | | |
| Fuji Electric | Toho Gas, Okazaki Shinkin Bank | 100 kW PAFC | Okazaki, Japan | Okazaki Shinkin Bank headquarters | Feb. 2004 | | | | Fuel cell purchase. |
| Fuji Electric | | 100 kW PAFC | Japan | Fuji Electric Human Resources Development Center | 2002 | | | | Provides power to the facility. |
| Fuji Electric | Yamagata City | Two 100 kW PAFC | Yamagata, Japan | Yamagata City Purification Center (sewage treatment facility) | May 2002 | Operational | Methane digester gas |  | The fuel cells cover 40 % of power consumption at the center. |
| Fuji Electric | Kajima Corporation, New Energy and Industrial Technology Development Organization (NEDO) | 100 kW PAFC | Kobe, Japan | Garbage anaerobic digestion facility | Jul. 2001 | | Methane biogas from anaerobic digestion of kitchen waste | | Generates hydrogen fuel from 6 tons of garbage/day. |
| Fuji Electric | | 100 kW PAFC | Japan | Fuji Electric factory | Dec. 2001 | | | | |
| Fuji Electric | Toho Gas Co., Ltd | 100 kW PAFC CHP | Nagoya, Japan | Nagoya Sakae Washington Hotel Plaza | Feb. 1999 | Operational | | | The plant reduces the hotel's energy costs by 40%. Used for hot water and air conditioning. Operated for over 40,000 hours. The fuel cell was overhauled in 2004, replacing cell stack and reformer. |
| Fuji Electric | Vattenfall AB | 50 kW PAFC | Varberg, Netherlands | | Feb. 1993 | | | | |
| Fuji Electric | Enagas | 50 kW PAFC | Madrid, Spain | | Dec. 1991 | | | | |
| Fuji Electric | WNAM Eniricerche | 50 kW PAFC | Milan, Italy | | Nov. 1991 | | | | |
| Fuji Electric | Sydraft AB | 50 kW PAFC | Astrop, Sweden | | Dec. 1991 | | | | The Swedish utility company will test the unit. |
| Fuji Electric | Vattenfall | 50 kW PAFC | Varberg, Sweden | | Nov. 1992 | | | | |
| Fuji Electric | Tokyo Electric Power Co (TEPCO) | 50 kW PAFC | Japan | TEPCO New Energy Park | Jun. 1993 | Completed Dec. 1996 | | | This unit accumulated 39,291 hours by 10/00. |
| Fuji Electric | Kansai Electric Power Co | 5 MW PAFC | Japan | Kansai Electric's "Urban Energy Center" | Installed between 1993-1995 | | | | |
| Fuji Electric | Kansai Electric Power Co | Fourteen 50kW PAFC units | Japan | Kansai Electric Power Co.'s Rokko Island test center | 1990's | | | | |

 

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| Fuji Electric | Kansai Electric Power Co | Twenty-one 50 and 200 kW PAFC units | Various locations, Japan | | Installed between 1993-1995 | | | | Other Kansai Electric listings in this chart may be a part of this purchase. |
| Fuji Electric | Osaka Gas, Global Environment Centre Foundation | 50 kW PAFC | Japan | Global Environment Centre Foundation office | Jul. 1993 | Completed Oct. 2000 | | | Operated for 50,358 hours. |
| Fuji Electric | Osaka Gas | Three 500 kW PAFC units | Japan | | | | | | |
| Fuji Electric | Osaka Gas | Fifteen 50 and 100 kW PAFC units | Japan | | Installed between 1993-1995 | | | | Other Osaka Gas listings in this chart may be a part of this purchase. |
| Fuji Electric | Tokyo Electric Power Co (TEPCO), Mitsubishi | 200 kW PAFC | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Toho Gas | 50 kW PAFC | Japan | | Mid-1990s | | | | |
| Fuji Electric | | 100 kW PAFC power plant | Japan | | | | Town gas, LP gas | | |
| Fuji Electric | | 100 kW PAFC | Japan | Fuji Electric's Human Resources Development Center | | | | | Provides power to the facility. |
| Fuji Electric | Hokkaido Electric Power Co | 200 kW PAFC | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Tohoku Electric Power Co | Two 50 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Tokyo Gas | Ten 50 and 100 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Chubu Electric Power Co, Mitsubishi | Three 50 and 200 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Hokuriku Electric Power Co | 50 kW PAFC | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Chugoku Electric Power Co, Mitsubishi | Four 50, 100 and 200 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Toagosei Company, Shikoku Electric | 100 kW PAFC | Japan | Toagosei Company's Toshima plant | 1993 | Mar. 1999 | | | Cogeneration of waste heat for hot water. Operated 1,064 hours. Achieved power generating efficiency of 40.5% and an overall efficiency with cogeneration of 44.6%. |
| Fuji Electric | Shikoku Electric Power Co, Mitsubishi | 50 kW PAFC | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Kyushu Electric Power Co, Mitsubishi | One 50 and one 200 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | Saibu Gas | 50 kW PAFC | Japan | | Installed between 1993-1995 | | | | |
| Fuji Electric | | 1 kW PEM test stack | Japan | | | | | | Exceeded 10,000 hours of test operation. Prototype PEM for residential use was to be ready by 2004. The goal is for 20,000-30,000 hours of operation, with market entry in 2007-2008. Fuji may develop a 5 kW version for restaurants or convenience stores. |
| GenCell | | 40 kW MCFC | Storrs, | Connecticut | Delivered | | Natural gas | | Grid-connected. Provides |

 

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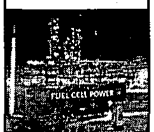
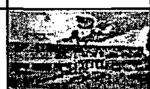
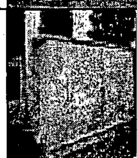
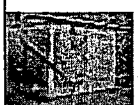
| | | CHP | Connecticut | Global Fuel Cell Center | Jan. 2005 | | | | power and heat, with excess power delivered to the grid. Funded by Connecticut Conservation & Load Management Fund and the Connecticut Clean Energy Fund. |
| General Electric | Florida Power & Light Co. (FPL), Florida Department of Environmental Protection | 5 kW PEM | Fort Lauderdale, Florida | Hugh Taylor Birch State Park Visitor Center | Dec. 2002 | One-year demonstration | Natural gas | | Located next to park manager's house. Provided power to FPL's electric grid. |
| Global Thermoelectric | Bonneville Power Administration (BPA) | Three 2 to 5 kW SOFC systems | Various locations, USA | Field testing sites | 2003 | To be delivered | Natural gas or propane | | |
| Global Thermoelectric | Montana State University, Montana Dakota Utilities Co. | 3 to 5 kW SOFC remote power system for light industrial applications | Billings, Montana | Montana State University | Agreement announced 2002 | Planned | Methane | | Two year testing and evaluation program. Partial funding from Montana-Dakota Utilities |
| Global Thermoelectric | Montana State University, Montana Dakota Utilities Co. | 2 kW SOFC | Billings, Montana | Montana State University | Agreement announced 2002 | Planned | Natural gas | | Two year testing and evaluation program. Partial funding from Montana-Dakota Utilities |
| Global Thermoelectric | Enbridge Inc. | Two 2.3 kW SOFC systems | Calgary, Canada | Enbridge Inc. facility | Late 2001 | 2002 | | | Six-month prototype testing. |
| GM | | 75 kW PEM | Manhattan, New York | General Motors Drive-In movie theater | May 2004 | Completed | Hydrogen | | Provided power to the movie screen for three days during the Tribeca Film Festival. |
| GM | Dow Chemical Company | 75 kW PEM | Freeport, Texas | Dow Chemical Company plant | Feb. 2004 | Phase I: 4-6 months | |   | More fuel cells and electrical generating capacity to be added during the summer months. The initial GM fuel cell will generate 75 kW of power, enough electricity for 50 average homes. Dow and GM plan to install up to 400 fuel cells to generate 35 megawatts of electricity, enough power for 25,000 average sized American homes. DOW Chemical Harold Nicoll 989-636-5162 hgnicoll@dow.com GM Scott Fosgard 586-947-3295 scott.fosgard@gm.com |
| GM | | 75 kW PEM | Rochester, New York | GM's fuel cell research facility | 2001 | Ongoing | Natural gas, methanol, gasoline |  | Prototype testing |
| H Power Corp. | Gaz de France | 4 kW PEM | Dunkerque, France | Dunkerque traffic control center | May 2003 | Testing between 2002 and 2005 | Natural gas |  | H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | Gaz de France, The National Polytechnical Institute of Lorraine (INPL) | 4 kW PEM | Nancy, France | The National Polytechnical Institute of Lorraine | Feb. 2003 | Testing between 2002 and 2005 | Natural gas |  | Produces heat and electricity for green-houses of the bio and agricultural department of INPL, outside the university buildings, and close to the greenhouses. H Power was acquired by |

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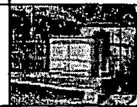
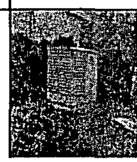
| | | | | | | | | | Plug Power in March 2003. |
| H Power Corp. | Gaz de France | 4 kW PEM | Limoges, France | City Hall of Feytiat | Apr. 2003 | Testing between 2002 and 2005 | Natural gas |  | H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | Gaz de France | 4 kW PEM | Sophia-Antipolis, France | Centre Scientifique et Technique du Bâtiment's computer rooms and science laboratory | Jun. 2003 | Testing between 2002 and 2005 | Natural gas |  | H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | US National Park Service, Fall River Rural Electric Cooperative, Energy Co-Opportunity, Inc. | 4.5 kW PEM CHP | Yellowstone National Park, Montana | West Entrance of Yellowstone National Park | Jun. 2002 | | Propane |  | Part of "Greening of Yellowstone" initiative. Powers lights, communication equipment and computers to ticket kiosks and an office. The system's byproduct heat is used for space heating. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | Mitsui & Co., Ltd., Osaka Gas | 500 W PEM Alpha residential CHP | Kansai area of Japan | | Jan. 2002 | Completed | Natural gas | | Osaka Gas's In-house and field beta testing for the Japanese residential market. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | Naps Systems Oy, Birka Energi, ABB | 4 kW PEM CHP | Stockholm, Sweden | Environmental Information Centre in Hammarby Sjostad | Jun. 2002 | | Hydrogen produced through a photovoltaic solar cell system, biogas from municipal waste | | Excess electricity generated by the fuel cell system to be fed back into the power grid. H Power Corp. was acquired by Plug Power in 2003. |
| H Power Corp. | Gaz de France | 4 kW PEM | Dunkerque, France | City Hall of Petite Synthe | Nov. 2002 | Testing between 2002 and 2005 | Natural gas |  | Supplies electricity and space heating. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | US Department of Defense | Three 500 W PEM units | Fort Belvoir, Virginia | Fort Belvoir office building | 2002 | | Hydrogen | | H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Energy Co-Opportunity Inc, Rappahannock Electric Cooperative | 4.5 kW Beta PEM CHP | Bowling Green, Virginia | Rappahannock Electric Cooperative | 2002 | | Propane | | Provides stand-along power and heat for the 2,000 square foot office facility with the grid available for back up. The cooperative also participated in alpha testing. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Energy Co-Opportunity Inc, Delta-Montrose Electric Association | 4.5 kW Beta PEM CHP | Montrose, Colorado | Delta-Montrose Electric Association | 2002 | | Propane | | The cooperative also participated in alpha testing. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Energy Co-Opportunity Inc, Enerstar Power Corporation | 4.5 kW Beta PEM CHP | Paris, Illinois | Enerstar Power Corporation | 2002 | | Propane | | The cooperative also participated in alpha testing. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Energy Co-Opportunity Inc, Platte-Clay Electric Cooperative | 4.5 kW Beta PEM CHP | Kearney, Missouri | Platte-Clay Electric Cooperative | 2002 | | Propane | | The cooperative also participated in alpha testing. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | US Department of Defense, Southern Maryland Electric Cooperative | 4.5 kW PEM | Patuxent River, Maryland | Patuxent River Naval Air Station Natural Resources office | Oct. 2002 | One-year demonstration | Propane |  | DOD Residential Fuel Cell Demonstration Program H Power was acquired by Plug Power in March 2003. |

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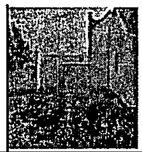
| H Power Corp | US Department of Defense, Southern Maryland Electric Cooperative | 4.5 kW PEM | Patuxent River, Maryland | Patuxent River Naval Air Station single-family home | Oct. 2002 | One-year demonstration | Natural gas |  | DOD Residential Fuel Cell Demonstration Program H Power was acquired by Plug Power in March 2003. |
| H Power Corp | U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) | 4.5 kW PEM | Herlong, California | Sierra Army Depot barracks | Installed Oct. 2002 | | Propane |  | H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | Gaz de France | Beta PEM CHP | La Plaine Saint-Denise, France | Gaz de France's research and development campus, model house | 2002 | | | | H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Kamata Inc. | 4.5 kW PEM CHP | Gotenba, Japan | Kamata's Gotenba employee facility | June 2002 | | Propane | | The first field test of a propane-powered PEM for an actual load in the Japanese residential market. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | US Air Force Expeditionary Forces Battlelab (AEFB) | 4 kW PEM | USA | US Air Force base | 2001 | Completed | | | Demonstrated under the Air Force's Common Core Power Production (C2P2) Initiative. The system powered an office suite, followed by a flight line lighting unit. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | US Air Force Expeditionary Forces Battlelab (AEFB) | Two 4 kW PEM units | USA | US Air Force base | 2001 | Completed | | | Demonstrated under the Air Force's Common Core Power Production (C2P2) Initiative. Supplied power to a simulated aircraft load on the ground. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | US Air Force Expeditionary Forces Battlelab (AEFB) | Three 4 kW PEM units | USA | US Air Force base | 2001 | Completed | | | Demonstrated under the Air Force's Common Core Power Production (C2P2) Initiative. Powered industrial shop equipment and various aircraft support equipment. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Fortum Oy, Finnish Chemicals Oy | PEM CHP | Aetsa, Finland | Test house | Mar. 2001 | | Hydrogen | | Supplied all electricity and heat used by a typical household and was "net metered" to sell surplus electricity to the local electric utility. H Power was acquired by Plug Power in March 2003. |
| H Power Corp. | Gaz de France | Alpha PEM CHP | La Plaine Saint-Denise, France | Gaz de France's research and development campus model house | Jan. 2001 | Jul. 2001 | Natural gas | | Five month evaluation. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | US Department of Defense | 4.5 kW PEM CHP | Various locations | ECO Fuel Cells, LLC facility | Mar. 2000 | | | | First H Power prototype stationary fuel cell. In 2001 ECO agreed to purchase 12,300 stationary fuel cell systems for an aggregate purchase price of $81 million. The full delivery has not yet occurred. H Power was acquired by Plug Power in March 2003. |
| H Power Corp | Hydro-Quebec | Stationary PEM | Canada | Hydro-Quebec laboratory | Nov. 2000 | | Propane | | Generates both electricity and hot water. H Power |

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| | | | | | | | | | was acquired by Plug Power in March 2003. |
| Hydrogenics, Corp. | Florida Department of Environmental Protection, Progress Energy Florida | PEM | Homosassa,, Florida | Homosassa Springs State Wildlife Park'sWildlife Pavilion | Mar. 2005 | | Hydrogen gas generated by an electrolyzer | | Integrated fuel cell/solar photovoltaic system provides a portion of the Pavilion's electricity. |
| Hydrogenics, Corp. | Japan Automobile Research Institute (JARI) | 10 kW HyPM PEM | Tsukuba, Japan | Japan Automobile Research Institute | Delivery during first quarter 2005 | | | | To be used as part of JARI's mandate to establish standards for fuel cell power module testing, a program sponsored by Japan's Ministry of Economy, Trade and Industry and the New Energy and Industrial Technology Development Organization. |
| Hydrogenics, Corp. | NASA | 5 kW PEM | USA | | Oct. 2004 | | Hydrogen-oxygen | | To be used in NASA's research program for fuel cell operation in future aerospace applications This was Hydrogenics' first hydrogen-oxygen PEM stack sale. The stack was designed to be very light, which is critical for this type of application. |
| Hydrogenics, Corp. | Unspecified power company | 25 HyPM 10kW PEM | | | 2004--2005 | | | | HyPM fuel cells will be incorporated into back-up power products for one of the world's largest suppliers of uninterruptible power. |
| Hydrogenics, Corp. | City of Toronto | HyLYZER PEM powered hydrogen refueler | Toronto, Canada | Exhibition Place at Hydrogen Village | Aug. 2004 | | | | The refueler will use electricity generated by a wind turbine, sited at Exhibition Place, to produce clean hydrogen. |
| Hydrogenics, Corp. | Itochu Corp, Hitachi Zosen Corporation | 10 kiW HyPM | Yokkaichi, Japan | "Communal facilities" | Jul. 2004 | One-year test | Hydrogen supplied by water electrolysis | | Demonstration project. An electrolyser will produce hydrogen on site using electricity from existing solar photovoltaic panels. The hydrogen will then be stored to fuel the power module during hours of peak electricity demand. |
| Hydrogenics, Corp. | US Navy | PEM-powered refueler | Crane, Indiana | US Navy's Naval Surface Warfare Center-Crane Division | Mar. 2004 | | | | |
| Hydrogenics, Corp. | Science World | 20 kW HyPM-LP2 PEM | Vancouver, Canada | Science World geodesic dome | Feb or Mar. 2003 | Completed | | | Used to light the Science World geodesic dome. |
| Hydrogenics, Corp. | Nextel | 25 kW HyUPS | Northern California | Nextel Communications remote cell tower site | Jul. 2002 | Sept. 2003 | | | Integrated with an electrolyser to charge the fuel storage module with hydrogen for use by the fuel cell in the event of a power outage. Test protocol was designed to compress the profile of a full year's intermittent outages into a two-month time period. |
| IdaTech | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), Arizona State University, City of Mesa | 5 kW nGen PEM | Mesa, Arizona | Sgt. Herrera US Army Reserve Center | Apr. 2005 | Operational | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Two fuel cells, made by different manufacturers (Idatech and Plug Power), are operated in parallel during the demonstration. One project objective is to evaluate he performance of each unit under the |

 

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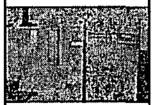
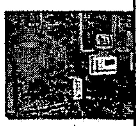
| | | | | | | | | | severe heat of Arizona summers. |
| IdaTech | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), Omaha Public Power District | 5 kW EtaGen5 PEM | Omaha, Nebraska | Offutt Air Force Base, Elkhorn Communications Detachment | Jun. 2005 | Operational | Propane |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Provides grid independent power to field office support loads. |
| IdaTech | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), Rappahannock Electric Cooperative | 5 kW EtaGen 5 PEM | Rappahannock, Virginia | Fort AP Hill Administrative Support building | Jun. 2005 | Operational | Propane | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Operating off-grid to provide security lighting. |
| Idatech | RWE Fuel Cells | Nine PEM units | Various locations, Europe | | | Ongoing in 2004 | | | Being tested at RWE locations and partner sites |
| IdaTech | RWE Fuel Cells | Two 5 kW PEM CHP units | Berlin, Germany | Office of the representative of the State of the North Rhine-Westphalia | Mar. 2004 | Operational | Natural gas | | Used in conjunction with a micro gas turbine for the decentralized supply of power, heat and air conditioning for the innovative building. |
| IdaTech | RWE | 4.6 kW EtaGen PEM | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | | Ongoing | | | RWE is testing the fuel cells in a joint project with the municipal utilities and regional suppliers in 2005. |
| IdaTech | Portland General Electric, Bonneville Power Administration | 5 kW PEM | Portland, Oregon | Portland General Electric Earth Advantage National Center | Jan. 2004 | Operational | | | Part of BPA's Northwest demonstration program. First fuel cell in Oregon connected to a power grid. Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| IdaTech | Propane Education & Research Council | 3.6 kW PEM | Bend, Oregon | Remote telecommunications site | Aug. 2003 | | Propane | | Off-grid telecom application for field test and evaluation in the Cascade mountain range. |
| IdaTech | Electricite de France | 1.2 kW FCS 1200 PEM | France | Remote locations | 2003 | | | | Will be used for integration with solar photovoltaic technology in a hybrid power system for remote locations. The fuel cell system will act as a backup and primary power source, charging the batteries when sunlight is not adequate for the PV panels to generate electricity. |
| IdaTech | Bonneville Power Administration, Central Electric Co-Operative | 5 kW PEM Alpha unit | Redmond, Oregon | Central Electric Co-Operative | Winter 2003 | No longer operational | |  | First commercial testing of residential fuel cell systems in the northwest. Six were installed at participating utilities in the initial phase of the test. Buy Down Program Recipient FY1999. (Alpha) fuelcells@bpa.gov Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| IdaTech | Portland General Electric, Bonneville Power Administration program, Emerald Peoples Utility District | 3 kW PEM Alpha unit | Eugene, Oregon | Emerald Peoples Utility District | Winter 2003 | No longer operational | Methanol | | Alpha unit testing. Supplied power for lights, heat and a cable puller used to stock line trucks from a great spool for 14 hours during a power outage in 2002. Mira Vowles 503.230.4796 mkvowles@bpa.gov |

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| IdaTech | Bonneville Power Administration, PNGC Power | 5 kW PEM Alpha unit | Rotating location, USA | PNGC Power | Winter 2003 | No longer operational | | | Alpha unit testing. Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| IdaTech | Bonneville Power Administration, Energy Northwest Mobile | 5 kW PEM Alpha unit | Richmond, Washington | Energy Northwest Mobile | Winter 2003 | No longer operational | | | Alpha unit testing. Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| IdaTech | Bonneville Power Administration, Lincoln Electric | 5 kW PEM Alpha unit | Eureka, Montana | Lincoln Electric | Winter 2003 | No longer operational | | | Alpha unit testing. Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| IdaTech | Bonneville Power Administration, Fergus Electric | 5 kW PEM Alpha unit | Lewiston, Montana | Fergus Electric | Winter 2003 | No longer operational | | | Alpha unit testing. Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| IdaTech | Governor's Office of Planning and Research, California EPA, the Sacramento Public Utility District | FCS 1200 PEM fuel cell unit | Sacramento, California | California EPA building | Dec. 2002 | Completed | | | Powered lights on a holiday tree. |
| IdaTech | Electricite de France (EDF) | 3 kW PEM unit | France | Research and Development Division of EDF | Feb. 2001 | Spring 2002 | | | Field test of prototype unit, targeted for a residential application in France. |
| IdaTech | Bonneville Power Administration | One-hundred - ten 6 kW CHP fuel cell units | Various locations in the northwest USA | Bonneville Power Administration | 2000 | No longer operational | | | 10 "alpha" units first installed and tested by BPA, then the remaining 100 "beta" units shipped in late 2000. Testing performed at a variety of electric utility customer sites in the Pacific Northwest, including Central Electric Cooperative in Redmond, Oregon, Consumer's Power Incorporated in Philomath, Oregon; Oregon; Fergus Electric in Lewistown, Montana; Lincoln Electric in Eureka, Montana; and Energy Northwest in Richland, Washington, among others. |
| IdaTech | Bonneville Power Administration, Kootenai Electric Cooperative | PEM | Post Falls, Idaho | "Next House" showcase home | Jul. or Aug. 1999 | Completed | | | |
| IdaTech | Sandia National Laboratories, University of Alaska-Fairbanks | Three PEM fuel cell units | Alaska | | Nov. 1998 | | | | Initially tested at Sandia Labs before moving to the University of Alaska. |
| IdaTech | Bonneville Power Administration | 5 kW PEM | Bend, Oregon | Private home | Nov. 1998 | Completed | Methanol | | Provided electricity to a residence. The home was disconnected from the electric power grid of Pacific Power & Light prior to testing and reconnected afterward. |
| Industrial Research Laboratory (IRL) | Australian Cooperative Research Center for Renewable Energy | 6 kW alkaline fuel cell | Perth, Australia | Wind turbine at Murdoch University | Oct. 2002 | | Hydrogen | | The proof-of-concept system is linked to a wind turbine powering an electrolyzer to generate hydrogen. The fuel cell stores energy generated by the turbine and serves as back up when the wind turbine is not capable of producing power. The AFC |

 

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| | | | | | | | | | was replaced by a PEM unit in late 2004. |
| Intelligent Energy | Centre for Renewable Energy Systems Technologty (CREST) | 2 kW PEM CHP | Leicestershire, UK (England) | West Beacon farm | Installed Fall, 2003 | | | | Intelligent Energy is a spin-off company from Loughborough University. Part of the HARI (Hydrogen and Renewable Integration) Project. Incorporates a fuel cell, two wind turbines, electrolyzer and hydrogen storage and feeds commercial and domestic loads on a local mini-grid at West Beacon Farm. |
| Ishikawajima-Harima Heavy Industries (IHI) | Takagi Industry, Shizuoka Gas, Ishikawajima Shibaura Machinery | Several 1 kW PEM units | Various locations, Japan | Residential | Aug. 2005 | | Natural gas | | Commercialization planned in 2006. |
| Ishikawajima-Harima Heavy Industries (IHI) | Idemitsu Kosan | 5 kW PEM | Suzuka, Japan | Fire station | Mar. 2005 | Oct. 2005 | LP gas | | Will operate 8 hours/day and provide 30% of the electric needs of the building and heat for hot water. |
| Ishikawajima-Harima Heavy Industries (IHI) | Idemitsu Kosan | 5 kW PEM | Tomakomai, Japan | Hokkaido Oil Refinery dormitory | Mar. 2004 | | | | Provides one-sixth of the power and hot water requirements of the facility. |
| Ishikawajima-Harima Heavy Industries (IHI) | Chubu Electric | 300 kW MCFC | Nagoya, Japan | Chubu Electric's Shin-Nagoya Thermal Power Station | Spring 2004 | | Waste gas | | |
| Ishikawajima-Harima Heavy Industries (IHI) | Japan Gas Association | PEM | Japan | | 2003 | | | | Japan Gas Assoc. Phase 2 test of residential PEM fuel cells of different manufacturers. |
| Ishikawajima-Harima Heavy Industries (IHI) | Idemitsu Kosan | 5 kW PEM | Japan | Anegasaki Service Station of Keiyo Apollo Co., Ltd. (subsidiary of Idemitsu Kosan) | Jul. 2003 | | Kerosene | | Demonstration unit. |
| Ishikawajima-Harima Heavy Industries (IHI) | Chubu Electric Power Co., New Energy and Industrial Technology Development Organization (NEDO), MCFC Research Association | Two 300 kW MCFC units | Nagoya, Japan | Chubu Electric's Kawagoe Thermal Power Station | Jan. 2003 | Mid-2004 | | | Verification of performance and durability for 10,000 h by the first half of 2004. |
| Ishikawajima-Harima Heavy Industries (IHI) | Chubu Electric Power Co., New Energy and Industrial Technology Development Organization (NEDO), MCFC Research Association | 300 kW MCFC | Nagoya, Japan | Chubu Electric's Shin-Nagoya Thermal Power Plant | 2002 | | Waste gas | | |
| Ishikawajima-Harima Heavy Industries (IHI) | Toyota, New Energy and Industrial Technology Development Organization (NEDO) | 300 kW MCFC-gas turbine hybrid system | Toyota City, Japan | Motomachi Environmental Center of Toyota Motor Corporation | Oct. 2002 | | | | Incorporated with a 50 kW gas turbine manufactured by Toyota Turbine and Systems. |
| Ishikawajima-Harima Heavy Industries (IHI) | Hitachi, Chubu Electric, New Energy and Industrial Technology Development Organization (NEDO), MCFC Research | (1 MW MCFC without internal reformer (Four 250 kW units) | Nagoya, Japan | Chubu Electric's Kawagoe Thermal Power Station | Jun. 1999 | 1999 | | | 5,000 hour demonstration. |

 

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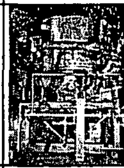
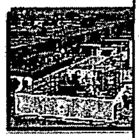
| | Association | | | | | | | | |
| Ishikawajima-Harima Heavy Industries (IHI) | | 40 kW MCFC | Japan | | Apr. 1996 | 3,000-5,000 hours of operation were planned | |  | Verification testing. World's first MCFC with external reforming. Plans for future commercialization. |
| Ishikawajima-Shibaura Machinery Co. (ISM) | Shizuoka Gas, Takagi Industry Co. | Multiple 1 kW PEM units | Japan | Residential | Aug. 2005 | | Natural gas | | Demonstration of cogeneration system as part of a national large scale monitoring demonstration project. Commercialization planned in 2006. |
| M-C Power Corp. | San Diego Gas and Electric Co, Bechtel National Inc, Alternative Energy Systems Consulting, Stewart and Stevensen | 75 kW MCFC | San Diego, California | Marine Corp Air Station -- Miramar | 2002 | Five-month test completed | | | Operated for 3,300 hours. The fuel cell generated 250 kW of electricity. Heat produced by the fuel cell was used in adjacent buildings at the site. |
| M-C Power Corp. | Electric Power Research Institute, Gas Research Institute, Institute of Gas Technology, Ishikawajima-Harima Heavy Industries Co., Ltd, San Diego Gas & Electric, U.S. Department of Energy | 250 MCFC kW | San Diego, California | Marine Corp Air Station -- Miramar | 1997 | 1998 | |  | This unit operated for 2,350 hours and delivered 158 MW/hr of direct current output and 296,500 pounds of 110 psig steam to the base. |
| M-C Power Corp. | San Diego Gas and Electric Co, Gas Research Institute, Bechtel Corp, Stewart and Stevenson, Electric Power Research Institute, Southern California Gas, Institute of Gas Technology | 250 MCFC kW | Brea, California | Unocal's research center | 1995 | Decommission ed | | | |
| Minaton (Russian Ministry of Atomic Energy) | International Science and Technology Centers (ISTC), Gaz-prom, Norelsk Nickel Company, Russian Academy of Sciences | 1 kW SOFC | Snezhinsk, Russia | All Russia Research Institute of Technical Physics facility | Dec. 2003 | Test system operated for several days | Natural gas |  | First SOFC tested in Russia, built at Minaton factory. Part of multi-national ISTC fuel cell construction initiative. Plans to develop a 2.5 kW system. |
| Matsushita Electrical Industrial Co. | Osaka Gas, Ministry of Land, Infrastructure and Transport | 1 kW PEM | Osaka, Japan | | 2004 | | | | Field test. |
| Matsushita Electrical Industrial Co. | Tokyo Gas | 1.3 kW PEM | Saitama, Japan | Tokyo Gas employee's residence | Ten month test operation | Mar. 2003 | |  | Cogeneration units. |
| Matsushita Electrical Industrial Co. | Japan Gas Association | Two 1.3 kW PEM units | Japan | | 2002 | | Natural gas | | Japan Gas Assoc. Phase 2 test of residential PEM fuel cells of different manufacturers. |

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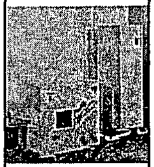
| Matsushita Electrical Industrial Co. | Japan Gas Association | 1 kW PEM | Demonstration tests (7 companies) held in Tokyo, Osaka and Nagoya, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | |  | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of operation in Phase I testing, 8,000 hours scheduled in Phase 2 using fuel cells of different manufacturers. |
| Mitsubishi Electric Corp. | Japan Gas Association | 1 kW PEM | Japan | | 2002 | | Natural gas | | Japan Gas Assoc. Phase 2 test of residential PEM fuel cells from nine manufacturers. |
| Mitsubishi Electric Corp. | Japan Gas Association | 1 kW PEM | Demonstration tests (7 companies) held in Tokyo, Osaka and Nagoya, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | | | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of operation in Phase I testing, 8,000 hours scheduled in Phase 2 using fuel cells of different manufacturers. |
| Mitsubishi Heavy Industries (MHI) | Electric Power Development Co. (EPDC) | 150-200 kW SOFC | Japan | EPDC's Technology Development Center | 2006 | Planned | | | 10,000 hour test planned. |
| Mitsubishi Heavy Industries (MHI) | Nippon Oil Corp. | 10 kW PEM | Hiroshima Japan | Hiroshima Diamond Hotel | Jun. 2005 | | Kerosene | | |
| Mitsubishi Heavy Industries (MHI) | Iwatani | PEM CHP | Moriyama, Japan | Shiga technology center | Mar. 2005 | | LP gas | | |
| Mitsubishi Heavy Industries (MHI) | Electric Power Development Co. (EPDC) | 25 kW SOFC with internal reforming | Japan | EPDC's Technology Development Center | Apr. 2005 | | | | |
| Mitsubishi Heavy Industries (MHI) | Nippon Oil Corp. | 10 kW PEM | Tokyo, Japan | Convenience store | Mar. 2004 | One-year test | Kerosene | | |
| Mitsubishi Heavy Industries (MHI) | | Twelve 1 kW PEM units | Japan | | Two units shipped Dec. 2002, ten units in 2003 | | City gas | | Field testing to verify performance. |
| Mitsubishi Heavy Industries (MHI) | Electric Power Development Co. (EPDC) | SOFC | Japan | EPDC's Wakamatsu Works coal gasification pilot plant | Feb. 2002 | | | | |
| Mitsubishi Heavy Industries (MHI) | Chubu Electric Power | 15 kW T-MOLB SOFC | Kobe, Japan | MHI's Kobe dockyard | Jul. 2000 | | Natural gas | | Test operated for 7,500 hours. |
| Mitsubishi Heavy Industries (MHI) | Electric Power Development Co. | Pressurized 1 kW SOFC | Nagasaki, Japan | MHI's Nagasaki Dockyard and Shipping Works | 1996 | | | | |
| Mitsubishi Heavy Industries (MHI) | Electric Power Development Co. | 1 kW SOFC | Japan | EPDC's Wakamatsu Power Station | 1993 | | | | Operated continuously for 3,000 hours. |
| MOSAIC Energy | NiSource Inc., Ishikawajima-Harima Heavy Industries, Gas Technology Institute, Nippon Mitsubishi Oil Corp. | 5 kW PEM | Yokohama, Japan | Nippon Mitsubishi Oil's Negishi retail gasoline service station | Jul. 2001 | 2002 | Naphtha | | World's first liquid fuel PEM fuel cell test. |
| MOSAIC Energy | NiSource Inc., Ishikawajima-Harima Heavy Industries, Gas Technology Institute | 3 kW PEM | Chesterton, Indiana | Residential unit in new housing development | 2000 | | Natural gas | | 9+ months of field testing during 2000-2001. |

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| MTU CFC Solutions | Ansaldo Fuel Cells Spa, IZAR, FhG Umsicht, CESPA, Z.A.E., OVM, University Genova, ASM, Nitra, Technip, E.ON | "MW-sized" MCFC fuel cell plant | Spain | | Planned | | Biogas | | BICEPS project--Biogas Integrated Concepts. |
| MTU CFC Solutions | Seaborne GmbH | 300 kW MCFC | Owschlag, Germany | Seaborne's industrial research center | May 2002 | Completed six-month test | Industfial waste biogas | | Part of the EFFECTIVE Project, which is testing biogas purification in combination with MCFC units. Co-funded by EU. Operated for 2,500 hours. Used a mobile test bed, with tests on this unit performed in Germany, Austria and Spain. |
| MTU CFC Solutions | Urbaser SA, CIEMAT | 300 kW MCFC | Pinto, Spain | Urbaser waste treatment plant | Feb. 2004 | Summer 2004 | Landfill gas | | Part of the EFFECTIVE Project, which is testing biogas purification in combination with MCFC units. Co-funded by EU. Operated for 2,000 hours. Used a mobile test bed, with tests on this unit performed in Germany, Austria and Spain. |
| MTU CFC Solutions | University of Nitra | 300 kW MCFC | Nitra, Slovak Republic | University of Nitra's Agricultural Biogas plant | | Two-year test | Agricultural biogas | | Part of the EFFECTIVE Project, which is testing biogas purification in combination with MCFC units. Co-funded by EU. Operated for 2,400 hours in the first cycle, 3,300 hours in the second cycle and 3,600 hours in the third cycle. Achieved less than 10 ppm of H2S in the outlet gas. |
| MTU CFC Solutions | Linz AG | 300 kW MCFC | Linz, Austria | Asten waste water treatment plant | Mar. 2003 | Two-month test | Wastewater treatment biogas | | Part of the EFFECTIVE Project, which is testing biogas purification in combination with MCFC units. Co-funded by EU. Operated for 1,500 hours. Used a mobile test bed, with tests on this unit performed in Germany, Austria and Spain. |
| Nuvera | US Department of Defense, Earthwell Energy | 4.6 kW PEM | Fort Knox, Kentucky | Fort Knox indoor pool | Planned | Contract awarded Jun. 2004 | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| Nuvera | Deere & Co. | 5.5 kW H2e PEM | | Deere & Co. | *Sale* completed Mar. 2005 | | | | Sold for testing and evaluation as a potential off-road equipment power source. |
| Nuvera | Toro Co. | H2e PEM | | Toro Co. | Delivered Nov. 2004 | | | | For evaluation for potential use in professional grounds and turf care equipment. |
| Nuvera | Takagi Industrial Co., Ltd, Japan Gas Association, Mitsui & Co. Ltd | 3.3 kW Avanti PEM | Japan | Japan Gas Association facility | Mar. 2004 | | Natural gas | | Delivered under the Japanese government's Millennium Program – a five-year effort to examine PEM fuel cells to establish technical codes and standards for the Japanese market. |
| Nuvera | US Army Corps of Engineers, Construction Engineering Research Lab (CERL) | Two 5 kW Avanti PEM units | Bristol, Rhode Island | Coast Guard Aids to Navigation Team, maintenance facility | Feb. 2004 | Completed | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Project FY 2002.. Operated in parallel with the electric grid. Grant awarded by Connecticut Renewable Energy Trust's |

 

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| | | | | | | | | | Green Power Fuel Cell Initiative. |
| Nuvera | Aventine Renewable Energy (formerly Williams Bioenergy) | 15 kW PEM | Pekin, Illinois | Visitors Center at Aventine Renewable Energy's ethanol production facility | Planned | Announced in 2003 | Corn-based ethanol | | Six-month, 4,000 hour demonstration planned. |
| Nuvera | RWE | Twenty-five 5 kW CHP PEM units | Germany | Apartment buildings | Aug. 2002 | | Natural gas | | Field test--part of joint venture between Nuvera and RWE Plus AG to develop and distribute fuel cell systems up to 50 kW (CHP) to Europe.Gianfranco.mora@denora.it |
| Nuvera | RWE | 5 kW PEM | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Aug. 2002 | Completed | | | Field testing for use in residential energy sector. |
| Nuvera | Verizon | 5 kW PEM | Cambridge, Massachusetts | Arthur D. Little's international headquarters | 2001 | Two-year demonstration | Natural gas | | Powered a portion of the telecommunications infrastructure. |
| Nuvera | Massachusetts Technology Collaborative, SatCon Tech. Corp., KeySpan Energy Delivery, Verizon | 5 kW PEM | Woburn, Massachusetts | Verizon's engineering facility | Dec. 2001 | Completed 500-hour demonstration | Natural gas | | US's first fuel cell powered telecommunications site. Grant awarded by Connecticut Renewable Energy Trust's Green Power Fuel Cell Initiative. Mark.a.marchand@verizon.com Derby.r@nuvera.com |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenCore PEM | Washington, DC | Department of State, Administrative Center of the International Chancery Conclave (ICC) | Planned | Contract awarded Aug. 2003 | Hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Will provide grid parallel service to selected circuits in the administration building to simulate support of critical or emergency loads. |
| Plug Power, Inc. | State of Florida, US Department of Defense | 5 kW PEM | Florida | Tyndall Air Force Base tent city | Planned | Contract awarded Jun. 2005 | Propane | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| Plug Power, Inc. | US Department of Defense, LOGANEnergy | 5 kW GenSys PEM | Colorado Springs, Colorado | US Air Force Academy gymnasium | One year demonstrati on planned | Contract awarded Jun. 2005 | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. The unit will be electrically configured to provide grid parallel service to the site and it will also be thermally integrated with a building domestic hot water system. |
| Plug Power, Inc. | US Department of Defense, LOGANEnergy | 5 kW PEM | Puerto Rico | Muniz Air National Guard base | Planned | Contract awarded Jun. 2005 | Propane | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| Plug Power, Inc. | US Department of Defense, LOGANEnergy | Two 5 kW PEM units | Keflavick, Iceland | US Naval Air Station | Planned | Contract awarded Jun. 2005 | Hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| Plug Power, Inc. | US Department of Defense, LOGANEnergy | Two 5 kW PEM units | Fort Hood, Texas | Fort Hood | Planned | Contract awarded Jun. 2005 | Hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| Plug Power, Inc | Federal Aviation Administration, LOGANEnergy | 5 kW PEM | Sandersonville, Georgia | FAA site, Sandersonville Airport | Planned | Contract awarded Jun. 2005 | Hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| Plug Power, Inc. | Alcorn State University, LOGANEnergy | 5 kW PEM | Lorman, Mississippi | Alcorn State University ROTC facility | Planned | Contract awarded Jun. 2005 | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |

 

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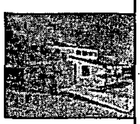
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW PEM | Austin, Texas | NGB Camp Mabry Texas National Guard Museum | Planned | One year demonstration | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Will provide grid parallel service to the site and will also be thermally integrated with a small desiccant HVAC unit to provide seasonally warm or cool dry air to benefit moisture sensitive displays in the museum. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys PEM | London, United Kingdom | US Embassy, Abbey Road Residence, mechanical room | Planned | Contract awarded Apr. 2004 | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY2003 and UK PEM demonstration project. Will be electrically configured to provide grid parallel / grid independent service to the facility. The fuel cell installation will also provide up to 8,000 Btu/h to the facility's hot water system. |
| Plug Power, Inc. | US Department of Defense | Ten 5 kW PEM units | Warner Robins, Georgia | Robins Air Force Base | Planned | Announced Jul. 2005 | Liquefied petroleum gas | | Part of the US Department of Defense Common Core Power Production Program. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys 5C PEM | Champaign, Illinois | ERDC / CERL equipment shed | Planned | One-year demonstration | Liquid propane gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Will provide grid parallel/grid independent service to the site, as well as be thermally integrated with a fan coil space heater to provide supplemental heating to the equipment shed during the test period. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW PEM | Biloxi, Mississippi | Keesler Air Force Base housing | Mar. 2005 | Operational | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003 |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW PEM | Eastover, South Carolina | McEntire Air National Guard fire station | Mar. 2005 | Operational | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Electrically configured to provide grid parallel/grid independent service to the facility and will also be thermally integrated with its gas-fired water to support domestic thermal loads |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW PEM | Herlong, California | Sierra Army Depot housing | Mar. 2005 | One year demonstration | Propane | | Electrically configured to provide grid parallel/grid independent service to the site, and it will also be thermally integrated with a SynDex heat pump to provide supplemental heating and cooling. US Department of Defense Residential PEM Fuel Cell Demonstration Program |
| Plug Power | | GenCore PEM | New York | New York Institute of Technology campus | Fall 2005 | | Hydrogen supplied by PV panels |  | The fuel cell provides power and heat to the "Green machine/Blue Space" project, a 100% solar house competing in the US DOE's Solar Decathalon. The house will be displayed on the National Mall, Washington |

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| | | | | | | | | | DC during Oct. 2005. Partly funded by the Long Island Power Authority. |
| Plug Power, Inc | H.M. Cragg Co, FTTH Communications LLC, Loretel Systems | 5 kW GenCore PEM | Albertville, Minnesota | FTTH Communications facility | Installed Sep. 2005 | | Hydrogen | | Partly funded by a Minnesota Department of Commerce grant for fuel cell telecom back up power projects. |
| Plug Power, Inc. | Delaware County Electric Cooperative, State University of New York-Delhi, Gaia Power Technologies | PEM | Tompkins, New York | Residential | Jun. 2005 | One-year demonstration | Propane | | The fuel cell is integrated with a power electronics and battery storage system. Demonstration is part of a New York State Energy Research and Development Authority (NYSERDA) and US DOE Energy Storage Initiative. Funded by a $300,000 grant under a US Congressional Earmark and $175,000 NYSERDA grant. |
| Plug Power, Inc. | Vaillant, EnBW, Caritas, Stadtwerke Ettlingen GmbH | EURO 2 PEM CHP | Ettlingen, Germany | Caritas Nursing Home | Jun. 2005 | | Natural gas | | Provides heat and power. |
| Plug Power, Inc. | Tyco Electronics Power Systems | Ninety-eight 5 kW GenCore 5T PEM units | | Tele-communication sites | Sale announced July 2005 | | | | Purchased by Tyco Electronics Power Systems for resale to a US telecommunications company. |
| Plug Power, Inc. | Vaillant | 4.6 kW PEM micro-CHP | Lievin, France | | First quarter 2005 | | Natural gas | | |
| Plug Power, Inc. | Florida Department of Environmental Protection | Twelve 5 kW GenCore PEM units | Florida | Florida Department of Environmental Protection field offices throughout the state | Sale announced June 2005 | | Hydrogen gas | | Will provide back-up power. |
| Plug Power, Inc. | Yurtec Corporation of Tohoku Electric Power Co., Inc | 5 kW PEM | Miyagi Prefecture, Japan | Yurtec Corp's Development Center of Human Resources | Apr. 2005 | One-year demonstration | | | |
| Plug Power, Inc. | Long Island Power Authority (LIPA), Local 25 International Brotherhood of Electrical Workers (IBEW) | 5 kW PEM | Hauppauge, New York | Local 25 International Brotherhood of Electrical Workers headquarters | Apr. 2005 | Installed | | | Will generate electricity and provide supplemental domestic hot water to the IBEW facility. During an electrical outage the fuel cell is capable of operating independent of the electric grid, supplying electricity to critical loads and emergency lighting throughout the facility. |
| Plug Power, Inc. | The Stella Group Ltd. | 5 kW GenCore PEM | Arlington, Virginia | The Stella Group Ltd. office | Leased May 2005 | | Hydrogen | | |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys PEM CHP | Kaneohe Bay, Hawaii | Marine Corp Base Hawaii-Kaneohe Bay base housing | Mar. 2005 | Ongoing | Propane | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Supplies power to kitchen appliances and outlets, and cogenerated heat is used for hot water. |
| Plug Power, Inc. | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), Arizona State University, City of Mesa Gas Division | 5 kW GenSys 5CS PEM | Mesa, Arizona | Sgt. Herrera US Army Reserve Center | Mar. 2005 | Operational | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Two fuel cells, made by different manufacturers (Idatech and Plug Power), are operated in parallel during the demonstration. One project objective is to evaluate he performance of each unit under the severe heat of Arizona |

 

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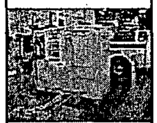
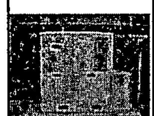
| | | | | | | | | | summers. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), Flint Energies | 5 kW PEM | Ft. Benning, Georgia | Ft. Benning Sandhill Recreation Center | Contract awarded Jun. 2004 | Installed | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Will operate in grid parallel mode to provide supplemental on-site power and usable heat for heating and domestic hot water. |
| Plug Power, Inc. | Vaillant, Salzburg AG, Salzburg Wohnbau | EURO 2 PEM CHP | Salzburg, Austria | Apartment | Late 2004 | Two-year project | Natural gas | | Provides heat and power. Testing project for possible future introduction of a fuel cell CHP product by Salzburg AG and Salzburg Wohnbau. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys5P PEM | Honolulu, Hawaii | Schofield Barracks fire station | Dec. 2004 | Operational | Propane |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Combines both grid parallel/grid independent electrical configurations to support the power requirements of the fire station. The unit is also thermally integrated with the fire station's hot water heater in order to transfer fuel cell process heat to the fire station's hot water tank. |
| Plug Power, Inc. | Vaillant, Dalkia | 4.6 kW PEM micro-CHP | Giromany, France | | Dec. 2004 | Ongoing | | | |
| Plug Power, Inc. | Vaillant | 4.6 kW PEM micro-CHP | Orleans, France | | Dec. 2004 | Ongoing | Natural gas | | |
| Plug Power, Inc. | Vaillant, EDF, Dalkia, OPHLM of Sarreguemines | Fifty-two 4.6 kW PEM micro-CHP, Euro 2 version | Sarreguemines, France | Various residences | Jun. 2004 | Ongoing | Natural gas | | Produces power, and heat for hot water. Vaillant is evaluating performance. |
| Plug Power, Inc. | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), City of Mesa Gas Division, Arizona Army National Guard | 5 kW GenSys 5CS PEM | Mesa, Arizona | Arizona Army National Guard Center | Jul. 2005 | On- year demonstration | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Grid connected in parallel mode. The thermal energy produced will be used to generate domestic hot water for the building. |
| Plug Power, Inc. | Montana State University, US Army Corp of Engineers Construction Engineering Research Laboratory (CERL) | 5 kW GenSys 5CS PEM | Billings, Montana | Montana Army National Guard Armed Forces Reserve Center | Dec. 2004 | One-year demonstration | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. The unit will operate at 50% capacity and configured to serve a portion of the base electrical load, operating in parallel with the existing grid-supplied power. The project is also configured for heat recovery. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys 5C PEM | El Segundo, California | Los Angeles Air Force Base Civil Engineering Office | May 2005 | Operational | Natural gas | | Electrically configured to provide grid parallel/grid independent service and also thermally integrated with the facility's hot water system. US Department of Defense Residential PEM Fuel Cell Demonstration Program |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys 5C PEM | Hill Air Force Base, Utah | Hill Air Force Base fire station | Feb. 2005 | One year demonstratoin | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003 |
| Plug Power, Inc. | US Army Corps | 5 kW GenSys | Riverside, | March Air | Feb. 2005 | Operational | Natural gas | | Electrically configured to |

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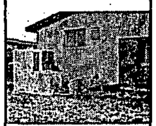
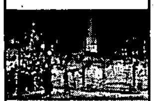
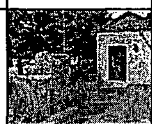
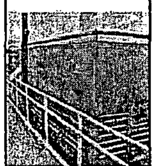
| | of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5C PEM | California | Reserve Base airman's dormitory | | | | | provide grid parallel/grid independent service and also thermally integrated with the facility's hot water system. US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003 |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys5C PEM | Alexandria, Virginia | Fort Belvoir fire station | Mar. 2005 | One year demonstration | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Will provide grid parallel/grid independent service to the facility and it is also thermally integrated with its gas-fired water heater to support domestic thermal loads. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5kW GenSys5P PEM | Cherry Point, North Carolina | Marine Corps Air Station Cherry Point maintenance facility | Dec. 2004 | Operational | Propane | | US Department of Defense Residential PEM Fuel Cell Demonstration Program. FY 2002. Operates in both grid parallel and grid independent configurations. To demonstrate the thermal energy capability of the fuel cell, a 22,000 BTU fan coil unit will be installed on the facility's ceiling to distribute waste heat from the fuel cell. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy, Georgia Tech, Energy Signature Associates | 5 kW GenSys5C PEM | Atlanta, Georgia | Georgia Institute of Technology Air Force ROTC resource center | Mar. 2005 | Operational | Natural gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy, Energy Signature Associates. | 5 kW GenSys 5C PEM | Fort Gordon, Georgia | Fort Gordon Army University of Technology Resource Center | Jun. 2004 | Demonstration completed | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Provided back up to the servers that support the online virtual training center. |
| Plug Power, Inc. | BOC Group plc, Johnson Matthey, Greater London Authority, London Hydrogen Partnership, siGEN. | 5 kW PEM GenCore 5T | London, UK (England) | Trafalgar Square | Dec. 2004 | Completed | |  | Provided electricity for the holiday tree located in London at Trafalgar Square |
| Plug Power, Inc. | Oneida County Rural Telephone Company | 5 kW PEM GenCore 5T | Oneida County, New York | Remote telecommunications hut | Jul. 2004 | Ongoing | Natural gas |  | Has successfully provided backup power during storm-related power interruptions. |
| Plug Power, Inc. | HyRadix Inc, Department of Energy, Propane Education and Research Council, Texas Fuel Cell Partnership | 5 kW PEM | San Antonio, Texas | Texas Department of Transportation TransGuide headquarters | Apr. 2004 | Completed three month demonstration | Propane |  | Technical Contact: Dan Kelly dan.kelly@rrc.state.tx.us Partnership Contact: Ken Zarker kzarker@tceq.state.tx.us |

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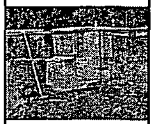
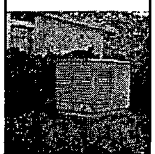
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy, Energy Signature Associates | 5 kW GenSys5P PEM | Stennis Space Center, Mississippi | Mars Habitat at the Stennis Space Center's Visitors Facility | Sep. 2004 | Ongoing | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Project FY 2002. |
| Plug Power, Inc. | Orange, BOC Group, FDT Associates | 5 kW PEM GenCore 5T PEM | Elgin, UK (Scotland) | Remote telecommunications site at Huntly Nordic Ski Center training site | Jan. 2004 | Ongoing | Hydrogen |  | The cell site is situated in a forest at the Huntly Nordic Ski Center, providing tele-communication coverage between Rhynie and Elgin. The GenCore provides back-up power to a LPG generator. |
| Plug Power, Inc | LP Gas, Logan Energy Corp, US Army Corp of Engineers Construction Engineering Research Lab (CERL) | 5 kW PEM GenSys 5P | Yosemite National Park, California | Administration building at Yosemite Village | Apr. 2004 | Operational | Liquid petroleum gas (LPG) |  | Yosemite National Park PEM Fuel Cell Demonstration Project. The fuel cell provides electricity to the Administration Building in Yosemite Village and fuel cell heat is used to provide hot water. A set of plug-ins added to the circuit from the cell to the building allows the park to recharge its electric car fleet. A second Plug Power fuel cell has been purchased and will be installed at a separate location in the park. |
| Plug Power, Inc. | Florida Power and Light Co., US Department of Energy, Florida Department of Environmental Protection | 5 kW PEM | North Port, Florida | North Port High School | Apr. 2004 | Installed | | | The first of 10 Hydrogen Education sites nationwide. DOE has supplied the school with a hydrogen curriculum and laboratory experiments. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), Southern Maryland Electric Cooperative | 5 kW PEM | Patuxent River, Maryland | Patuxent Naval Air Station office building | Jan. 2004 | Completed 12-month demonstration | Propane |  | Department of Defense PEM Residential Fuel Cell Demonstration Program FY 2001. Powered 9 desktop computers, office lighting, oil furnace, and life support systems for animals on display in environmental / conservation building. Grid connected. Excess power transferred to the grid. Cogenerated heat used to provide heat to the building during cold months. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), Southern Maryland Electric Cooperative | 5 kW PEM | Patuxent River, Maryland | Patuxent Naval Air Station single-family residence | Jan. 2004 | Completed 12-month demonstration | Natural gas |  | Department of Defense PEM Residential Fuel Cell Demonstration Program FY 2001. Powered lighting, boiler and pumps, refrigerator, kitchen counter receptacles and sump pump. Grid connected. Excess power transferred to the grid. Co-generated heat used the entire year for water heater. |
| Plug Power, Inc. | Long Island Power Authority (LIPA) | Two 5 kW GenSys 5C PEM CHP units | Garden City, New York | Nassau Community College | Installed Feb. 2004 | Operating | Natural gas | | |
| Plug Power, Inc. | VNG, Freiberger Erdgas | 4.5 kW EURO 2 PEM CHP | Freiberg, Germany | Nursing home | Fall 2004 | Operating | Natural gas | | Part of the VNG DemoCell project. Provides power, heating, and heat for hot |

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| | | | | | | | | | water. |
| Plug Power, Inc. | siGEN, Centre for Renewable Energy and Sustainable Technology (CREST) | 5 kW Gencore PEM | UK | Beacon Energy | Summer, 2004 | | | | Part of CREST's HARI (Hydrogen and Renewables Integration) project. |
| Plug Power, Inc. | Vaillant, Erdgas, Energie AG | 4.5 kW Euro 2 PEM CHP | Dietachdorf, Austria | Restaurant and hotel | Feb. 2004 | | Natural gas | | Provides heat and power. |
| Plug Power, Inc. | Ichitaka Co., Mitsuuroko Co, Kamata Co., Sanwa | 4 kW PEM | Tsukuba, Japan | House exhibition center | Aug. 2004 | One-year demonstration | Liquefied petroleum gas (LPG) | | Cogeneration system |
| Plug Power, Inc | siGEN, Unst Partnership | 5 kW Gencore PEM | Unst, UK (Scotland) | Hagdale Business Park | Contract signed Jan. 2004 | | | | Part of the Pure (Promoting Unst Renewable Energy) Project. Incorporates a fuel cell, two wind turbines, electrolyzer and hydrogen storage. |
| Plug Power, Inc. | Vaillant, EWE, E.ON Energie | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Remscheid, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid" |
| Plug Power, Inc. | Vaillant, EWE, E.ON Energie | Three 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Oldenburg, Germany | Two units at apartment buildings, one unit at the Federal Technological Center for Electrical Engineering and Information Technology | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, EWE, E.ON Energie | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Aurich, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, EWE, E.ON Energie | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Cuxhaven, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Ruhrgas, EAM EnergiePlus | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Wolfhagen, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Ruhrgas, EAM EnergiePlus | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Volkmarsen, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Ruhrgas, EAM EnergiePlus | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Baunatal, Germany | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the |

 

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| | | | | | | | | | electricity grid |
| Plug Power, Inc. | Vaillant, Ruhrgas, Stadtwerke Hilden, E.ON Energie | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Hilden, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, ELE, Ruhrgas, E.ON Energie | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Gelsenkirchen, Germany | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie,Vereniging van Eigenaren Minervaflat | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Groningen, Netherlands | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie, Essent | Two 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Hertogenbosch, Netherlands | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie, Inter Paris | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Klazienaveen, Netherlands | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie, Woonstade Hookgerk-Noorddijk | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Hoogkerk, Netherlands | Apartment building | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie, Vereniging van Eigenaren Hoogzandveld | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Nieuwegein, Netherlands | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie, St. Elisabeth zorg en Verpleeghuis | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Amersfoort, Netherlands | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie Wonen Breeburg | Two 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Tilburg, Netherlands | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie Vidomes | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance | Leidschendam, Netherlands | | Installed late 2003 or early 2004 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled |

 

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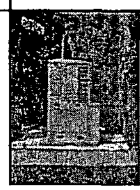
| | | (FCHA) | | | | | | | controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | DLR, Sistemas De Calor | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Almeria, Spain | | Late 2003 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | IST | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | Lisbon, Portugal | Instituti Superior Tecnico at the University of Lisbon | Late 2003 | Scheduled completion in 2006 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie, BMW Den Haag | 4.6 kW Euro 2 (GenSys) PEM Fuel Cell Heating Appliance (FCHA) | The Hague, Netherlands | BMW dealership | 2003 | Scheduled completion in 2006 | Natural gas |  | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid. Also part of BMW's H2ague Project promoting the non-mobile use of fuel cells. |
| Plug Power, Inc. | Vaillant, SOTEG Luxembourg, town of Luxembourg | 4.6 kW Euro 2 (Gensys) PEM Fuel Cell Heathing Appliance (FCHA) CHP | Luxembourg City, Luxembourg | School and Sporting Center | Jun. 2003 | | | | |
| Plug Power, Inc. | Mitsui & Co. Ltd, Osaka Gas | Eight 500 W Beta PEM CHP units | Kansai, Japan | Osaka Gas facility and field locations | Apr. 2003 | | Natural gas | | Technical venture to develop a 500W residential cogeneration fuel cell system for the Japanese market. Provides primary power and hot water for a residence. One unit has been installed in Osaka Gas' NEXT21, an experimental condominium complex located in Osaka. |
| Plug Power, Inc. | Marubeni, New Energy Foundation | Two 5 kW GenSys PEM units | Japan | | Lease announced Sep. 2003 | | Town gas | | |
| Plug Power, Inc. | Marubeni | 5 kW GenSys PEM | Oga, Japan | | Lease announced Sep. 2003 | | Propane | | |
| Plug Power, Inc. | Long Island Power Authority (LIPA) | Three 5 kW CHP PEM units | Hauppauge, New York | Suffolk County William Rogers Legislative Building | Installed Aug. 2003 | | Natural gas | | Will be interconnected to LIPA's grid and operate in a combined heat and power mode, providing electricity and heat on-site |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), Gas Technology Institute, Southwest Research Institute | GenSys5CS 5 kW PEM | San Antonio, Texas | Brooks City Base Challenger Learning Center | Feb. 2003 | Completed one-year demonstration | Natural gas |  | DOD Residential Fuel Cell Demonstration Program. Provided heat and power. |
| Plug Power, Inc | US Department of Defense, LOGANEnergy, Energy Signature Associates, Flint Energies | 5 kW GenSys5C PEM | Warner Robins, Georgia | Robins Air Force Base fire station | Apr. 2003 | Demonstration completed | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. |

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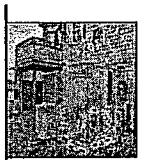
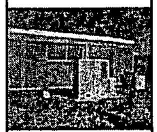
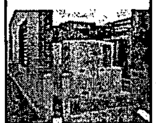
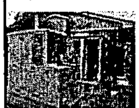
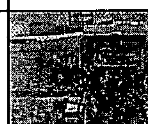
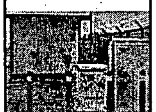
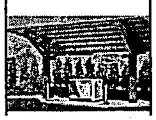
| Plug Power, Inc | US Army Corps of Engineers Construction Engineering Research Lab (CERL) | Eight 5 kW PEM units | Saratoga Springs, New York | Saratoga Springs Naval Support Unit base housing | Apr. 2003 | Jul. 2004 | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Provided electricity and hot water to four separate apartment buildings |
| Plug Power, Inc | US Army Corps of Engineers Construction Engineering Research Lab (CERL),LOGAN Energy, North Caroline State Agricultural andTechnical University | 5 kW GenSys 5CS PEM | Greensboro, North Carolina | North Carolina State Agricultural and Technical University's ROTC facility | Apr. 2003 | Apr. 2004 | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Operated in both a grid parallel and grid independent configuration. Provided stand-by power to a critical circuit panel and was outfitted with a thermal recovery system to capture waste heat for a hot water storage tank to supplement the current hot water system. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), DTE Energy Technologies | Two 5 kW GenSysT5CS PEM units | Selfridge Air National Guard Base, Michigan | Selfridge Air National Guard Base fire station | Nov. 2003 | Demonstration completed | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Provided electricity and recovered waste heat for domestic hot water usage. The units operated in parallel with the base electrical grid and incorporate standby capability to allow the units to supply power to critical loads during grid outage. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW GenSys5CS PEM | Sumpter, South Carolina | Shaw Air Force Base residence | May 2003 | May 2004 | Natural gas |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Provided power in a grid parallel /grid independent stand-by power to a 100amp critical circuit panel that serves plug loads in the kitchen area of the home. The system also contained a thermal recovery loop that supplemented the residence's hot water heater. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), Southwest Research Institute | Three GenSys5CS 5 kW PEM units | San Antonio, Texas | Brooks Air Force Base housing | Feb. 2003 | Mar. 2004 | Natural gas |  | US Department of Defense PEM Demonstration Program FY 2001. |
| Plug Power, Inc. | Verizon, NY State Energy Research and Development Authority (NYSERDA) | 5 kW PEM GenCore | Albany, New York | Albany Airport | Jul. 2003 | Demonstration completed in 2004 with subsequent purchase of the system | Natural gas |   | Prototype GenCore demonstration began in Jul. 2003, replaced by the Gencore 5T in Feb. 2004. At completion of the project, Verizon purchased several GenCore 5T systems, siting one at Albany Airport. |
| Plug Power, Inc. | Honda R&D Co., Ltd. | PEM Home Energy Station with reformer | Torrance, California and Latham, New York | Honda R&D facility in California and Plug Power facility in New York | Oct. 2003 | Ongoing | Natural gas |   | Generates hydrogen from natural gas for use in fuel cell vehicles while supplying electricity and hot water to the home. 2003 Phase I demonstration in Torrance, CA; 2004 Phase II demonstration in Latham, NY |

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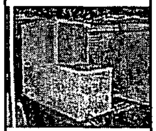
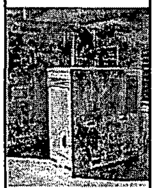
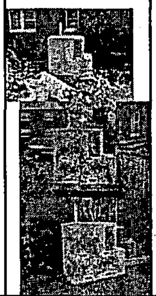
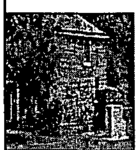
|---|---|---|---|---|---|---|---|---|---|
| Plug Power, Inc. | Long Island Power Authority (LIPA), State University of New York (SUNY) | Three 5 kW GenSys™ 5C PEM CHP units | Farmingdale, New York | SUNY Farmingdale | 2003 | Operating | Natural gas | | |
| Plug Power, Inc. | Long Island Power Authority (LIPA) | 5 kW GenSys 5C PEM CHP | Hempstead, New York | Wantagh Animal Shelter | Oct. 2003 | Operating | Natural gas | | |
| Plug Power, Inc. | Long Island Power Authority (LIPA) | Two 5 kW GenSys 5C PEM CHP units | Southampton, New York | Southampton College | 2003 | Operating | Natural gas | | |
| Plug Power, Inc. | Bonneville Power Adminsitration (BPA), Northwest Natural Inc. | 5 kW GenSys PEM CHP | Hillsboro, Oregon | Harkins House Juvenile Detention Facility | Nov. 2003 | Operational | Natural gas |  | Produces electricity, water and usable heat. Can generate 40,000 kw-hrs/yr, about 20% of the needs of the 14,000 sq. ft. facility. Surplus energy will be fed into the PGE power grid. Mira Vowles 503.230.4796 mkvowles@bpa.gov |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy, Energy Signature Associates | GenSys 5CS 5kW PEM | New Orleans, Louisiana | Coast Guard Station Administration and Operations building | Nov. 2003 | Completed one-year demonstration | Natural gas |  | US Department of Defense PEM Demonstration Program FY 2001. Provided stand-by power to a dedicated load of the facility's freezers. Waste heat was captured to be a preheat source for the existing natural gas-fired hot water heaters. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL) | Three 5 kW GenSys 5CS PEM units | West Point, New York | West Point Military Academy officer's quarters | May 2003 | May 2004 (2 units), July 2004 (one unit) | Natural gas |  | Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2002. Providesd electricity to the facilities. Waste heat supplement edthe existing domestic hot water and space heating systems. Provided power during the 2003 Northeast US grid power outage. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), LOGANEnergy Corp. | 5 kW PEM | Bossier City, Louisiana | Barksdale Air Force Base airmen's dormitory | Feb. 2003 | Feb. 2004 | Natural gas |  | One year demonstration. US Department of Defense PEM Demonstration Program FY 2001. |
| Plug Power, Inc. | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW PEM | Columbia, South Carolina | Fort Jackson officer's residence | Mar. 2003 | Mar. 2004 | Natural gas |  | US Department of Defense PEM Demonstration Program FY 2001 |
| Plug Power, Inc. | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), LOGANEnergy | 5kW GenSys 5CS PEM | Atlanta, Georgia | Fort McPherson single-family residence | Oct. 2003 | 2004 | Natural gas |  | US Department of Defense PEM Demonstration Program FY 2001. Provided stand-by power to a dedicated load. The waste heat of the fuel cell is captured and acts as a preheat source for the existing hot water heaters. |
| Plug Power, Inc. | Vaillant GMBH, Gaz de France | 4.6 kW EURO 1 (GenSys) PEM | La Plaine Saint-Denis, France | Gaz de France test research center experimental building | Oct. 2003 | Ongoing | Natural gas | | Produces electricity used for building needs and provides heating and hot water accumulated in balloons for 7 experimental residences. Has operated over 3,146 hours. |
| Plug Power, Inc. | Vaillant, MVV Energie | 4.1 kW EURO I PEM Fuel Cell | Mannheim, Germany | MVV headquarters | Early 2003 | | Natural gas | | |

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|---|---|---|---|---|---|---|---|---|---|
| | | Heating Appliance CHP | | factory | | | | | |
| Plug Power, Inc. | Long Island Power Authority/Central 03 | Forty-five 5 kW GenSys 5CS PEM units | Long Island, New York | Twenty-five units to West Babylon Fuel Cell Test Site, twenty units to single- or multi-family residences on Long Island | Announced 2003 | | | | Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program ($225,000). |
| Plug Power, Inc. | Vaillant, Ruhrgas, EAM EnergiePlus, E.ON Energie | Two 4.1 kW EURO 1 (GenSys) PEM Fuel Cell Heating Appliance CHP units | Baunatal, Germany | Two semi-detached apartment buildings | Installed Winter 2002/2003 | Scheduled completion in Mar.2005 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, EWE, E.ON Energie | 4.1 kW EURO 1 (GenSys) PEM Fuel Cell Heating Appliance CHP | Oldenburg, Germany | Apartment building | Installed Winter 2002/2003 | Scheduled completion in Mar.2005 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, EWE, E.ON Energie | 4.1 kW EURO I (GenSys) PEM Fuel Cell Heating Appliance CHP | Brake, Germany | Apartment building | Installed Winter 2002/2003 | Scheduled completion in Mar.2005 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Gasunie | 4.1 kW EURO 1 (GenSys) PEM Fuel Cell Heating Appliance CHP | Groningen, Netherlands | Workshop | Installed Winter 2002/2003 | Scheduled completion in Mar.2005 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant, Ruhrgas, Stadwerke Remscheid, EWR, E.ON Energie | Two 4.1 kW EURO 1 (GenSys) PEM Fuel Cell Heating Appliance CHP units | Remscheid, Germany | Apartment building | Installed Winter 2002/2003 | Scheduled completion in Mar.2005 | Natural gas | | Part of European Commission-funded project "European Virtual Fuel Cell Power Plant" to examine centrally controlled fuel cell heating systems connected to the electricity grid |
| Plug Power, Inc. | Vaillant GmbH | Fifty PEM units | Various locations in Germany, Netherlands, Austria, Luxembourg | Apartments and small businesses | 2002/2003 | Scheduled completion in Mar. 2005 | Natural gas | | Plug Power launched the European Union Fuel Cell Virtual Power Plant project with academic and industrial partners in Europe. Preproduction is planned in 2007, to be marketed by the end of the decade. A number of these installations are listed separately in this chart. |
| Plug Power, Inc. | Fuel Cell Test and Evaluation Center (FCTec) | 5 kW PEM | Johnstown, Pennsylvania | FCTec test facility | Sale announced Sept. 2002 | | Natural gas | | Combined heat and power unit purchased to develop a test protocol for residential fuel cells. |
| Plug Power, Inc. | Miller Burton Homes, Built Green Colorado, City and County of Denver, Govenor's OEMC, IREA, Xcel Energy | 5 kW PEM CHP | Denver, Colorado | Miller Burton Homes' Roaring Fork Parade Home | Aug. 2002 | Oct. 2002 | Natural gas | | After the Parade of Homes, this unit will be stationed at the City and County of Denver's fire station at Washington Park. |

 

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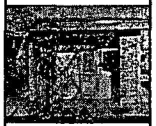
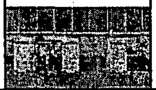
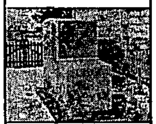
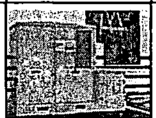
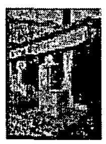
| Plug Power, Inc. | Governor's Office of Energy Management and Conservation, Xcel Energy, City and County of Denver, Alpha Technologies | 5 kW PEM CHP | Denver, Colorado | Washington Park Fire Station | Dec. 2002 | One-year demonstration | Natural gas |  | Provides a portion of the facilities' electricity and heat, to operate the fire station's computers, lights and garage doors. After the demonstration, Plug Power will replace the fire station's fuel cell with a future production model. |
| Plug Power, Inc. | Long Island Power Authority (LIPA), Hofstra University | Three 5 kW GenSys 5C PEM CHP units | Hempstead, New York | Hofstra University, dormitory | 2002 | Operating | Natural Gas | | Providing power to the dormitory. |
| Plug Power, Inc. | Long Island Power Authority (LIPA) | 5 kW GenSys 5C PEM CHP | Babylon, New York | Town Hall | Jul. 2002 | Ongoing | | | Produces 5 kW of electricity. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL), Waterviliet Arsenal | Ten 5 kW PEM fuel cell units | Watervliet, New York | Waterviliet Arsenal 's R&D test lab (three units), telecommunications room (three units) and officer's quarters (four units) | Jan. 2002 | Completed Jan. 2003 | Natural gas |    | Department of Defense PEM Residential Fuel Cell Demonstration Program FY 2001. Provided supplemental power to telecommunications facility and laboratory. Provided all power for four units of base housing. Operated for more than 80,000 hours and generated about 210,000 kWh of electricity. |
| Plug Power, Inc. | New York State Energy Research and Development Authority (NYSERDA), US Department of Energy | Two 5 kW SU-1 PEM units | Lewiston, and Colden, New York | Two single family homes | Apr. 2002 | One-year demonstration | Natural gas |  | |
| Plug Power, Inc. | Long Island Power Authority (LIPA), US Army Corps of Engineers Construction Engineering Research Lab (CERL), | Three 5 kW GenSys 5C PEM units | Kings Point, New York | US Merchant Marine Academy | Planned installation Fall 2002 | | Hydrogen | | The new system marks Plug Power's first shipment into the backup/UPS markets.. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL) | Eight 5 kW GenSys 5C CHP PEM units | San Diego, California | Naval Air Station North Island enlisted quarters, gymnasium and laundry | Sep. 2002 | Ongoing | Natural gas | | Will provide electricity and heat for hot water. |
| Plug Power, Inc. | US Army Corps of Engineers Construction Engineering Research Lab (CERL) | 5 kW GenSys 5C CHP PEM | China Lake, California | Naval Air Weapons Station indoor pool | Sep. 2002 | | Natural gas |  | Provided electricity and heat to the indoor pool. |
| Plug Power, Inc. | Long Island Power Authority (LIPA), Hunt Enterprises/McDonalds | 5 kW GenSys 5C PEM CHP | Deer Park, New York | McDonalds | 2002 | 2003 | Natural gas |  | |
| Plug Power, Inc. | DTE Energy Technologies, Detroit Edison | Two 5 kW PEM units | Commerce Township, Michigan | Detroit Edison's Hancock Station | Jun. 2002 | 2003 | Natural gas | | Provides heat and electricity to the Center. |
| Plug Power, Inc. | Flint Energies and GE Fuel Cell Systems | 5 kW PEM | Warner Robins, Georgia | Flint Energies Service Center facility | Jul. 2002 | Ongoing | Natural gas | | Generates electricity and heat. The heat will be used in water heaters in Flint's service center. |
| Plug Power, Inc. | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), LOGANEnergy | 5 kW PEM | Fort Bragg, North Carolina | Fort Bragg Environmental Center | Nov. 2002 | Feb. 2004 | Natural gas |  | US Department of Defense PEM Demonstration Program FY 2001 |
| Plug Power, Inc. | Osaka Gas Co. | 500 W PEM | Osaka, Japan | NEXT21 experimental | Apr. 2002 | | | | Will provide power and heat. |

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| | | | | condominium | | | | | |
| Plug Power, Inc. | Japan Gas Association | 4.5 kW PEM | Japan | | 2002 | | | | Japan Gas Assoc. Phase 2 test of residential PEM fuel cells of different manufacturers. |
| Plug Power, Inc. | Japan Gas Association | 3 kW hybrid PEM/battery | Japan | | 2002 | | | | Japan Gas Assoc. Phase 2 test of residential PEM fuel cells of different manufacturers. |
| Plug Power, Inc. | Japan Gas Association | 1 kW PEM | Demonstration tests (7 companies) held in Tokyo, Osaka and Nagoya, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | | | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of operation in Phase I testing, 8,000 hours scheduled in Phase 2 using fuel cells of different manufacturers. |
| Plug Power, Inc. | Gaz de France | Six 4.5 kW PEM beta CHP units | La Plaine Saint-Denise, France | Gaz de France | Dec. 2001 - Feb. 2002 | | Natural gas | | |
| Plug Power, Inc. | Vaillant, E.ON, ELE, EUS, Ruhrgas | 4 kW PEM Fuel Cell Heating Appliance (FCHA) | Gelsenkirchen, Germany | Multiple family home | Dec. 2001 | Scheduled test completion at end of 2002 | Natural gas | | Supplies seven families with electricity, room heat, and hot water. Provides 80% of the home's electricity and nearly all of the hot water and room heating requirements. Supported by the North Rhine-Westphalia (NRW) Ministry of Economic Affairs as part of "Rational Energy Use" program |
| Plug Power, Inc. | Vaillant, Stadtwerke Duesseldorf, Ruhrgas AG, E.ON, ELE, EUS, German Gas Association, German Technical Surveillance Organization | 4.1 kW GenSys PEM Fuel Cell Heating Appliance (FCHA) | Dusseldorf, Germany | Im Füchschen micro-brewery | Late 2001 | | Natural gas | | Supplies about 80% of the electricity and heat to the traditional brewery, plus hot water for the brewing process, cleaning and dishwashing. Excess power is fed to the power network of the adjacent building complex. Supported by the North Rhine-Westphalia (NRW) Ministry of Economic Affairs as part of "Rational Energy Use" program |
| Plug Power, Inc. | German Gas Association, German Technical Surveillance Organization, Ruhrgas, Vaillant | PEM Fuel Cell Heating Appliance (FCHA) | Essen, Germany | Multiple family home | 2001 | | | | Supported by the North Rhine-Westphalia (NRW) Ministry of Economic Affairs as part of "Rational Energy Use" program. |
| Plug Power, Inc. | Long Island Power Authority (LIPA), DOE, NY State Energy Research and Development Authority (NYSERDA) | 75 PEM systems | West Babylon, New York | Long Island Fuel Cell Farm R&D at LIPA substation | 2001 | | |  | Forty-five of the original seventy-five units were in use as of 2003. The electricity is distributed to customers through LIPA's electric transmission and distribution system. Expected to produce more than 1 million kWh of electricity during the two-year project. Part of Gov. Pataki's Clean Energy Initiative. |
| Plug Power, Inc. | | Fifty 5 kW SU-1 PEM units | Various residential locations, New York | | Installed in 2001 | | Natural gas | | Part of Gov. Pataki's Clean Energy Initiative. |
| Plug Power, Inc. | Long Island Power Authority | Six alpha 5 kW PEM CHP units | Four Long Island locations, | Homes | 2000 | | Natural gas | | |

 

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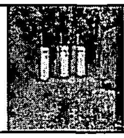
| | (LIPA), DOE, NY State Energy Research and Development Authority (NYSERDA), Elemco Testing Company | | New York | | | | | | |
| Plug Power, Inc. | Long Island Power Authority (LIPA), DOE, NY State Energy Research and Development Authority (NYSERDA) | Twelve 5 kW PEM units | New York | Various New York public facilities | 2000 | | | | |
| Plug Power, Inc. | Long Island Power Authority (LIPA), US Department of Energy, NY State Energy Research and Development Authority (NYSERDA) | Three 5 kW PEM units | Brookhaven, New York | DOE's Brookhaven National Lab | Mar. 2000 | | | | |
| Plug Power, Inc. | Hofstra University | Six PEM units | Hempstead, New York | Hofstra University | 2000 | Completed | | | These were among the first systems demonstrated outside of Plug Power's laboratory. |
| Plug Power, Inc. | | PEM | Latham, New York | Plug Power's Demonstration Home | Jun. 1998 | | Hydrogen , natural gas | | Four month demonstration using hydrogen fuel, followed by demonstration using natural gas. |
| Plug Power, Inc. | Long Island Power Authority/Central 02 | Thirty-seven 5 kW PEM units | New York | | | | | | Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program ($185,000). |
| Plug Power, Inc. | Idaho State University | 7 kW PEM | Idaho | | | | | | Buy Down Recipient FY1999 US DoD Climate Change Fuel Cell Program ($7,000). |
| Plug Power, Inc. | NJR Power Services Group, GE | Twenty7 kW 7000 PEM units | | | | | | | Buy Down Recipient FY1999 US DoD Climate Change Fuel Cell Program ($140,000). |
| Plug Power, Inc. | New York State Energy Research and Development Authority | Eighty 7 kW Plug Power 7000 PEM units | New York City metropolitan area, New York | New York State-owned facilities | | | Natural gas |  | 24 units tested in Phase I. 6 units in Phase II, 50 units in Phase III. |
| Plug Power, Inc. | Town of East Hampton | PEM | East Hampton, New York | Town Hall | | | | | |
| Plug Power, Inc. | Vaillant | PEM | Delitzsch, Germany | Apartment building | | | Natural gas | | |
| Plug Power, Inc | Vaillant, Weingas | 4.1 kW PEM Fuel Cell Heating Appliance (FCHA) | Vienna, Austria | Workshop | | | Natural gas | | |
| Plug Power, Inc. | Vaillant, Stadtwerke Bielefeld | 4.1 kW PEM Fuel Cell Heating Appliance (FCHA) | Bielefeld, Germany | Multi-family house | | | Natural gas | | |
| Plug Power, Inc. | HEW | 4.1 kW PEM Fuel Cell Heating Appliance (FCHA) | Hamburg, Germany | Workshop | | | | | |
| Plug Power, Inc. | Vaillant, Steirische Ferngas Austria, University of Graz, ESTAG | 4.1 kW PEM Fuel Cell Heating Appliance (FCHA) | St. Ruppert, Austria | Hotel Ochensberger | Jan. 2003 | May 2004 | Natural gas | | |
| Plug Power, Inc. | Vaillant, SOTEG Luxembourg | 4.1 kW PEM Fuel Cell Heating | Luxembourg | School | | | Natural gas | | |

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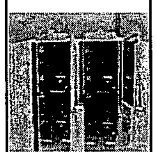
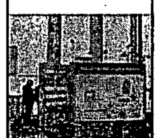
| | | Appliance (FCHA) | | | | | | | |
| Plug Power, Inc. | Vaillant, Weingas | Euro I PEM CHP | Wein, Austria | Residential | Feb. 2002 | Dec. 2004 | Natural gas | | |
| Proton Energy Systems | Public Utilities Commission | 15 kW regenerative fuel cell | Wallingford, Connecticut | Public Utilities Commission's Thorpe Avenue electric substation | Agreement announced May 2005 | One-month demonstration | | | Will provide back-up power to a sub-station located next to Proton Energy Systems' office. $500,000 is being provided by the Connecticut Clean Energy Fund. |
| ReliOn | US Department of Defense, Spokane Sector Department of Homeland Defense | Five 1 kW PEM units | Spokane, Washington | Radio repeater stations | Planned | | Hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2004. |
| ReliOn | US Army Corps of Engineers, Construction Engineering Research Lab (CERL) | Four 1 kW Independence 1000 PEM units | Fort Rucker, Alabama | Fort Rucker Localizer and Glide Slope buildings (1 unit each), middle beacon (1 unit) and outer marker beacon (2 units) | Planned | | Industrial grade hydrogen gas | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Provides air traffic control back up power. The Localizer and Glide Slope are located on Cairns Army Air Field just outside of Ft. Rucker. The Middle Marker is located just outside of Cairns Army Air Field and the Outer Marker is located approximately 10 miles from Cairns Army Air Field near a peanut farm. Each site will utilize one fuel cell. |
| ReliOn | US Army Corps of Engineers, Construction Engineering Research Lab (CERL) | 4 kW Independence 1000 PEM units | Westhampton, New York | Gabreski Air National Guard, base telephone exchange | Dec. 2004 | Operational | Hydrogen |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. The fuel cells are connected to the 48 V battery string on a new uninterruptible power supply (UPS) system installed for this project. |
| ReliOn | US Army Corps of Engineers, Construction Engineering Research Lab (CERL) | Four 1 kW Independence 1000 PEM units | Tacoma, Washington | Fort Lewis Localizer and Glide Slope buildings, middle and outer marker beacons (1 unit each) | Jul. 2004 | Operational | Industrial grade hydrogen | | US Department of Defense Residential PEM Fuel Cell Demonstration Program FY 2003. Provides air traffic control back up power. |
| ReliOn | US Army Corps of Engineers, Construction Engineering Research Lab (CERL), Industrial Research Ltd. | Two 1 kW Independence 1000 PEM units | Christchurch, New Zealand | US Antarctic Division Scientific Foundation Building | Apr. 2005 | One-year trial | Methanol |  | US Department of Defense Residential PEM Fuel Cell Demonstration Program BY 2003. Supplies security lighting at night and automatically switched off during daylight hours. During the day power output will be continually available for charging and other demonstration field instrumentation loads. |
| ReliOn | havePOWER, State of Washington | Independence 1000 PEM | Washington | Washington State Highway Patrol Emergency 911 system | Installed | Operational | | | |
| ReliOn | havePOWER, State of Washington | Independence 1000 PEM | Washington | Washington State Department of Transportation Emergency-911 system | Installed | Operational | | | |

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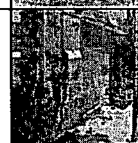
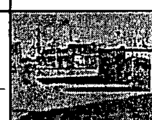
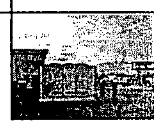
| ReliOn | Bonneville Power Administration, havePOWER | Independence 1000 PEM | Vancouver, Washington | Bonneville Power Administration's Ross Substation | April 2004 | Operational | |  | |
| ReliOn | HavePOWER, Multi-Agency Radio Communications System (MARCS) | Four Independence 1000 PEM units | Washington Township, Ohio | MARCS microwave radio towers | Oct. 2004 | Operational | |  | Deployed at the MARCS installations--instead of lead acid based battery banks and engine generators--to provide long-term, emergency back-up power to critical digital communication infrastructure. |
| ReliOn | Bonneville Power Administration, Northwest Energy Technology Collaborative, Central Washington University | 1 kW Independence 1000 PEM | Ellensburg, Washington | Central Washington University | Mar. 2004 | Operational | | | A television and video player are powered by the fuel cell. |
| ReliOn | Maryland Department of Transportation, havePOWER | Independence 1000 PEM | Hancock, Maryland | Fiber optic repeater station | Feb. 2004 | Operational | Hydrogen |  | World's first back-up for fiber optic repeater station. |
| ReliOn | Bahamas Telecommunicat ions, Inc. | Independence 1000 PEM | Nassau, Bahamas | Back up telecommunicati ons site | Aug. 2004 | Operational | |  | Successfully provided back up power during a Category 4 hurricane. |
| ReliOn | US Federal Aviation Administration | Independence 1000 PEM | Swinn's Valley, Wisconsin | Radio communication-link repeaters | Jun. 2004 | Operational | | | |
| ReliOn | US Federal Aviation Administration | Independence 1000 PEM | Wakeman, Ohio | Radio communication-link repeaters | Jun. 2004 | Operational | | | |
| ReliOn | US Federal Aviation Administration | Independence 1000 PEM | Fargo, North Dakota | Radio communication-air to ground | Sep. 2004 | Operational | | | |
| ReliOn | US Federal Aviation Administration | Independence 1000 PEM | Medical Lake, Washington | Radio communication-link repeaters | | Operational | | | |
| ReliOn | Avista Labs/ReliOn | Two Independence 1000 PEM | | Two Avista Corp/ReliOn substations | Sep. 2003 and Apr. 2004 | Operational | |  | Provides backup to substation protection and control equipment at two sites. |
| ReliOn | US Federal Aviation Administration | Independence 1000 PEM | Palwaukee, Illinois | Radio transmitter-repeaters | Dec. 2003 | Operational | | | |
| ReliOn | US Bureau of Reclamation | Independence 1000 PEM | Loveland, Colorado | Bureau of Reclamation Pole Hill plant | Oct. 2003 | Operational | |  | Provides backup power to plant communication systems |
| ReliOn | havePOWER, State of Maryland | Independence 1000 PEM | Elk Neck State Park, Maryland | Emergency 911 (MIEMSS) system remote telecommunicati ons site | Aug. 2003 | Operational | |  | Provides back-up power to a microwave radio site. Activated during Hurricane Isabel and provided continuous power until grid service was restored. Maryland has approved the fuel cell for primary back up power at other MIEMSS locations and the state's fiber optic network. |
| ReliOn (under former name-Avista Labs) | Army Corp of Engineers Construction Engineering | Six 500 W Independence 500 units (3 kW total power) | Tacoma, Washington | FAA radio transmitter-repeaters at McChord Air | Apr. 2003 | Apr. 2004 | Hydrogen |  | DOD Residential Fuel Cell Demonstration Program FY 2002. Provided critical backup power for a radio |

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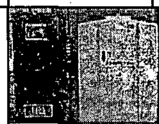
| | Research Laboratory (CERL) | | | Force Base | | | | | transmitter receiver (RTR) site. No cogeneration. |
| ReliOn (under former name- Avista Labs) | Flash Technology, havePOWER | EPAC PEM | Outside Wilkes Barre, Pennsylvania | Cellular communication tower | Feb. 2002 | Ongoing | |  | World's first cellular communication's tower powered by hydrogen fuel cells. Powers Flash Technology beacon on cell phone tower and cell phone radio. |
| ReliOn (under former name- Avista Labs) | US Department of Defense, LOGANEnergy | 5 kW PEM | Kaneohe Bay, Hawaii | Marine Corp Base housing | Dec. 2002 | | Propane | | No cogeneration |
| ReliOn (under former name- Avista Labs) | U.S. Army Corps of Engineers' Construction Engineering Research Laboratory (CERL) | 3 kW SR-72 PEM | Spokane, Washington | Washington Air National Guard maintenance facility at Geiger Field | Mar. 2002 | Mar. 2003 | Industrial grade bottled hydrogen |  | DOD Residential Fuel Cell Demonstration Program FY 2001. |
| ReliOn (under former name- Avista Labs) | U.S. Army Corps of Engineers' Construction Engineering Research Laboratory (CERL) | 5 kW PEM | Fayetteville, North Carolina | Fort Bragg base housing | Nov. 2002 | | Natural gas | | DOD Residential Fuel Cell Demonstration Program |
| ReliOn (under former name- Avista Labs) | SGS Future srl | Ten Independence 1000 PEM units | Cavalese, Italy | Mountaintop alpine lodge | End of 2002 | | | | Installed in a parallel configuration providing 10kW of power. |
| ReliOn (under former name- Avista Labs) | Fuel Cell Test and Evaluation Center (FCTec) | SR 12 PEM | Johnstown, Pennsylvania | FCTec facility | | | |  | Underwent testing and evaluation. |
| Sanyo Electric Co. | Urban Renaissance Agency (URA) | Forty-three 750 W PEM units | Osaka and Musashino, Japan | URA's rental condominiums | Mar. 2005 | | Town gas | | PEMs are installed in 26 out of 252 homes in Osaka and 17 out of 85 homes in Musashino. Provides 74% of electric demand and 92% of hot water demand. There is no additional charge for the fuel cell-equipped homes. |
| Sanyo Electric Co. | Sumitomo Corporation, Nippon Steel Corporation | 5 kW SOFC | Japan | Yahata Steel Works | Jun. 2004 | | | | Performance and demonstration test of unit designed by Sumitomo, Nippon Steel and Sanyo. |
| Sanyo Electric Co. | Daiwa House Industry Co., Ltd, Ministry of Land, Infrastructure and Transport | 1 kW PEM | Nara prefecture, Japan | | 2004 | | | | Field test. |
| Sanyo Electric Co. | Osaka Gas Co. | 1 kW PEM | Kyoto, Japan | Residential | Apr. 2002 | | | | |
| Sanyo Electric Co. | Coalition of the Kinki Bureau of Economy, Trade and Industry and 80 companies | Three 100 kW PEM units | Nishinomiya, Japan | Fire station | Apr. 2002 | | | | Will provide emergency power backup for lighting and rescue activity and emergency medical activity such as power for artificial respiration. The project was proposed after the Hanshin-Awaji Earthquake disaster. |
| Sanyo Electric Co. | Japan Gas Association | 1 kW PEM | Demonstration tests (7 companies) held in Tokyo, Osaka and Nagoya, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | | | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of |

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| | | | | | | | | | operation in Phase I testing, 8,000 hours scheduled in Phase 2 using fuel cells of different manufacturers. |
| Schatz Energy Research Center | | 100 W PEM | Redwood National Forest, California | Schoolhouse Peak | 1999, refurbished 2001 | 2003 | Hydrogen | | Part of Yurok Indian telecommunications system providing cell phone service to a remote portion of the reservation. Links to Pacific Bell's telephone network. Logged 3,239 operating hours on the first stack, 3,836 hours on second stack. |
| Siemens Power Generation, Inc | Gas Turbine Technologies, SpA (GTT) | 100 kW SOFC CHP | Turin, Italy | GTT facility | Successfully re-started Aug. 2005 | | | | Provides power and will provide heat and cooling to the building beginning Fall 2005. Grid connected. The fuel cell had previously operated for more than 20,000 hours in Germany and the Netherlands. |
| Siemens Power Generation, Inc | BP Alaska | 125 kW SOFC | Alaska | | Planned in 2006 | | Pipeline natural gas (PNG) | | |
| Siemens Power Generation, Inc | Stadtwerke Hanover AG, E.ON Energie AG | 250 kW SOFC | Hannover, Germany | Herrenhausen power plant | Planned installation in 2004 | | Pipeline natural gas (PNG) | | In normal operating mode will simultaneously feed 225 kW of electricity into the grid operated by Stadtwerke Hanover and 160 kW of heat for Hanover's district heating network |
| Siemens Power Generation, Inc | Edison SpA | 300 kW SOFC/gas turbine Pressurized Hybrid (PH) system | Sinetta Marengo, Italy | Edison thermo-electric power station | Early 2003 | One-year demonstration | Natural gas | | Electrical efficiency of 58%. |
| Siemens Power Generation, Inc | BP America | 250 kW SOFC CHP | Nikiski, Alaska | BP gas-to-liquids plant, administration building and warehouse | 2003 | | Natural gas |  | Excess power to be sold to local grid. Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program. ($250,000) One of two fuel cells installed at BP. |
| Siemens Power Generation, Inc | Ontario Power Generation, US Department of Energy and National Resources Canada, Kinectrics Inc. | 250 kW SOFC CHP | Toronto, Canada | Kinectrics (formerly Ontario Hydro) test facility | 2003 | Ongoing | |  | Proof-of-concept. By 2004 the system has operated for more than 1,100 hours. Buy Down Recipient FY1999 US DoD Climate Change Fuel Cell Program. |
| Siemens Power Generation, Inc | Univerisity of Toronto, Kinetrics, Ontario Power Generation | 250 kW SOFC | Mississauga, Canada | University of Toronto-Mississauga | 2003 | | | | Will be connected to the internal grid and is expected to provide 8% of the electrical needs for the campus as well as hot water. |
| Siemens Power Generation, Inc | Norske Shell | 250 kW SOFC hybrid | Bergen, Norway | Kollsnes gas processing plant | 2003 | | Natural gas | | Demonstration of capture of fuel cell exhaust carbon dioxide gas for sequestration or for use in other industries. |
| Siemens Power Generation, Inc | RWE | 300 kW SOFC/gas turbine Pressurized Hybrid (PH) CHP system | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Apr. 2002 | One-year demonstration | Natural gas |  | Provided power and heat to the RWE Meteorit Exposition Pavilion. Electrical efficiency of 58%. |
| Siemens Power Generation, Inc | Ontario Power Technologies | 250 kW SOFC/gas turbine hybrid system | Toronto, Canada | Ontario Power Technologies facilities | 2002 | Completed | Pipeline natural gas (PNG) | | Operated 1,000+ hours. Was to deliver 225 kW to the existing power grid and supply 145 kW of heat. FY 1999 US DoD Climate Change Fuel Cell |

 

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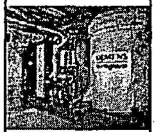
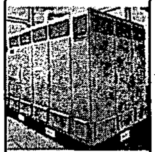
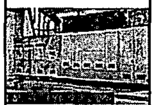
| | | | | | | | | | Program. ($200,000) |
| Siemens Power Generation, Inc | EnbW, TIWAG, Gax de France | 1 MW SOFC with micro-turbine generator | Austria | | Jan. 2000 | Dec. 2003 | | | |
| Siemens Power Generation, Inc | University of California, Edison Technology Solutions/Southern California Edison | 220 kW SOFC/gas turbine hybrid system | Irvine, California | National Fuel Cell Research Center at the University of California-Irvine | Jun. 2000 | Completed 2001 | Natural gas |  | Proof-of-concept Operated for nearly 3,400 hours and achieved an electrical efficiency of ~53% |
| Siemens Power Generation, Inc | Southern California Edison, National Fuel Cell Research Center, Tokyo Gas, Osaka Gas | 25 kW SOFC | Irvine, California | Highgrove Generation Station, (Southern California Edison), later relocated to the National Fuel Cell Research Center | 1994 | Will operate up to 20,000 hours. May be retired to the Smithsonian as the "world's first integrated solid oxide fuel cell system" | Jet fuel, diesel fuel, natural gas |  | Installed in 1994 at the Highgrove Generating Station of Southern California Edison. Operated approximately 6,500 hours on first stack before being replaced in 1995 with a new stack. Was shut down in 1996 after 11,500 hours of testing (5,000 hours on the new stack). Relocated to NFCRC and restarted in 1998. By 2002, the system has operated for a total of 19,750 hours (13,250 hours on the current stack). |
| Siemens Power Generation, Inc | EDB/Elsam, Nuon | 100 kW SOFC CHP | Westervoort, Netherlands; Essen, Germany | EDB/Elsam power plant; RWE Fuel Cell Pavilion, Meteorit Park | Dec. 1997 | Completed | Natural gas, pipeline natural gas (PNG) |  | Operated for 16,667 hours at a peak power of ~140 kW. Electrical efficiency was 46%. In June 2001 was moved to RWE Fuel Cell Pavilion and tested for an additional 3,700 hours, for a total of over 20,000 hours. |
| Siemens Power Generation, Inc | Joint Gas Utilities | 25 kW SOFC/as turbine hybrid system | Japan | | 1995 | Completed | Pipeline natural gas (PNG) | | Logged 13,294 hours of operation. |
| Siemens Power Generation, Inc | Unidentified utility company | 20 kW SOFC/gas turbine hybrid system | | | 1993 | Completed | Pipeline natural gas (PNG) | | Logged 7,064 hours of operation. |
| Siemens Power Generation, Inc | Unidentified utility company | 20 kW SOFC/gas turbine hybrid system | | | 1992 | Completed | Pipeline natural gas (PNG) | | Logged 2,601 hours of operation. |
| Siemens Power Generation, Inc | Unidentified utility company | 20 kW SOFC/gas turbine hybrid system | | | 1992 | Completed | Pipeline natural gas (PNG) | | Logged 1,579 hours of operation. |
| Siemens Power Generation, Inc | Joint Gas Utilities | 20 kW SOFC/gas turbine hybrid system | Japan | | 1992 | Completed | Pipeline natural gas (PNG) | | Logged 817 hours of operation. |
| Siemens Power Generation, Inc | Osaka Gas | Two 3 kW SOFC/gas turbine hybrid systems | Japan | | 1987 | Completed | H2+CO | | Logged 3,012 and 3,683 hours of operation. |
| Siemens Power Generation, Inc | Tokyo Gas | 3 kW SOFC/gas turbine hybrid system | Japan | | 1987 | Completed | H2+CO | | Logged 4,882 hours of operation. |
| Siemens Power Generation, Inc | Tennessee Valley Authority | 400 W SOFC/gas turbine hybrid power system | | | 1986 | Completed | H2+CO | | Logged 1,760 hours of operation. |
| Smart Fuel Cell AG (SFC) | | Multiple 120 W SFC A50 DMFC fuel cells | Brandenburg, Germany | Fire watch towers in Brandenburg | Jun. 2005 | | Methanol |  | Forest fire-watch cameras are operated by a photovoltaic system, with fuel cell back up power. |
| Sulzer Hexis | HEAG | SOFC | Darmstadt, Germany | Residence | Mar. 2005 | | Natural gas | | Provides electricity and heat. |

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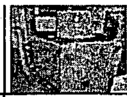
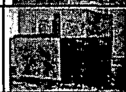
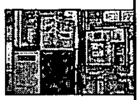
| Sulzer Hexis | VNG, DREWAG | 1 kW HXS 1000 Premiere SOFC CHP | Dresden, Germany | Kindergarten | Jan. 2004 | | Natural gas |  | Part of the VNG DemoCell project. |
| Sulzer Hexis | Axpo Holding AG | Pre-series HXS 1000 Premiere SOFC CHP system | Zurich, Switzerland | Single-family test house | Oct. 2003 | Two-year testing project | Natural gas | | |
| Sulzer Hexis | Gasverbund Mittelland AG | Thirty SOFC units | Northwestern Switzerland | Customer-residential | 2003 | | Natural gas | | Swiss natural gas supplier. Units delivered to interested customers. Very high demand for the 30 pre-production units. |
| Sulzer Hexis | Gaz de France | HXS 1000 Premiere SOFC | La Plaine Saint-Denis, Paris, France | Test house at Gaz de France research and development facility | Jan. 2003 | Completed Dec. 2003 | Natural gas | | One year testing project. |
| Sulzer Hexis | VNG, Berliner Gaswerke AG | HXS 1000 Premiere SOFC | Berlin-Buckow, Germany | One side of a two-family house | Aug. 2003 | Three year test | Natural gas |  | Part of the VNG DemoCell project. When the fuel cell can't produce as much heat as necessary, the integrated gas-fired condensing boiler steps in to meet peak needs. Surplus electricity is fed into the network of the local electricity supplier. |
| Sulzer Hexis | HGW, eon Hanse Gas AG, VNG | 1 kW HXS 1000 Premiere SOFC CHP | Gadebusch, Germany | Three-apartments in a multi-family dwelling | Nov. 2002 | | Natural gas |  | Part of the VNG DemoCell project. |
| Sulzer Hexis | VNG, Erdgas Mittelsachsen | 1 kW HXS 1000 Premiere SOFC CHP | Barby, Germany | Training center | Jun. 2002 | | Natural gas |  | Part of the VNG DemoCell project. |
| Sulzer Hexis | VNG, Stadtwerke Weimar | 1 kW HXS 1000 Premiere SOFC CHP | Weimar, Germany | Training center | Oct. 2002 | | Natural gas |  | Part of the VNG DemoCell project. |
| Sulzer Hexis | VNG | Sixteen 1 kW HXS 1000 Premiere SOFC CHP systems | Various locations, Germany | Customer-sited | Purchased over 2002-2003 | | Natural gas | | East German gas utility. Purchase over the period 2002 -2003. Thermal output of 2.5 kW. |
| Sulzer Hexis | E.ON Energie AG | Fifty-six 1 kW HXS 1000 Premiere SOFC CHP systems | Various locations, Germany | Customer-sited | Purchased over 2002-2003 | | Natural gas | | One of Europe's largest private electricity, gas and water utilities. Purchase over the period 2002 -03. Thermal output of 2.5 kW. |
| Sulzer Hexis | Thyssengas GmbH | Forty-two 1 kW HXS 1000 Premiere SOFC CHP systems | North Rhine-Westphalia area, Germany | Customer-sited | Purchased over 2002-2003 | | Natural gas | | Natural gas importer and supplier. Purchase over the period 2002 -03. Thermal output of 2.5 kW. |
| Sulzer Hexis | RWE | 1 KW HXS 1000 Premiere SOFC | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Apr. 2002 | Ongoing | Natural gas |  | Electrical output of 1 kW and thermal output of 2.5 kW. Designed exclusively for use in single-family homes. The SOFC achieves an electrical efficiency of approximately 25% and an overall efficiency of at least 80%. |
| Sulzer Hexis | Energie AG Oberösterreich, Oberösterreichischen Ferngas AG | 1 KW HXS 1000 Premiere SOFC | Attnang Puchheim, Austria | Technology Center Salzkammergut | Mar. 2002 | Mar. 2004 | Natural gas | | |
| Sulzer Hexis | Energy Research Centre of the Netherlands (ECN) | 1 KW HXS 1000 Premiere SOFC | Petten, Netherlands | ECN test laboratory | Summer 2002 | One-year testing and operation | Natural gas | | Testing/analysis for usability in Dutch households. |
| Sulzer Hexis | EnBW | Forty 1 kW HXS 1000 Premiere SOFC CHP systems | | Customer-sited | Purchased over 2001-2003, first installation in Dec. 2001 | | Natural gas | | Over 6,000 persons responded to an advertisement placed by EnBW seeking 25 customers to test a fuel |

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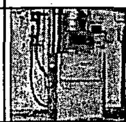
| | | | | | | | | | cell heating system. By 2006, about 55 customers will use this technology. The successor of the SOFC pre-series fuel cell system will be delivered in 2005. |
| Sulzer Hexis | EWE PLC | One hundred fifty-five 1 kW HXS 1000 Premiere SOFC CHP systems | Various locations, Germany | Customer-sited | Purchased over 2001-2003 | | Natural gas | | Purchase over the period 2001 – 03. Thermal output of 2.5 kW. Unit 001 was tested at EWE's lab. The remainder were to be made available to customers for testing.. |
| Sulzer Hexis | EWR | Sixty 1 kW HXS 1000 Premiere SOFC CHP systems | Various locations, Germany | Customer-sited | Purchased over 2001-2003 | | Natural gas | | Sited with utility customers within the Rheinhessen/Ried. Region. Purchase over the period 2001 – 03. Thermal output of 2.5 kW. |
| Sulzer Hexis | EREP SA, Universite Lausanne, Herr Chabloz | 1 kW SOFC | Lully, Switzerland | Chabloz biogas plant | Aug. 2001 | | Agricultural biogas | | Operated for 5,000 hours at 35% efficiency. |
| Sulzer Hexis | Tokyo Gas | 1 kW SOFC | Tokyo, Japan | Tokyo Gas Fundamental Technology Research Laboratory | Feb. 2000 | 2001 | City gas | | |
| Sulzer Hexis | Gasunie, Shell | 1 kW SOFC | Groningen, Netherlands | Gasunie research facility | May 2000 | | | | Integrated into heating system. |
| Sulzer Hexis | Gas de Euskad, Ikerlan Energy, School of Engineers-Bilbao, EVE | 1 kW SOFC CHP | Bilbao, Spain | Miñano technology park demonstration house | Installed Oct. 1999 | 2001 | Natural gas | | Combined heat and power. |
| Sulzer Hexis | City of Basel, AUE Basel | 1 kW SOFC CHP | Basel, Switzerland | School | Installed Oct. 1998 | 2001 | |  | Produces power for the school. Excess energy sent to the grid. Operated for more than 8,000 hours. |
| Sulzer Hexis | Deutschland Überregionales Gasversorgungs unternehmen, Thyssengas | 1 kW SOFC | Duisburg, Germany | | Installed Nov. 1998 | 2001 | | | |
| Sulzer Hexis | EWE, Deutschland Regionales Energieversorgu ngsunternehme n | 1 kW SOFC | Oldenburg, Germany | EWE facility | Installed Nov. 1998 | Sep. 2001 | |  | |
| Sulzer Hexis | Städtische Werke Wintherthur | 1 kW SOFC CHP | Winterthur, Switzerland | | May 1997 | 1998 | Natural gas |  | Field trial with Swiss utility company. Was controlled remotely by modem and telephone line. Was initially used to test various fuel cell developments under realistic conditions. Fed into the grid for the first time in Jul. 1998. |
| Sulzer Hexis | Dortmunder Energie- und Wasserversorgu ng GmbH | 1 kW SOFC CHP | Dortmund, Germany | | Sep. 1997 | 1998 | Natural gas | | Field trial with Germany utility company. Was remotely-controlled via modem and telephone line.. |
| Sulzer Hexis | | 1 kW SOFC | Basel, Switzerland | Sulzer Hexis test lab | 1997 | 1998 | Hydrogen | | Trial stack, operated over 12,000 hours. 35% energy efficiency. |
| Teledyne Energy Systems Inc. (formerly Energy Partners) | National Aeronautics and Space Administration (NASA) | 12 kW PEM | Cleveland, Ohio | NASA's Glenn Research Center | Delivered Aug. 2005 | | | | Will undergo vibration and thermal vacuum testing to simulate conditions in space. |
| Teledyne Energy Systems Inc. (formerly Energy Partners) | National Aeronautics and Space Administration | 5 kW PEM | Houston, Texas | NASA's Johnson Space Center | Delivered Apr. 2003 | | Hydrogen | | For system validation under simulated flight conditions. |

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| | (NASA) | | | | | | | | |
| Teledyne Energy Systems Inc. (formerly Energy Partners) | US Department of Energy (DOE) | 7 kW PEM | | | Late 2002 | | Natural gas | | For evaluation by DOE. |
| Tokyo Gas | | SOFC | Japan | Tokyo Gas laboratory | Dec. 1998 | Mar. 1999 | City gas | | World's first generation of power in the kilowatt range with a flat panel SOFC. The fuel cell was designed in-house. |
| Toshiba | Taiyo Oil Co., New Energy Foundation | Three PEM units | Matsuyama, Japan | Public facilities | Sep. 2005 | Two-year demonstration | Liquefied petroleum gas (LPG) | | |
| Toshiba | Taiyo Oil Co., New Energy Foundation | Four PEM units | Imabari, Japan | Residential | Sep. 2005 | Two-year demonstration | Liquefied petroleum gas (LPG) | | |
| Toshiba | Taiyo Oil Co., New Energy Foundation | PEM | Imabari, Japan | Nursing home | Sep. 2005 | Two-year demonstration | Liquefied petroleum gas (LPG) | | |
| Toshiba | Cosmo Oil Co Ltd | 700 W PEM | Isakacho, Japan | Isaka Dam Cycle Park administrative office | Mar. 2005 | Operational | Liquefied petroleum gas (LPG) | | Provides power and exhaust heat used for hot water. |
| Toshiba | Ministry of Land, Infrastructure and Transport, Tokyo Gas | 1 kW PEM | Yokohama, Japan | | 2004 | | | | Field test. |
| Toshiba | Chugoku Electric Power Co | PEM | Matsue, Japan | Research & Development Center for Energy Utilization Technology | Jun. 2003 | | Biogas from garbage | | |
| Toshiba | | 700 kW PEM | Kamo, Japan | Toshiba Home Technology factory | Sep. 2002 | | | | Cogeneration system. |
| Toshiba | Tohoku Electric | 1 kW PEM | Japan | Tohoku Electric research and development center | Early 2002 | | Town gas | | Grid connected. Produces power and the waste heat is used for hot water. |
| Toshiba | Japan Gas Association | 1 kW PEM | Demonstration tests (7 companies) held in Tokyo, Osaka and Nagoya, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | | | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of operation in Phase I testing, 8,000 hours scheduled in Phase 2 using fuel cells of different manufacturers. |
| Toshiba | Kyushu Electric Power Co. (KEPCO) | 700 kW PEM | Japan | KEPCO Research Institute | Dec. 2001 | 2003 | Town gas | | |
| Toyota | Japan Gas Association | 1 kW PEM | Demonstration tests (7 companies) held in Tokyo, Osaka and Nagoya, Japan | | Phase 1: Dec. 2001 | Phase I completed Feb. 2002 | | | Japan Gas Assoc. test of residential PEM fuel cells from seven manufacturers (Ballard, Matsushita Electric, Toshiba, Toyota, Sanyo Electric, Mitsubishi Electric, Plug Power). Completed 1,000 hours of operation in Phase I testing, 8,000 hours scheduled in Phase 2 with nine manufacturers.. |
| UTC Power | East Rochester School District | 200 kW PureCell 200 | East Rochester, New York | School | Planned | | Natural gas | | The fuel cell will provide 60-70% of the school energy needs. Will provide continuous electricity and heat for the high school and onsite backup power for the community's emergency response program.. The school district anticipates |

 

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| | | | | | | | | | saving about $100,000/year in energy costs. Total cost of the project is $2.5 million, with $1 million provided by NYSERDA and $1.5 million from the district's Capital Reserve Fund. |
| UTC Power | Verizon | 1.4 MW PAFC system (seven 200 kW units) | Garden City, New York | Major call-routing center serving (40,000 phone lines) | Commissioned Sep. 2005 | | Natural gas | | The largest fuel cell deployment project in the world, providing primary electrical power for the facility. Four natural gas powered generators operate in parallel with the fuel cells as a hybrid back up system that can generate up to 4.4 MW of electrical power. Buy Down Recipient FY1999 US DoD Climate Change Fuel Cell Program ($1.4 million). |
| UTC Power | New York Power Authority, Wildlife Conservation Society | 200 kW PAFC | Bronx, New York | Bronx Zoo's Old Lion House | Planned | | Natural gas | | Buy Down Recipient FY2002 US DoD Change Fuel Cell Program ($200,000). |
| UTC Power | New York Power Authority, New York City Transit | 200 kW PAFC | New York City, New York | Corona Rail Car Maintenance Facility | Will be installed Apr. 2006 | | Natural gas | | Will operate grid parallel to displace existing facility electric demand and can operate as stand alone generator during a power outage. Thermal energy will supplement the domestic hot water system. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Anaheim Public Utilities | 200 kW PAFC | Anaheim, California | East Anaheim Police Department and Community Center | Feb. 2005 | Operational | Natural gas |  | Used for combined heat and power and back up power. Buy Down Recipient FY2002 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Orgenergogaz (oil and gas pipeline engineering company) | 200 kW PureCell PAFC | Russia | Orgenergogaz facility | | Operational | | | Operated successfully during May 2005 grid power outage in Russia. |
| UTC Power | New York Power Authority, Grand Central Railroad | Two 200 kW PAFC | New York City, New York | Grand Central train station terminal | Installed Feb. 2005 | | Natural gas | | Can operate in grid parallel and grid independent modes. Thermal energy will be used to produce domestic hot water for use in adjacent restaurants and hotels. Partial funding by New York State Energy Research and Development Authority. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($400,000). |
| UTC Power | New York Power Authority, New York State Office of General Services | 200 kW PAFC | Hauppauge, New York | Suffolk State Office Building, Regional Emergency Management Office | Installed May 2005 | | | | Can operate in grid parallel and grid independent modes. Will supply power to New York Regional Emergency Management Office w. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Hilton New York | 200 kW PAFC | New York City, New York | New York Hilton Hotel | Installed Feb. 2005 | | Natural gas | | May install at other hotel properties. Will provide power. 100% waste heat recovery for hot water in |

 

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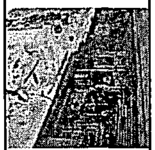
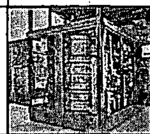
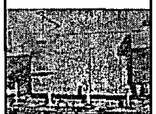
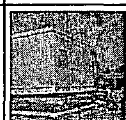
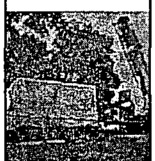
| | | | | | | | | | guest rooms, kitchens and laundry. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | LOGANEnergy, Army National Guard | 200 kW PC25 PAFC | Paso Robles, California | Camp Roberts Army National Guard Base SatCOM facility | Installed Feb. 2005 | Operational | Natural gas | | Grid parallel to reduce electric demand and provide power stabilization. A possible California grant may allow installation of heat cogeneration equipment. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | LOGANEnergy, Guaranty Savings | Three 200 kW PAFC units | Fresno, California | Guaranty Savings-owned office building housing federal offices | Installed May 2004 | Operational | Natural gas |  | Grid parallel to reduce facility electric demand. Provides uninterruptible power supply for computer server rooms, communications, building security, emergency lighting, elevator motors and stairwell ventilation fans. Also provides cooling and space heating. Buy Down Recipient FY2003 US DoD Climate Change Fuel Cell Program ($600,000). |
| UTC Power | RWE | 200 kW PC25 PAFC | Essen, Germany | RWE Fuel Cell Pavilion, Meteorit Park | Early 2004 | Completed | |  | As the system is no longer in operation, it offers visitors an insight of its interior. |
| UTC Power | The College of New Jersey | Three 200 kW PAFC units | Ewing Township, New Jersey | The College of New Jersey three building student housing facility | Planned start-up Sep. 2004 | | Natural gas | | Combined heat and power operating cost savings are estimated to be $259,000 per year. Buy Down Recipient FY2002 US DoD Climate Change Fuel Cell Program ($600,000). |
| UTC Power | Toshiba, Nippon Petroleum Gas Co | 200 kW PAFC | Japan | Nippon Petroleum's Niigata LPG import terminal | May 2004 | Two year test | Dimethyl esther | | |
| UTC Power | Northern Alberta Institute of Technology (NAIT) | 200 kW PAFC | Edmonton, Canada | NAIT's main campus Interpretive Centre | 2004 | Operational | |  | Buy Down Recipient FY2002 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | US Environmental Protection Agency, NORESCO | 200 kW PC25 PAFC | Ann Arbor, Michigan | EPA's National Vehicle Emissions Laboratory | Jan. 2004 | Operational | Natural gas |  | Grid Parallel setup. Manufactured in 1996, had numerous upgrades prior to installation here. US DoD Climate Change Fuel Cell Program ($200,000) |
| UTC Power | Erasto Gaertner children's cancer hospital, Sieco S.A., Company Paranaense de Energia | 200 kW PC25 PAFC | Curitiba, Brazil | Erasto Gaertner children's cancer hospital | Delivered 2004 | | Natural gas |  | First fuel cell in Brazil. Supplies around 85% of the lighting, as well as well as energy for hot water for the kitchen and rooms. |
| UTC Power | New Haven Water Pollution Control Authority (WPCA New Haven) | 200 kW PC25 PAFC | New Haven, Connecticit | WPCA facility | November 2003 | | Natural gas |  | Partly funded by Connecticut Clean Energy Fund. Providing the heat for a unique fat/oil/grease disposal system. |
| UTC Power | Johnson & Johnson | 200 kW PAFC | New Brunswick, New Jersey | Johnson & Johnson World Headquarters administrative offices | Dec. 2003 | Shut down Feb. 2005, experienced fuel reformer problems, anticipate restart summer 2006 | Natural gas |  | Grid dependent to supplement incoming electrical service, displacing existing electric demand. Thermal energy from the fuel cell is used to provide hot water heating for the facility. Buy Down |

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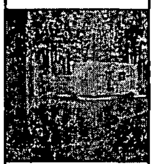
| | | | | | | | | | Recipient FY2003 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | New York Power Authority and New York State Energy Research and Development Authority | 200 kW PC25 PAFC | New York City, New York | Oakwood Beach Water Pollution Control Plant | April 2004 | Ongoing | Digester gas | | Grid Parallel |
| UTC Power | New York Power Authority, New York Department of Environmental Protection | Two 200 kW PC25 units | New York City, New York | Ward 26 Water Pollution Control Plant | Dec. 2003 | Ongoing | Digester gas | | |
| UTC Power | New York Power Authority, New York State Energy Research and Development Authority (NYSERDA) | Three 200 kW PC25 units | New York, New York | Hunts Point Water Pollution Control Plant | Feb. 2005 | Ongoing | Digester gas | | Operated in grid parallel mode. |
| UTC Power | New York Power Authority, New York State Energy Research and Development Authority (NYSERDA) | Two 200 kW PC25C units | New York City, New York | Red Hook Water Pollution Control Plant | Dec. 2003 | Ongoing | Digester gas | | Operated in grid parallel mode. |
| UTC Power | AB Parking Facility, LLC, Logan Energy | Three 200 kW PC25 PAFC units | Fresno, California | AB Parking Facilities | Installed June 2004 | | Natural gas | | Absorption chiller with fuel cells' waste heat will be used to provide 100 tons of cooling to 12 story commercial building. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program ($600,000). |
| UTC Power | St. Francis Hospital | 200 kW PC25 PAFC | Hartford, Connecticut | St. Francis Hospital | October 2003 | Operational | Natural gas | | Provides power security to operating room and interconnected with hospital's distribution and air conditioning system. |
| UTC Power | Richard Stockton College of New Jersey, South Jersey Industries | 200 kW PureCell PAFC | Pomona, New Jersey | Richard Stockton College of New Jersey | May 2003 | Operational | Natural gas |  | Buy Down Recipient FY2002 US DoD Climate Change Fuel Cell Program ($200,000). Officials anticipate the plant will cut energy costs by over $81,000 annually, recovering the college's investment within four years. |
| UTC Power | LOGANEnergy, Austin Energy Rebekah Baines Johnson Health Center | 200 kW PC25 PAFC | Austin, Texas | Rebekah Baines Johnson Health Center | Jul. 2002 | Ongoing | Natural gas |  | Electricity is fed into the Austin Energy electric grid, (the 1st fuel cell in Texas to feed power to the grid). The health center is using the 900,000 BTUs of thermal energy to heat their water. Austin Energy plans to provide tours and educational programs. Funding: $200,000 US DoD Climate Change Fuel Cell Program. (Buy Down Recipient FY1996-1997) |
| UTC Power | LOGANEnergy, Merck & Co. | 200 kW PC25C PAFC | Rahway, New Jersey | Merck & Co. plant | Jun. 2002 | Four-year demonstration | Natural gas |  | Funding: $710,000 from New Jersey Board of Public Utilities' clean energy initiative, $200,000 from US DoD Climate Change Fuel Cell Program. Buy Down Recipient FY1996-1997. |

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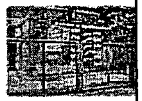
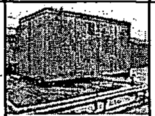
| UTC Power | Petrobras, Sieco S.A. | 200 kW PC25 PAFC | Rio de Janeiro, Brazil | Petrobras research and development center (CENPES) | Jan. 2002 | Operational | |  | Supplies electric power needs to the center. |
| UTC Power | LACTEC, Sieco S.A., Polytechnical Center of the Federal University | 200 kW PC25C PAFC | Curitiba, Brazil | LACTEC research and development facility | Apr. 2002 | Operational | Natural gas |  | Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Los Angeles Department of Water and Power (LADPW) | 200 kW PC25C PAFC | Los Angeles, California | LADWP Main Street Service Testing Facility | Feb. 2002 | Jul. 2003 | Natural gas |  | Buy Down recipient FY2000 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | New York Power Authority, New York State Energy Research and Development Authority | Two 200 kW PC25 PAFC | New York City, New York | Bowery Bay Waste Water Treatment Plant | 2002 | Ongoing | Digester gas | | Grid Parallel |
| UTC Power | Connecticut Clean Energy Fund | 200 kW PC25 PAFC | South Windsor, Connecticut | South Windsor High School | Oct. 2002 | Ongoing | Natural gas | | First municipal facility to be powered and heated by a fuel cell in Connecticut. Also serves as a basis of a comprehensive fuel-cell curriculum. The school also serves a regional emergency shelter. Funding was provided by the Connecticut Clean Energy Fund |
| UTC Power | Toshiba, Nippon Petroleum Gas Co | 200 kW PAFC | Numazu, Japan | Nishijima Hospital | 2001 | | Liquefied petroleum gas | | |
| UTC Power | Henry Doorly Zoo, Omaha Public Power District | 200 kW PC25 PAFC | Omaha, Nebraska | Lied Jungle exhibit at Henry Doorly Zoo | Installed Aug. 2001 | Ongoing | Natural gas |  | The PC25's waste heat is used to warm the water in a number of ponds and heat 5,000 gallons of water used for irrigation each night. Buy Down Recipient FY1999 US DoD Climate Change Fuel Cell Program. ($200,000) |
| UTC Power | Woking Borough Council | 200 kW PC25C PAFC | Woking, UK (England) | Woking Park | Jan. 2002 | | Natural gas |  | First commercial fuel cell operating in the UK. Provides electricity and heat for the recreational center and electricity to light the park. Waste heat will be used to meet the recreational center's summer cooling and dehumidification requirements via heat-fired absorption cooling. Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Toshiba, Institute of Energy Economics, New Energy, Industrial Technology Development Organization (NEDO) | 200 kW PC25 | Guangzhou, China | Hog farm | May 2000 | Inactive | Liquefied petroleum gas (LPG), waste methane gas produced at the farm | | First commercial fuel cell power installation in China. Sold to Toshiba Corp. which was modified and sold to the customer. The unit is managed by the Industrial Technology Development Organization (NEDO) of Japan. |

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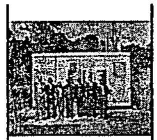
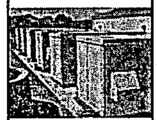
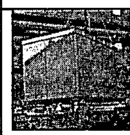
| UTC Power | Companhia Paranaense de Energia (COPEL), Sieco S.A. | 200 kW PC25 PAFC | Curitiba, Brazil | Companhia Paranaense de Energia (COPEL), computer system center | Aug. 2001 | Operational | Natural gas |  | First stationary fuel cell in Brazil. Supplies energy to the center (grid parallel). Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Connecticut Juvenile Training School | 1.2 MW PC25 (six 200 kW PAFC units) | Middletown, Connecticut | Connecticut Juvenile Training School | 2001 | Ongoing | Natural gas |  | Used in conjunction with traditional generators and the grid to provide primary power to the school. The heat produced by the fuel cells is used for heating and cooling the facility. Buy Down Recipient FY1996-1997 ($1.2 million). |
| UTC Power | CTG Corporation, Mohegan Sun | Two 200 kW PAFC systems | Uncasville, Connecticut | Mohegan Sun Casino Hotel | March 2002 | Ongoing | Natural gas | | Provides back-up power. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program. ($400,000) |
| UTC Power | LOGANEnergy, Motor Co. | 200 kW PAFC | Irvine, California | Ford Motor Company's North American Premier Automotive Group headquarters | Dec. 2001 | Ongoing | Natural gas | | Provides 25% of the building's power and hot water needs. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | New York Power Authority (NYPA), KeySpan Energy, New York City Wildlife Conservation Society | 200 kW PC25 | Coney Island, New York | New York Aquarium | Installed Dec. 2001 | Operational | Natural gas |  | Provides 20% of the aquarium's power needs (grid parallel). The installation will allow the Aquarium to decrease its demand on standard sources of electricity. It will also provide enough waste heat to warm domestic hot water and boiler supply water for buildings and tanks, further reducing energy needs |
| UTC Power | US Department of Energy, BEW GmbH, Thyssengas GmbH, TBE | 200 kW PC25C PAFC | Bocholt, Germany | St. Agnes Hospital | Jan. 2001 | Ongoing | Natural gas |  | Provides electrical power, heat and air conditioning--8,000 hrs of uninterrupted operation in first year, setting a European record. The fuel cell saves roughly 500 tons of carbon dioxide per year. Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25A PAFC | Tucson, Arizona | Arizona Air National Guard Pinal Air Park | Mar. 2001 | Operational | Natural gas | | The power plant was moved from Vandenberg Air Force Base (see entry below) to Pinal Air Park. It is now operating at 175 kW to facilitate long-term operation of the power plant. |
| UTC Power | Chevron | 200 kW PAFC | San Ramon, California | Chevron Data Center | Jan. 2002 | Ongoing | Natural gas |  | Supports critical data and retail transaction systems. During a power outage, special switching equipment ensures the fuel cell will continue to provide electricity to these systems without interruption. FY 2000 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Hamburg Gas Consult | 200 kW PAFC | Frankfurt, Germany | Frankfurt-Hoechst industrial park | Jul. 2001 | | | | Provides combined heat and power. |
| UTC Power | Los Angeles Department of Water and Power | 200 kW PAFC | Los Angeles, California | Playa Vista Project (commercial and residential development) | March 2002 | Inactive | | | Initially connected to the electric grid, with plans to provide electricity and heat to tenants of the Playa Vista Project. Buy Down |

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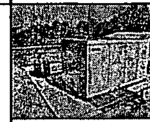
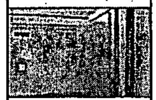
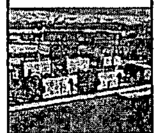
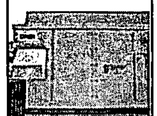
| | | | | | | | | | Recipient FY2000 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Alcorn State University, Logan Energy | 200 kW PC25C PAFC | Lorman, Mississippi | Arcorn State University | Oct. 2000 | Oct. 2001 | Natural gas |  | Supports campus electricity grid. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program. ($200,000) |
| UTC Power | Energy 2000, Las Virgenes Waste Water Treatment | Two 200 kW PC25 PAFC | Calabasas, California | Las Virgenes Wastewater Treatment Plant | Dec. 1999 | Inactive | Methane |  | Provided 99% of on-site electricity. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program ($400,000) |
| UTC Power | Chugach Electric Association | 1 MW PAFC (five 200 kW PC25 200 PAFC units) | Anchorage, Alaska | US Postal Service headquarters | Aug. 2000 | Ongoing | Natural gas |  | Was the largest commercial fuel cell system in the nation in 2000 and was the first time a fuel cell system was part of an electric utility's grid. Supplies all electrical power for the main postal sorting facility in Anchorage. Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($1 million). |
| UTC Power | TBE GmbH, GEW Koln AG | 200 kW PC25C PAFC | Cologne, Germany | Cologne-Rodenkirchen sewage treatment plant | Installed Mar. 2000 | Aug. 2001 | Digester gas |  | Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($200,000). The first time in Europe a fuel cell was used to utilize waste methanol produced from sewage to generate electricity and heat efficiency. Heat generated will be used in the sewage treatment process. Operated 9,000 hours. |
| UTC Power | City of Mesa Utilities Department | 200 kW PC25C PAFC | Mesa, Arizona | City of Mesa Utilities Department headquarters | Apr. 2000 | Operational | |  | Buy Down Program Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Logan Energy, Chevron Texaco | 200 kW PC25C PAFC | Bellaire, Texas | Texaco Energy Systems Central Plant | May 2000 | Inactive | | | Combined heat and power production. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program ($200,000) |
| UTC Power | McBride Energy, College of New Jersey | Two 200 kW PAFC units | Mahwah, New Jersey | Ramapo College dormitory and computer center | Installed Nov. 2000 | | Natural gas |  | Grid parallel. Supplies power and thermal energy (hot water, space heating) to a student Dormitory and a core academic building complex (housing a computer center, telephone exchange and cable TV station). Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($400,000). |
| UTC Power | New York Power Authority, KepSpan Energy, New York City Health and Hospitals Corporation | 200 kW PAFC | Bronx, New York | North Central Bronx Hospital | Installed Dec. 2000 | Ongoing | Natural gas |  | Supplies supplemental power and back-up power. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program. ($600,000) |
| UTC Power | Niagara Mohawk/Plum Street Enterprises, Onondaga- | 200 kW PC25 PAFC | Liverpool, New York | Liverpool High School | Feb. 2000 | Ongoing | Natural gas |  | Serves as an educational resource for science teachers. Grid-independent--will allow the high school to become an |

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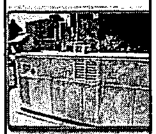
| | Courtland-Madison Board of Cooperative Educational Services | | | | | | | | emergency shelter during community disasters. Buy Down Recipient in FY1995-1996-1997 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Durst Corporation | Two 200 kW PAFC systems | Manhattan, New York | 4th floor Conde Nast Building in *Times Square* | Feb. 2000 | Ongoing | Natural gas |  | Provides power for the NASDAQ sign. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program ($400,000). |
| UTC Power | Electricite de France, Gaz de France, GEPPAC | 200 kW PC25C PAFC | Chelles, France | Council flats | Jan. 2000 | Inactive | Natural gas |  | Provides heat and supplements power to 200 homes. |
| UTC Power | AEB | 200 kW PC25 PAFC | Basel, Switzerland | AEB | 2000 | | | | Provides electricity to the local grid and heat to a school. |
| UTC Power | DBI Gas, Technische Universitat Dresden, Gastec N.V., NVG, Hamburg Gas Consult | 200 kW PC25C PAFC | Kamenz, Germany | Maltesser Hospital | Feb. 2000) | 37-month project | Natural gas | | Produces power, heat, and air-conditioning |
| UTC Power | Oak Ridge National Laboratory | 200 kW PC25 PAFC | Oak Ridge, Tennesseee | | June 2003 | | Natural gas | | Buy Down Recipient FY2000 US DoD Climate Change Fuel Cell Program. ($200,000) |
| UTC Power | Louisiana Gas Services, Citizens Utilities | 200 kW PC25C PAFC | Harvey, Louisiana | Louisiana Gas Services Systems Operation Facility | March 1999 | Decom-missioned | Natural gas |  | Project decommissioned after customer relocated. Buy Down Recipient FY1997 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Reliant Energy Company, US Department of Defense | 200 kW PC25C PAFC | Gulfport, Mississippi | Navy Combat Construction Battalion Base | 1999 | Inactive | | | Provides combined heat and power for mess hall. Buy Down Recipient FY1997 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | CLC S.r.l. Italy Ansaldo , Sun Chemical Corporation, Keyspan Energy, Brooklyn Union Gas Company | Two 200 kW PC25 PAFC units | Staten Island, New York | Sun Chemical manufacturing facility | Installed Jun. 1996 | | Natural gas |  | By 2002, both units had operated 40,000 hours each. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($400,000). |
| UTC Power | CLC Srl Italy Ansaldo, Stadtwerke Oranienburg, Hamburg Gas Consult | 200 kW PC25C PAFC | Oranienburg, Germany | Stadtwerke Oranienburg Power Generation Plant | Installed Jan. 1998 | | Natural gas | | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | CLC Srl | 200 kW PAFC | Italy | | | | Natural gas | | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | CLC.r.l. Italy Ansaldo, GSA, Hamburg Gas Consult | 200 kW PC25C PAFC | Halle, Germany | | Installed Aug. 1997 | | Natural gas | | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Ansaldo | 200 kW PAFC | Leipzig, Germany | | 1997 | | | | |
| UTC Power | HEW, Hamburge Gas Consult | 200 kW PC25C PAFC | Hamburg, Germany | Residential building at Lyserstrasse | Aug. 1997 | | Pure liquid hydrogen | | The project is supported by the European Commission within the framework of the EQHHPP. Focus on technical and operatino aspects of hydrogen-fueled fuel cell, as well as public acceptance of, and legal aspects involved, in transporting and storing liquid hydrogen in an urban area. |

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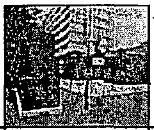
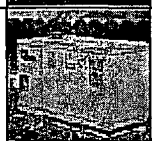
| UTC Power | Hamburg Gas Consult, HEW | 200 kW PC25A PAFC | Hamburg, Germany | Residential building at Lyserstrasse | Jun. 1993 | | Natural gas |  | Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program. |
| UTC Power | CLC.r.l. Italy Ansaldo, Stadtwerke Saarbrucken AG, Erdgas Energie Systeme, ABB Energie Systeme, VVS | 200 kW PC25C PAFC | Saarbrucken, Germany | Housing estate | Installed May 1997 | | Natural gas | | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). Supplying energy to the "Nachtweide" district. Supplies electricity to 400 dwellings and heat to 125. |
| UTC Power | Ansaldo, Energie und Wasserversorg, Erdgas Energie Systeme, ABB Energie Systeme, Austria Ferngas, US Department of Defense | 200 kW PC25C PAFC | Nuremberg, Germany | | Installed Jan. 1998 | | Natural gas |  | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). Average electrical efficiency of the fuel cell plant was more than 39% in 1998. The total efficiency of the system was about 70% in this period. |
| UTC Power | Connecticut Natural Gas Corp. | 200 kW PAFC | Hartford, Connecticut | Connecticut Natural Gas headquarters | | | Natural gas | | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program. Fuel cell provided power to Connecticut Natural Gas headquarters then was donated to the Department of Engineering at the University of Connecticut for research in 2001. |
| UTC Power | Equitable Resources | 200 kW PAFC | Oakmont, Pennsylvania | Presbyterian Medical Center | | | Natural gas |  | Buy Down Recipient FY1995 |
| UTC Power | Equitable Resources | 200 kW PC25A PAFC | Squirrel Hill, Pennsylvania | Riverview Center for Jewish Seniors | 1992 | | Natural gas | | For demonstration purposes. |
| UTC Power | Hamilton Sunstrand | 200 kW PC25A PAFC | Windsor Locks, Connecticut | Hamilton Sundstrand *Data Center* | Installed Dec. 1997 | | Natural gas |  | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | US Department of Defense | 200 kW PC25C PAFC | Pittsburgh, Pennsylvania | 911 Air Lift Wing | Feb. 1997 | Decommissioned Feb. 2001 | | | |
| UTC Power | Lord & Company | Three 200 kW PAFC units | | | | | | | Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program. ($600,000) |
| UTC Power | Bharat Heavy Electricals Ltd., India's Department of Non-conventional Energy Sources | 200 kW PC25C PAFC | India | Bharat Heavy Electricals test facility | 1998 | 2000 | Liquefied petroleum gas (LPG) | | Was to be restarted late using natural gas as fuel. |
| UTC Power | State of Alaska | Two 200 kW PAFC units | Anchorage, Alaska | Anchorage Readiness Center office-training facility | Dec. 1996 | | Natural gas | | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($400,000). |
| UTC Power | Toshiba Corporation, HEAG AG | 200 kW PC25C PAFC | Endersbach, Germany | | 1997 | | Natural gas |  | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program. |
| UTC Power | Toshiba Corporation-Power Systems and Service Co. | 200 kW PAFC | Japan | Toshiba Fuchu Works | | | Natural gas |  | Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Ontario Hydro | 200 kW PAFC | Markham, Canada | Ontario Hydro's Markham Centre | Installed between | | | | Provides baseload heat and electricity. |

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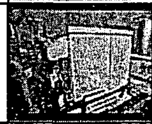
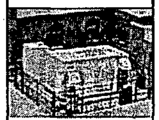
| | | | | | 1993-1995 | | | | |
| UTC Power | Sapporo Brewery | 200 kW PC25 PAFC | Chiba, Japan | Sapporo Brewery | Jun. 1998 | Ongoing | Digester gas |  | Estimated total energy savings at the Chiba brewery was about 4%. |
| UTC Power | Asahi Brewery | 200 kW PC25 PAFC | Shikoku, Japan | Asahi Brewery | | Ongoing | Methane gas from brewing process |  | |
| UTC Fuel Cells | Washington Water and Power, Avista Corporation, Double Tree Inn | 200 kW PC25C PAFC | Spokane, Washington | Double Tree Inn Hotel | Installed Jul. 1997 | | Natural gas |  | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). Provides the hotel's minimum electric load of 200 kW and supplements hot water requirements |
| UTC Power | ABB Energie Systeme GmbH | 200 kW PC25C PAFC | Kaltenkirchen, Germany | School | Oct. 1998 | | Natural gas | | Supplies power and heat. |
| UTC Power | Massachusetts Water Resources Authority, New England Power Company | 200 kW PC25C PAFC | Boston, Massachusetts | Deer Island Sewage Treatment Plant | 1997 | Decommissioned Jun. 2002 | Digester gas |  | Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | AEC South County Hospital | 200 kW PC25 PAFC | Wakefield, Rhode Island | South County Hospital | 1999 | | Natural gas |  | Provides electricity and heat. Produces one-third of hospital's electricity during peak hours, saving $60,000-$90,000/year. Also provides back up power to the hospital's critical loads. Buy Down Recipient FY1998 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | New York Power Authority, KeySpan Energy, New York City Police Department | 200 kW PureCell PAFC | Manhattan, New York | Central Park police headquarters | Apr. 1999 | Ongoing | Natural gas |  | Provides all electricity for the police station, independent of the electric grid. |
| UTC Power | NORESCO, First National Bank of Omaha, Sure Power Corp. | Four 200 kW PC25 PAFC units | Omaha, Nebraska | First National Bank | Nov. 1999 | Ongoing (purchase) | Natural gas |  | Provides the main power for a critical data processing facility. The bank is one of the largest credit card processors in the nation. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($800,000). |
| UTC Power | Onondaga-Courtland-Madison Board of Cooperative Educational Services (BOCES) | 200 kW PC25C PAFC | Syracuse, New York | BOCES Regional Information Center | Jan. 1997 | | Natural gas | | Has operated for more than 22,000 hours. Funded by the US DoD Climate Change Fuel Cell Program ($200,000) and NYSERDA ($331,212) |
| UTC Power | Cape Cod Community College, NORESCO | 200 kW PC25C PAFC | West Barnstable, Massachusetts | Cape Cod Community College library | Installed Apr. 1999 | | Natural gas |  | Non-critical baseload power, with limited cogeneration (library space heating). Provides 15% of peak and 46% of summer powe r demand. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Town of Groton, International Fuel Cells, US Environmental Protection Agency | 200 kW PC25 PAFC | Groton, Connecticut | Flanders Road Landfill | Jun. 1996 | | Anaerobic digester gas | | Provided approximately 140 kW of electricity to the Connecticut Light and Power Company |

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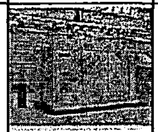
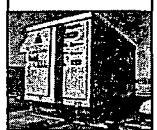
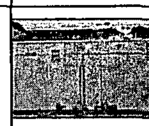
| UTC Power | Northeast Utilities, International Fuel Cells, US Environmental Protection Agency | 200 kW PC25 PAFC | Sun Valley, California | Penrose Landfill power plant | 1993 | Completed 6 - month demonstration | Landfill gas | | Power generated during the project was sold to the Los Angeles Department of Water and Power to help offset costs Relocated to Flanders Road Landfill in Connecticut. |
| UTC Power | Fuel Cell Test and Evaluation Center (FCTec) | 200 kW PC25C PAFC | Johnstown, Pennsylvania | FCTec at National Defense Center for Environmental Excellence | Jan. 1999 | Jan. 2003 | Natural gas |  | http://www.fctec.com/main.html |
| UTC Power | City of Portland | 200 kW PAFC | Portland, Oregon | Columbia Blvd. Waste Water Treatment Plant | Jul. 1999 | Inactive | Methane digester gas |  | Provides heat and electricity to the facility. Portland's fuel cell generates as much as 1.6 million kW-hrs/yr. Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Australian Technology Park Sydney LTD | 200 kW PAFC | Sydney, Australia | Australian Technology Park | Nov. 1998 | Operational | Natural gas |  | Australia's First fuel cell. Provides power to medical centers, labs and computer systems located within the Technology Park. Buy Down Program Recipient FY1998 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Newport News, Virginia | Fort Eustis, gymnasium/ pool | Sept. 1995 | Jan. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Thermal output to DHW and pool (~68% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers, Consolidated Natural Gas | 200 kW PC25C PAFC | Pittsburgh, Pennsylvania | 911th Airlift Wing Central Heating Plant | Feb. 1997 | Off-line Sep. 2001 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected (no emergency back-up) |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | White Hall, Arkansas | Pine Bluff Arsenal Boiler Plant | Oct. 1997 | Jan 2000 | Natural gas |  | US Department of Defense PAFC Demonstration Program Grid connected at splice after pole mounted transformer. Grid independent terminals power the boiler plant. Thermal output heats boiler make-up water. Total estimated thermal utilization ~90%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Minneapolis, Minnesota | 934th Tactical Air Group Boiler Plant | Feb 1995 | Sep. 2000 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at new electrical transformer (fuel cell option). Thermal output to preheat boiler make-up water (~45% est. thermal utilization) |
| UTC Power | US Department of Defense | 200 kW PC25B PAFC | West Point, New York | West Point Military Academy Central Boiler Plant | Dec. 1995 | Feb. 2001 | Natural gas |  | US Department of Defense PAFC Demonstration Program . Grid connected at existing panel. Thermal output for boiler make-up water (~70% estimated thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Albany, New York | Watervliet Arsenal, Central Boiler Plant | Oct. 1997 | Jul. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program . Grid connected at existing electrical panel. Emergency back-up for grid-independent operation. Thermal output to preheat boiler make-up (~58% est. thermal |

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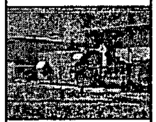
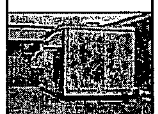
| | | | | | | | | | utilization). |
| UTC Power | US Department of Defense | 200 kW PC25C PAFC | Bossier City, Louisiana | Barksdale Air Force Base hospital | Jul. 1997 | Oct. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected. Total estimated thermal utilization ~90%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Tucson, Arizona | Davis-Monthan Air Force Base gymnasium | Dec. 1997 | Apr. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at new transformer (program option). High grade thermal output (program option) to absorption chillers. Low grade thermal output to hot water storage tank. Total estimated thermal utilization ~65%. |
| UTC Power | US Department of Defense | 200 kW PC25C PAFC | Palmdale, California | Edwards Air Force Base hospital | Jul. 1997 | Jul. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at existing Transformer. High grade thermal output. (Program option) to space heating loop. Total estimated thermal utilization ~23%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Albuquerque, New Mexico | Kirtland Air Force Base Boiler Plant | Sep. 1995 | Dec.-2001 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at switch tied to electrical transformer/. Grid independent connection to entire boiler plant. Thermal output to deaerator tank (~55% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Del Rio, Texas | Laughlin Air Force Base Hospital | Sep. 1997 | Nov. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at existing electrical transformer (no emergency back-up). Thermal output to space heat/cool reheat loop and DHW loop (-75% estimated thermal utilization) |
| UTC Power | US Army Corp. of Engineers | 200 kW PC25C PAFC | Jacksonville, Arkansas | Little Rock Air Force Base hospital | Oct. 1997 | Shut down Dec. 2000, was to be transferred to another facility | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at electrical panel. Thermal output heats space conditioning recirculation loop. Total estimated thermal utilization ~85%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Las Vegas, Nevada | Nellis Air Force Base Central Plant for dormitory facility | Oct. 1995 | Jun. 2001 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at main breaker panel .Thermal to make-up water and heat pump loop (~40% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25A PAFC | Lompoc, California | Vandenberg Air Force Base, Space Control Center | Mar. 1994 | Feb. 2001 | Natural gas |  | Department of Defense PAFC Demonstration Program. The power plant was moved to Pinal Air Park, Arizona Air National Guard in Tucson, Arizona. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Johnstown, Pennsylvania | Naval Defense Center for Environmental Excellence (NDCEE) Industrial Building | Aug. 1997 | Operational | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected in spare panel slot. High grade thermal output heats evaporator tank. Total estimated thermal utilization ~19%. |

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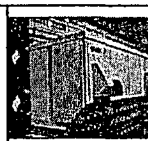
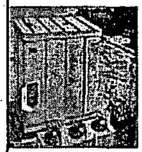
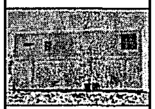
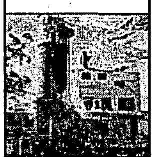
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Annapolis, Maryland | Naval Academy galley | Sep. 1997 | Sep. 2002 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected in electrical room. Thermal output heats make-up water. Total estimated thermal utilization ~78%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Groton, Connecticut | Navy Subase New London Boiler Plant | Oct. 1997 | Operational | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at existing electrical panel. Thermal output heats boiler make-up water. Total estimated thermal utilization ~90%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Twentynine Palms, California | Twentynine Palms Marine Corp Base Naval Hospital | Jun. 1996 | May 2000 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at existing sub panel. Grid independent connection at new electrical sub panel. Thermal output to DHW loops (~60% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Newport, Rhode Island | Naval Education Training Center Boiler Plant | Feb. 1995 | Apr. 2001 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at boiler plant electrical transformer. Thermal output to preheat boiler make-up water (~60% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Stennis Space Center, Mississippi | Naval Oceanic Center for NAVO support, Stennis Space Center | Sep. 1997 | Oct. 2002 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at electrical panel. Grid independent load connected at new panel. Thermal output used for space heat/reheat loop Total estimated thermal utilization ~12%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Fallon, Nevada | Naval Air Station galley | Mar. 1997 | Mar. 2002 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at new electric transformer (fuel cell option). Grid independent connection at new electric transformer (fuel cell option). Thermal output to DHW loop (~10% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Jacksonville, Florida | Naval Air Station Naval Hospital | Apr. 1997 | Apr. 2002 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at existing electrical panel (no emergency back-up. Thermal output to DHW loop (~56% est. thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Natick, Massachusetts | US Army Soldier Systems Command Boiler Plant | Feb. 1995 | Jan. 2003 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at existing sub panel. Thermal output to storage tank. Thermal output to storage tank (~45% estimated thermal utilization). |
| UTC Power | US Department of Defense | 200 kW PC25B PAFC | Dover, New Jersey | Picatinny Arsena, Boiler Plant | Oct. 1995 | Jul. 2001 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at panel Inside electric room. Thermal output preheats make-up water (~100% estimated thermal utilization). |
| UTC Power | US Army Corp | 200 kW PC25C | Anchorage, | Fort Richardson | Apr. 1997 | Apr. 2001 | Natural gas | | US Department of Defense |

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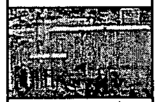
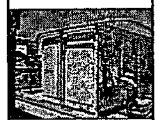
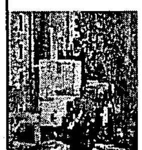
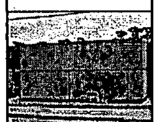
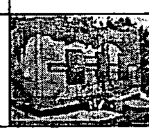
| | of Engineers | PAFC | Alaska | National Guard Armory | | | |  | PAFC Demonstration Program. Grid connected at existing electrical panel (no emergency back-up. High grade thermal output (option) to space heating Loop. Thermal output to domestic hot water (total ~45% estimated thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW C25B PAFC | Oceanside, California | Marine Corp Base Camp Pendleton Naval Hospital | Oct. 1995 | Jan. 2002 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at existing panel. Thermal output for DHW storage (~75% est. thermal utilization). |
| UTC Power | US Department of Defense | 200 kW PC25B PAFC | Sierra Vista, Arizona | Fort Huachuca Riley Barracks | Jul. 1997 | Inactive | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at existing Electrical transformer (no emergency back-up). High grade thermal output (option) to space heating loop. Thermal output to domestic hot water (total ~44% estimated thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | West Point, New York | U.S. Military Academy Central Boiler Plant | Dec. 1995 | Feb. 2001 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at existing panel. Thermal output for boiler make-up water (~70% estimated thermal utilization). |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | Chicopee, Massachusetts | Westover Air Reserve Bas, Boiler Plant | Sep. 1997 | Jul. 2002 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at new electrical transformer (Program option). Low grade thermal output heats boiler make-up water. High grade thermal output (Program option) to condensate return loop. Total estimated thermal utilization ~45%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25B PAFC | Port Hueneme, California | CBC, Port Hueneme swimming pool | Aug. 1997 | Dec 2001 | Natural gas |  | Department of Defense PAFC Demonstration Program. Grid connected at new transformer. Thermal output heats swimming pool. Total estimated thermal utilization ~92%. |
| UTC Power | US Army Corp of Engineers | 200 kW PC25C PAFC | El Paso, Texas | Fort Bliss laundry | Sep.-1997 | Jun. 2002 | Natural gas |  | US Department of Defense PAFC Demonstration Program. Grid connected at new transformer. Thermal output heats laundry hot water storage tanks. Total estimated thermal utilization ~17%. |
| UTC Power | New York Power Authority, KeySpan Energy, Westchester County Department of Environmental Facilities | 200 kW PAFC | Yonkers, New York | Yonkers Wastewater Treatment Plant | Apr. 1997 | Ongoing | Anaerobic digester gas |  | Supplies grid parallel supplemental power. World's first anaerobic digester gas-fueled fuel cell. |
| UTC Power | Yankee Gas Services | Two 200 kW PAFC units | South Windsor, Connecticut | Yankee Corporation headquarters | Oct. 1997 | | Natural gas |  | Buy Down Recipient FY1996-1997 US DoD Climate Change Fuel Cell Program. ($400,000) |

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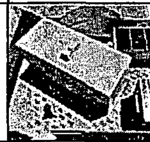
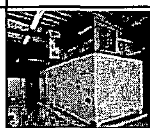
| UTC Power | Braintree Electric Light Department | 200 kW PC25C PAFC | Braintree, Massachusetts | Landfill | Sep. 1999 | Inactive | Landfill gas, natural gas | | Baseload power serving town utility grid (less than 1% of peak load). Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | US Airways, Peoples' Natural Gas | 200 kW PC25C PAFC | Pittsburgh, Pennsylvania | U.S. Air's hanger #2 at Pittsburgh International Airport | | | Natural gas |  | |
| UTC Power | Toshiba Corporation | 200 kW PAFC | Houston, Texas | | 1998 | Operational | Natural gas | | Grid-independent operation. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000). |
| UTC Power | Brooklyn Union Gas Co., St. Vincent's Medical Center | 200 kW PAFC | New York, New York | Saint Vincent's Medical Center laundry facility | Oct. 1992 | Ongoing | Natural gas | | 1995 Cogeneration Project of the Year by the Cogeneration and Competitive Power Institute |
| UTC Power | Toho Gas | 200 kW PAFC | Japan | | Installed between 1993-1995 | | | | |
| UTC Power | Osaka Gas | Ten 200 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| UTC Power | Tokyo Gas | Ten 200 kW PAFC units | Japan | | Installed between 1993-1995 | | | | |
| UTC Power | Kaiser Permanente, Southern California Gas CO, Gas Research Institute, US Department of Energy | Two 200 kW PC25A units | Riverside, California | Riverside Medical Center | Sep. 1994 | Feb. 2000 + Mar. 2001 | Natural gas |  | Provided power and cogeneration of waste heat. Won the 1994 Efficient Building Award for Energy and the Environment sponsored by Energy User News |
| UTC Power | Southern California Gas Company | 200 kW PC25A PAFC | Santa Barbara, California | Santa Barbara jail | Oct. 1994 | Mar. 2001 | Natural gas |  | Provides electricity and hot water. |
| UTC Power | Mitsubishi Electric, Toshiba Corporation | 200 kW PC25 PAFC | Japan | Kyobashi DHC | Feb. 1994 | Oct. 2000 | | | This unit accumulated 43,139 hours by Oct. 2000. |
| UTC Power | Bharat Heavy Electricals Ltd. (BHEL), Toshiba | 200 kW PAFC | India | BHEL testing facility | 1998 | 2000 | Liquefied propane gas (LPG) | | Tested in grid-dependent and grid-independent modes. |
| UTC Power | Tokyo Electric Power Co (TEPCO). Toshiba Corporation | 200 kW PC25 PAFC | Japan | TEPCO Research and Development Center | Sep. 1994 | | City gas |  | This unit accumulated 44,011 hours by Oct. 2000 |
| UTC Power | Corporation, Southern California Gas, Kaiser Permanente | 200 kW PC25A PAFC | Anaheim, California | Anaheim Medical Center | May 1993 | End of Life May 2000 | Natural gas |  | Provided power and cogeneration of waste heat. Buy Down Recipient FY1995 US DoD Climate Change Fuel Cell Program ($200,000) |
| UTC Power | Sacramento Municipal Utility District, Kaiser Permanente | 200 kW PAFC | Sacramento, California | South Sacramento Medical Center | Early 1990s | | | | Provided power and cogeneration of waste heat. |
| UTC Power | Southern California Gas | 200 kW PC25A PAFC | Buena Park, California | Kraft Foods | Jul. 1993 | Removed Jun. 1996 | Natural gas | | Sold to City of Mesa, AZ |
| UTC Power | Southern California Gas | 200 kW PC25A PAFC | Santa Barbara, California | University of California | Sep. 1993 | Life ended Jun. 1998 | Natural gas |  | |

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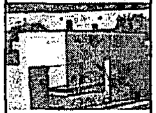
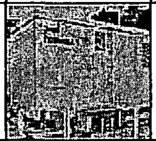
| UTC Power | Commonwealth Gas | 200 kW PC25 PAFC | Natick, Massachusetts | U.S. Army Soldier Systems Command | FY 1993 | | Natural gas |  | |
| UTC Power | Southern California Gas | 200 kW PC25A PAFC | Irvine, California | Hyatt Hotel | Sep. 1992 | Life ended Mar. 2002 | Natural gas |  | |
| UTC Power | Southern California Gas | 200 kW PC25A PAFC | Los Angeles, California | SCAQMD Office Building | Apr. 1992 | | Natural gas |  | Had a lifetime of about 40,000 hours. Cell stack was replaced in 1998 and returned to service. Provides 20-25% of building power. |
| UTC Power | Service du Gaz | 200 kW PC25 PAFC | Geneva, Switzerland | | Mar. 1993 | | | | Operated for 40,000 hours. |
| UTC Power | Tokyo Gas, Toshiba Corporation | 200 kW PC25A PAFC | Tokyo, Japan | Tokyo Gas Research & Development facility | Apr. 1992 | 2000 | |  | |
| UTC Power | Tokyo Electric Power Co, Toshiba Corporation | 11 MW PAFC unit (twenty 700 kW units) | Ichihara, Japan | Goi Station of Tokyo Electric Power Co | Mar. 1991 | Completed Mar. 1997 | Liquefied natural gas (LNG) | | This unit accumulated 23,140 hours by Oct 2000. |
| UTC Power | Seiko Epson | 400 kW PAFC | Ina, Japan | Seiko Epson's Quartz Devise Division facilities | Jan. 2000 | | | | |
| UTC Power | Toftlund Fjernvarmevaer, Naturgas Syd Sonderjyllands | 200 kW PC25A PAFC | Toftlund, Denmark | District Heating System | Nov. 1992 | | | | Europe's first fuel cell. |
| UTC Power | PreussenElektra , E.ON, MAINOVA AG, Hamburg Gas Consult | 200 kW PC25C PAFC | Frankfurt, Germany | Bergen-Enkheim public swimming pool | Nov. 1998 | | |  | Provides heat to the pool. The fuel cell contribution to peak thermal power is only 17 %, but makes up more than 50 % of all heat requirements over the year. |
| UTC Power | Hamburg Gas Consult | 200 kW PC25C PAFC | Bargteheide, Germany | | 1998 | | Natural gas | | |
| UTC Power | Ruhrgas AG, Stadtwerke Bochum | 200 kW PC25A PAFC | Dorsten, Germany | Testing at Rohrgas, followed by two-year field test at Stadtwerke Bochum | Testing began Sep. 1992; field test started Feb. 1994 | Completed | | | Tested over 40,000 hours. |
| UTC Power | Thyssengas, Stadtwerke Duren | 200 kW PC25A PAFC | Duren, Germany | Thyssengas facility--one year; Stadtwerke Duren—four years | Oct. 1992 | Decommissioned after 5 years of operation | Natural gas | | Tested at Thysssengas facility in Duisburg before moving to Duren. |
| UTC Power | Sydkraft AB | 200 kW PAFC | Bara, Sweden | | Jun. 1992 | | | | |
| UTC Power | Imatran Voima Oy | 200 kW PC25A PAFC | Tavastehus, Finland | Vanaja Power Plant | Dec. 1992 | | | | |
| UTC Power | Azienda Consortiale Servizi Reno, SEABO Spa, Ansaldo CLC | 200 kW PC25A PAFC | Bologna, Italy | SEABO thermorefrigeration plant | Apr.1993 | | | | Grid connected, operating concurrently with ENEL network electric network. Residual heat used in thermo-refrigeration plant. Operated over 17,490 hours. |
| UTC Power | Austria Ferngas, Wiengas, EVN | 200 kW PC25A PAFC | Vienna, Austria | Tested at Austria Ferngas for 1.5 years, then moved to District Heating Plant of EVN | Installed Jan. 1993 by Austria Ferngas, transferred to EVN in 1994 | 1997 | |  | |
| UTC Power | HEAG-AG | 200 kW PC25A PAFC | Darmstadt, Germany | | Jun. 1993 | | Natural gas | | |
| UTC Power | Equitable Resources | 200 kW PC25 PAFC | Pittsburgh, Pennsylvania | Presbyterian Nursing Home | | | Natural gas | | |
| UTC Power | Peoples' Gas & Light | 200 kW PC25 PAFC | Chicago, Illinois | Div. of Street & Meter Repair | | | Natural gas | | |

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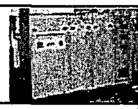
| UTC Power | Jersey Central Power & Light, GPU | 200 kW PC25 PAFC | Morristown, New Jersey | AT&T Research Laboratory | | | Natural gas | | |
| UTC Power | National Fuel Gas | 200 kW PC25 PAFC | Buffalo, New York | Riefler Concrete | | | Natural gas | | |
| UTC Power | Rochester Gas & Electric | 200 kW PC25 PAFC | Rochester, New York | Rochester Institute of Technology | | | Natural gas | | |
| UTC Power | | 200 kW PC25 PAFC | Ulsan, South Korea | Hotel | | | Natural gas | | |
| UTC Power | Ansaldo Ricerche, ENEA, Milan Municipal Energy Co | 1.3 MW PAFC with reformer | Milan, Italy | | | | Natural gas | | Located in Bicocca "technology zone". Hydrogen produced by the reformer is used for a hydrogen vehicle fueling station located on-site, with extra hydrogen used to fuel a 500 kW MCFC plant. |
| UTC Power | Ruhrgas, Stadtwerke Bochum | 200 kW | Bochum, Germany | Stadtwerke Bochum facility | 1989 | | | | Tested for almost 40,000 hours. |
| UTC Power | Tokyo Electric Power Co. | 200 kW PC25 PAFC | Japan | Shibaura DHC | Mar. 1989 | Completed March 1997 | | | This unit accumulated 45,333 hours by Oct. 2000. |
| UTC Power | Virginia Power, Virginia Natural Gas, Gas Research Institute | 40 kW PAFC CHP | Norfolk, Virginia | Old Dominium University, 600 bed dormitory | 1986 | Concluded | Natural gas | | Grid connected. Supplied hot water to the dormitory. |
| UTC Power | Tokyo Electric Power Co, Toshiba Corporation | 4.5 MW PAFC | Ichihara, Japan | Goi Station of Tokyo Electric Power Co | 1983 | | | | |
| Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) (Center for Solar Energy and Hydrogen Research) | Gaz de France, The National Polytechnical Institute of Lorraine (INPL) | 500 W PEM | Nancy, France | Agronomy laboratory at the National Polytechnical Institute of Lorraine | Feb. 2003 | | | | ZSW is developing fuel cells in the 2 W - 20 kW range. |
| ZTEK Corp. | Black Country Housing and Community Services Group | 4.4 kW Alkaline fuel cell | Telford, UK (England) | Black Country Housing and Community Services Group house | Announced Jan. 2005 | | Com-pressed hydrogen | | UK's first fuel cell house. |
| ZTEK Corp. | Connecticut Clean Energy Fund, The Renewable Resources Group, LLC | 25 kW SOFC | Rocky Hill, Connecticut | Dinosaur State Park | Installed | Two-year demonstration with possible extension | Natural gas | | Provides some of the park's baseload power and heating/ air conditioning for the Visitor Center. This system was previously demonstrated at the Tennessee Valley Authority's Huntsville, AL site. |
| ZTEK Corp. | Tennessee Valley Authority | 25 kW SOFC | Huntsville, Alabama | Huntsville Utilities | 1998 | 2000 | Natural gas |  | |
| ZTEK Corp. | Electric Power Research Institute | 1 kW SOFC | Japan | EPRI facility | 1994 | 1995 | Laboratory gas mixture partially comprised of bottled hydrogen | | Proof of concept. Operated for over 16,000 hours. |
| Unknown | | Alkaline fuel cell | Totara Valley, New Zealand | | 2004 | | | | Wind-Hylink-AFC demonstration project. Uses wind generator and electrolyzer to produce hydrogen, which is carried by pipeline to power the fuel cell. |
| Unknown | U.S. Army Corps of Engineers Construction and Engineering Research | Fuel cell | Yellowstone National Park, Montana | Yellowstone National Park | Planned | | Canola oil | | |

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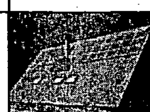
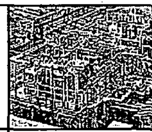
| | Laboratory (CERL) | | | | | | | | |
| Unknown | RWE Fuel Cells, Ahaus | 5 kW fuel cell with gas turbine | Germany | Ahaus facility | Planned | | | | Ahaus utility will integrate the fuel cell/turbine hybrid unit into their local heating system. |
| Unknown | State of Florida, unspecified investor-owned utility and college | Fuel cell | Florida | Unspecified college residential complex | Planned | | | | |
| Unknown | Shizuoka Resources, Shizuoka Gas Co. | Fuel cell | Shizuoka, Japan | School lunch center | 2006 | Planned | Mixture of natural gas and garbage biogas | | |
| Unknown | Kawasaki City | 200 kW PAFC | Kawasaki, Japan | Tama Hospital | 2005 or 2006 | Planned | Town gas | | Cogeneration system |
| Unknown | Osaka Gas Co. Takenaka Corp. | 200 kW PAFC | Osaka, Japan | Umeda Center Building | | | | | Operated for over 40,000 hours. Provides 5% of the power requirements for the 80,000 square meter building. Co-generated waste heat is used to supply 70% of the hot water needs. |
| Unknown | Japan Energy Corp. | About one-hundred-fifty 700 W PEM units | | | Announced Jun. 2005 | | Liquefied petroleum gas (LPG) | | About 30 fuel cells will be installed in the Kanto area in the first year. About 150 total will be installed within three years. |
| Unknown | Northern Alberta Institute of Technology (NAIT) | 5 kW SOFC | Edmonton, Canada | NAIT Power Engineering Laboratory | Planned for early 2005 | | | | For demonstration, education and research. |
| Unknown | Arakawa Ward | PEM | Arakawa Ward, Japan | Haketa-daini Primary School | Sept. 2005 | | Kerosene | | |
| Unknown | Tokuyama Corp, Yamaguchi Prefecture | 1 kW fuel cell | Yamaguchi Prefecture, Japan | Tokuyama Works | | Mar. 2005 | Hydrogen produced at the factory | | |
| Unknown | Idemitsu Kosan Co, Corona Co. | 1 kW PEM | Sanjo, Japan | Corona Co.'s New Energy Research Center | Apr. 2005 | | | | Test system. |
| Unknown | Idemitsu Kosan Co, Corona Co. | 1 kW PEM | Sanjo, Japan | Idemitsu Kosan's Central Research Laboratory | Apr. 2005 | | | | Test system. |
| Unknown | Osaka Gas, Urban Renaissance Agency (URA) | Twenty-one fuel cells | Japan | | 2005 | | | | Twenty-one fuel cells will be delivered to URA by Osaka Gas. URA will demonstrate 80-100 fuel cells by various manufacturers. |
| Unknown | Sharp Corp. | 10 kW PEM/solar cell hybrid electric system | Japan | Yokkaichi Technical High school | Mar. 2005 | | | | Combined power capacity of 10 kW. Generated power is stored in a battery and used for emergency power. Exhaust heat is supplied to the greenhouse. |
| Unknown | Sekisui House Corporation, Tokyo Gas | Seven PEM units | Mosashino, Japan | Residential | Sales began Apr. 2005 | | Natural gas | | Seven out of 31 homes will be equipped with stationary PEMs. The home price will be higher than other homes in the development, but heating and electric costs will be lower. |
| Unknown | Yamaguchi Prefecture | Three 1 KW and one 5 kW fuel cell CHP units | Syunan, Japan | | Jan. 2005 | One year test | Pipeline-supplied hydrogen | | |
| Unknown | | Fuel cell | Strasbourg, France | | July 2004 | | |  | Fuel cell operates in tandem with a photovoltaic unit. |
| Unknown | Kandenko | 3.7 kW PEM | Saitama, Japan | Kandenko's Urawa dormitory | Oct. 2004 | | | | Cogeneration system (power and heat). |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Produces 25% of the facilities power. |
| Unknown | Nippon Oil, Sekisho | PEM | Tsukuba, Japan | Company residence | Plan announced Aug. 2004 | | Liquefied petroleum gas (LPG) | | Cogeneration system |
| Unknown | New Energy Foundation | Two 1 kW PEM units | Tokyo and Oita Prefecture, Japan | Condominiums | Aug. 2004 | | Pipeline-supplied hydrogen | | |
| Unknown | Tokyo Gas | 1 kW PEM | Japan | Minami-Senju Techno Station model house | May 2004 | | | | The house is open to the public. |
| Unknown | Hokkaido University, Japan Steel Works. Ministry of Land, Infrastructure and Transport | Fuel cell | Hokkaido, Japan | | Jun. 2004 | | Biogas from livestock waste | | |
| Unknown | Mie Prefecture, Yuasa Corp., Cosmo Oil, Fuji Electric Advanced Technology Co, Showa Shell Sekiyu K.K. , Idemitsu Kosan Co, Mie Prefecture, Mie University | PEM units of less than 10 kW | Yokkaichi, Kawagoe or Kusunoki , Japan | Residential | 2004 | 2006 | Liquefied petroleum gas (LPG) | | This is the first step for "Establishment of the Center for FC Related Industries in Northern Part of the Prefecture". Three companies expressed their intention to participate and Toshiba IFC has been formally nominated. |
| Unknown | Nippon Oil Corp., Gas Bureau of city of Sendai | 1 kW PEM | Sendai, Japan | "Gas Salon" of Gas Bureau | Feb. 2004 | | | | |
| Unknown | Nippon Oil, Matsumura Bussan Co. | 5 kW PEM | Kanazawa, Japan | Osada gasoline service station | Apr. 2004 | | | | |
| Unknown | Niigata Prefecture | 700 W PEM | Nagaoka, Japan | | Mar. 2004 | Dec. 2004 | | | Data to be transmitted automatically to the Industrial Research Institute of Niigata Prefecture. |
| Unknown | Nippon Oil Corp. | 1 kW PEM | Shizuoka, Japan | Suzuyo Irie Dormitory | Aug. 2003 | One-year test | | | Testing e simulated conditions of a ordinary home and to verify the energy savings. |
| Unknown | Nippon Oil Corp. | Multiple 1 kW PEM units | Various locations, Japan | Public and company residences | Beginning Jan. 2003 | | Liquefied petroleum gas (LPG) | | At least 80 demonstration units will be installed at locations including Yokohama, Niigata prefecture, Shizuoka prefecture, Tokyu Construction Co, Mitsubishi Estate Co, official residence of the Yokohama mayor, and others. Nippon Oil will follow operating conditions at the a monitoring center in Yokohama Refinery and deal with troubles 24 hours |
| Unknown | Nippon Oil Corp. | PEM | Shimizu, Japan | Gas station | Dec. 2002 | | Naphtha | | Demonstration unit of fuel cell cogeneration system operating on naphtha fuel. |
| Unknown | Nippon Oil Corp. | 1 kW PEM | Kanagawa Prefecture, Japan | Kanagawa Dome Theater | Jul. 2002 | | Liquefied petroleum gas (LPG) | | Fuel cell cogeneration system. |
| Unknown | Shikoku Electric Power Co. | PEM CHP | Japan | Shikoku Research Institute, Inc. | Feb. 2002 | Mar. 2004 | | | Verification testing. |
| Unknown | Tokyo Electric | Two 3 kW PEM units | Japan | Tokyo Electric Power Technology Development Center | Mar. 2001 | | Liquefied petroleum gas (LPG), town gas | | Purchased for testing |
| Unknown | Mitsubishi, Kansai Electric Power Co. | Two 200 kW units | Japan | | Installed between 1993-1995 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Unknown | Toshiba | 50 kW fuel cell unit | Japan | | 1984 | | |  | |
| Unknown | Hokkaido Gas, Hokkaido University | PEM | Japan | Hokkaido University | | | | | Demonstration and testing. This unit will be replaced by a newer model 1 kW unit. |
| Unknown | Hokkaido Gas, Japan Gas Association | PEM | Sapporo, Japan | Residence | | | | | |
| Unknown | MVV Energie | Fuel cell | Mannheim, Germany | Rehabilitated apartment complex | | | | | Provides heat and power. "Three liter home" project goal is to reduce the building's annual energy requirements for heat to an equivalent of just three liters of heating oil per square meter of living space. |
| Unknown | City of Mesa, AZ, Arizona National Guard | Two 200 kW fuel cell units | Marana, Arizona | Western Army National Guard Aviation Training Site | Installed | | | | Power reliable supply to flight simulator. Fuel cells were donated by a military base and a research facility. |
| Unnknown | Tokyo Gas, Toshiba | 1 MW fuel cell cogeneration plant | Japan | Tokyo Gas site | | | | | Installed by Toshiba |
| Unknown | TKG Consulting, San Diego Gas and Electric | Fuel cell | San Diego, California | TKG Consulting office | | | Natural gas | | The group is aiming for LEED certification and also has 5 kW photovoltaic power installation. |
| Unknown | Mulheim Hotel | 3 kW PEM | Mulheim, Germany | Mulheim Hotel | | | | | |
| Unknown | Hartford Gas (now Connecticut Natural Gas) | Fuel cell | Connecticut | Experimental home powered by a fuel cell | 1969 | Completed | Natural gas | | |

Notice: For additional information or comments on Fuel Cells 2000's charts, contact Jennifer Gangi at: jennifer@fuelcells.org.

# Electric Power Research Institute "Status & Trends for Stationary Fuel Cell Power Systems"

**2005**

ELECTRIC POWER RESEARCH INSTITUTE

# Status and Trends for Stationary Fuel Cell Power Systems

Dan Rastler

Technical Leader, Distributed Energy Resources Program

drastler@epri.com

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EPRI

# Fuel Cell Types and Comparisons

| Fuel Cell Type and Scale in kW | Electrical Efficiency, LHV | Current and {Projected} Cost $/kW | Status |
|---|---|---|---|
| **PAFC**<br>200 – 1,000 | 40% | $ 4000<br>{3000} | Commercial |
| **MCFC**<br>250-1000 | 44-55% | $4000<br>{1200} | Pre-commercial |
| **PEMFC**<br>5 kW to 1,000 | 32-42% | $2000-$4000<br>{900} | Pre-production trials<br>Under development |
| **SOFC**<br>5 kW – 1,000 | 40-55% | $20,000<br>{700-900} | Beta trials<br>Under development |

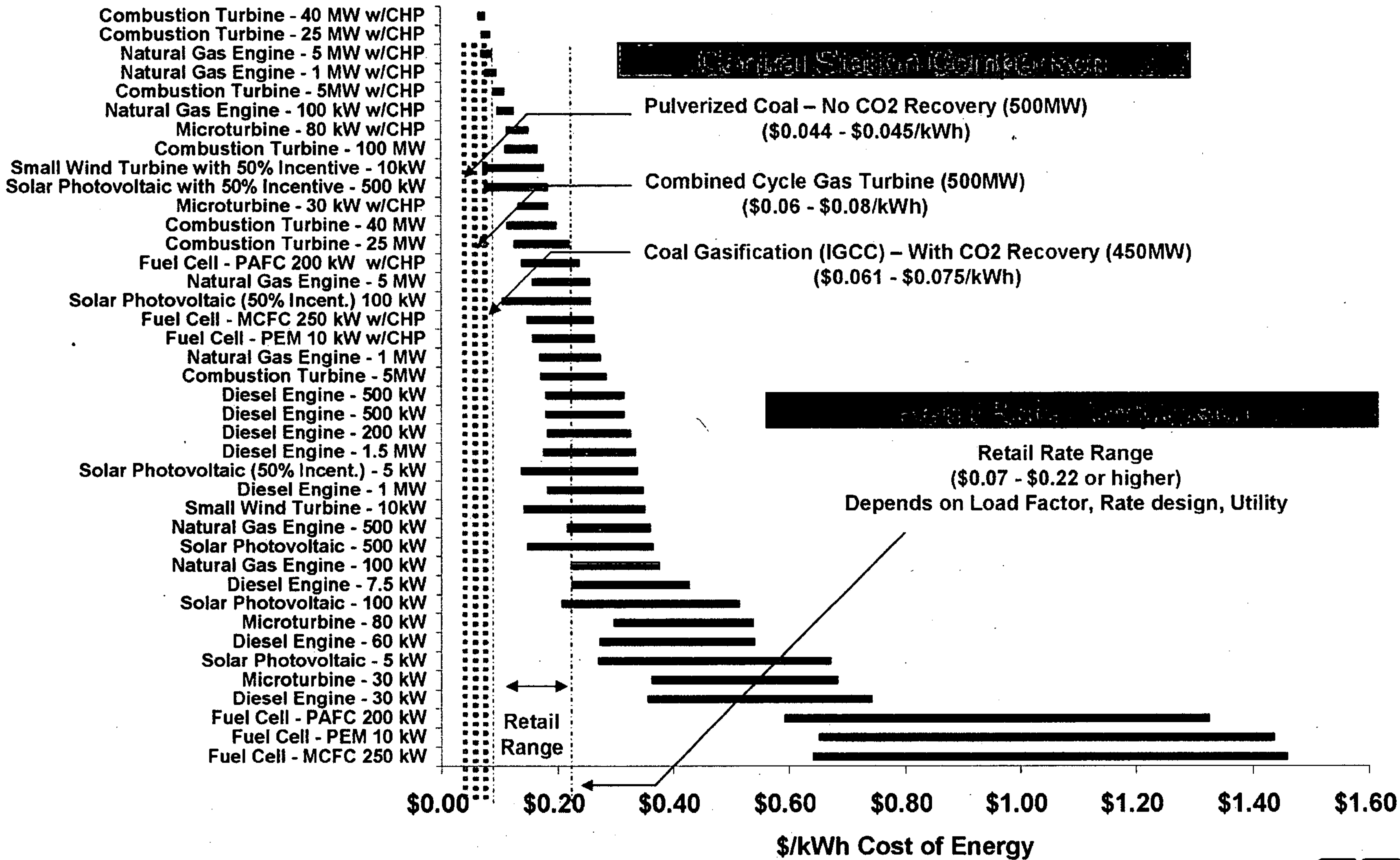


EPRI

# Benchmarking Fuel Cells

## Range of Total Energy Cost ($/kWh)

*Includes Capital, Financing, Fuel, and Maintenance (Net of Recovered Waste Heat)*





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ATTACHMENT H3
FUEL CELL TODAY
"FACTS & FIGURES"
(NO DATE)

# Fuel Cell Today

# "Facts & Figures"

# (no date)

# FUEL CELL TODAY

Opening doors to fuel cell commercialisation

## Facts & Figures

**Fuel Cell Today – Education Kit 9**

The history of the fuel cell can be traced back to the nineteenth century. Since then the development and the usage of fuel cells in various applications have come a long way.

- William Grove invented the fuel cell in 1839.
- In 1959, Francis Bacon demonstrated a 5kW alkaline fuel cell.
- General Electric invented proton exchange membrane fuel cells in the 1950s.
- The first "commercial" use of fuel cells was by NASA in the 1960s during the Apollo space missions. Alkaline fuel cells have flown over 100 missions and operated for over 80,000 hours in spacecraft operated by NASA.
- The US Navy has used fuel cells in submarines since the 1980s.

- Fuel cell buses are running in several cities around the world. Currently, the largest fuel cell bus demonstration programme is the European Union backed CUTE project (Clean Urban Transport for Europe).
- All major car manufacturers already have prototypes on the road; the first few fuel cell cars have been leased to customers.
- Iceland is planning to convert its fishing fleet from diesel engines to hydrogen fuel cells as part of a national project to create a fossil fuel free economy.

- Many companies are hoping to produce their first semi-commercial models of fuel cell cars during the next decade. However, it is very unlikely that fuel cell cars will be produced in real commercial numbers before 2010.
- Companies have started to bring real fuel cell products to the market in 2004. In the future, portable direct methanol fuel cells could power mobile phones, laptops and cameras.
- Small stationary fuel cells, including residential units, have become available in small numbers from late 2004. They should become available to the public soon afterwards.

- Most commercial fuel cells are currently PEM (Proton Exchange Membrane) fuel cells, which operate at around 80°C.
- Solid oxide fuel cells operate at 800-1000°C.
- The main types of fuel cells are: alkaline, direct methanol, molten carbonate, phosphoric acid, proton exchange membrane and solid oxide.
- A fuel cell is around 60 per cent efficient at converting fuel to power, double the efficiency of an internal combustion engine.

# University of California, Berkeley

# "Fuel Cell System Economics: Comparing the Costs of Generating Power with Stationary and Motor Vehicle PEM Fuel Cell Systems"

# (pages 1 and 113)

## April 2004

# FUEL CELL SYSTEM ECONOMICS: COMPARING THE COSTS OF GENERATING POWER WITH STATIONARY AND MOTOR VEHICLE PEM FUEL CELL SYSTEMS

**UCD-ITS-RP-04-21**

April 2004

by

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email: itspublications@ucdavis.edu

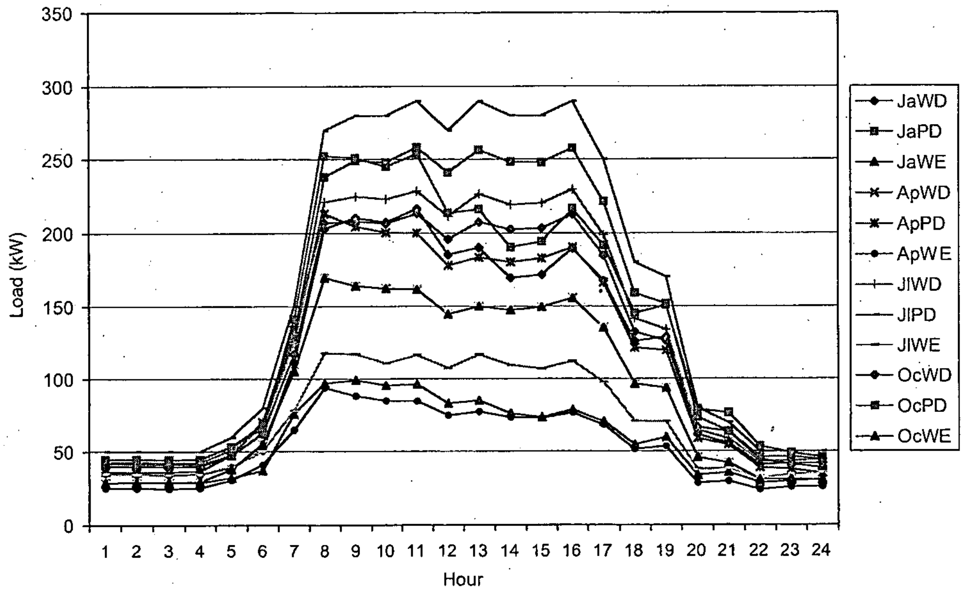



Fig. 6. California medium office building site load shape patterns.

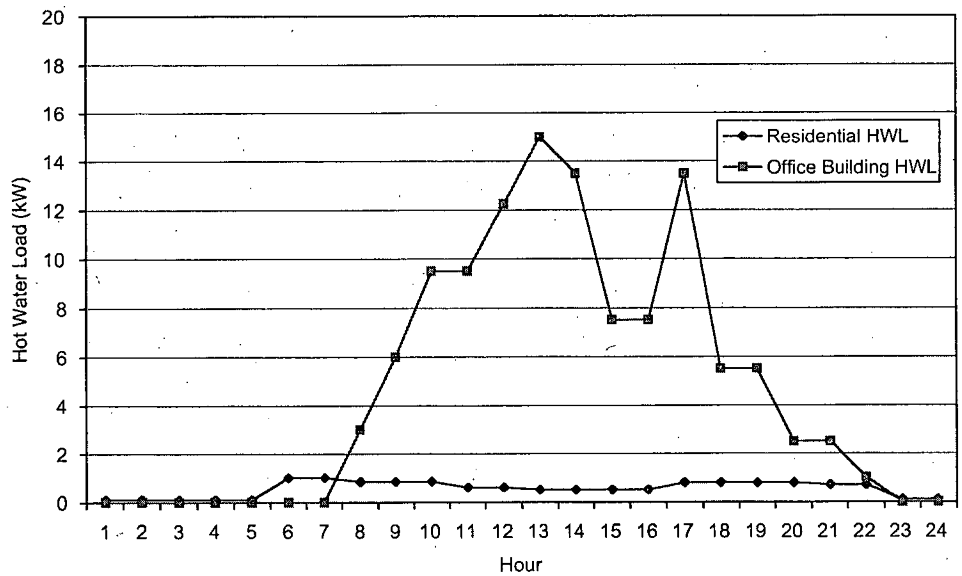



Fig. 7. Residential and office building hot water load profiles source: (Arthur D Little, 1994).

## 10. Economic variable input assumptions

This analysis is intended to estimate the potential costs of using stationary and automotive fuel cells for distributed power in the 2010–2015 timeframe. Thus, we analyze cases with fuel cell system capital costs that are much lower than present-day capital costs for PEM fuel cells, which we believe to be on the order $3000–4000 per kW[3]. PEM fuel cells are an emerging technology that is just beginning to become commercial after a decade of intense development throughout the 1990s, and costs are expected to fall sharply as production volume and manufacturing experience grow. However, manufacturing costs and sale prices of PEM fuel cells and natural gas reformers in higher volume production are uncertain, owing to several variables that can affect manufacturing cost. These variables include production volume, product design, material choices and material utilization rate improvements, production process development, and cost vs. efficiency tradeoffs with regard to fuel cell system operation (e.g., higher efficiency levels can be maintained with larger and more expensive fuel cell stacks).

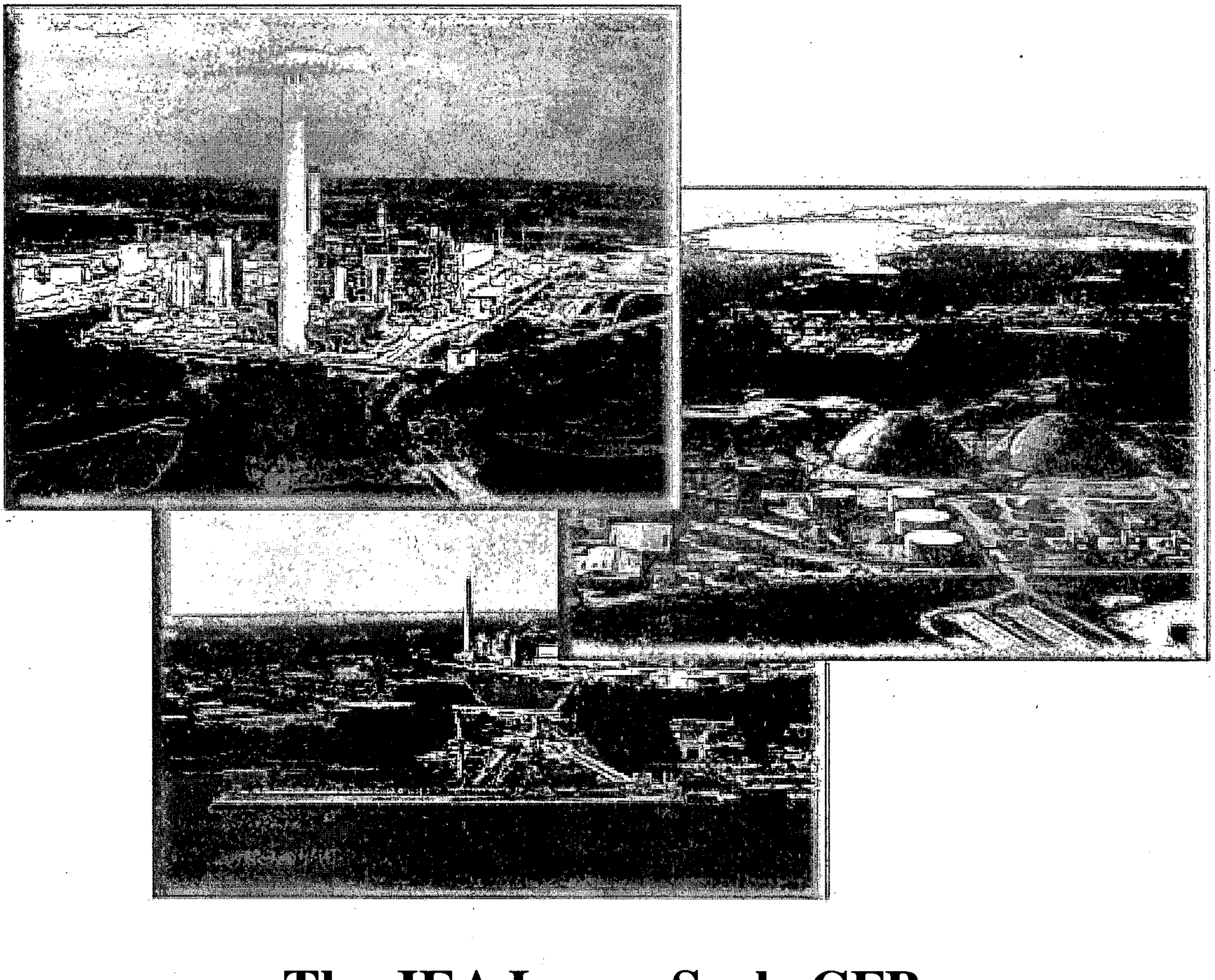
[3] PEM fuel cell manufacturing costs are proprietary, and even selling prices are difficult to determine at present because systems in the 5–250 kW size range are not yet commercially available.

# U.S. Department of Energy
# and JEA

# Joint Study
# Clean Coal Technology
# Technical Report Number 22
# "The JEA Large-Scale CFB Combustion Demonstration Project"
# (Cover Page and pages 1 – 3 )

## March 2003

CLEAN COAL TECHNOLOGY



# The JEA Large-Scale CFB Combustion Demonstration Project

# *Executive Summary*

The Clean Coal Technology (CCT) Demonstration Program is a government and industry co-funded effort to demonstrate a new generation of innovative coal utilization processes in a series of facilities built across the country. These projects are carried out on a commercial scale to prove technical feasibility and provide the information required for future applications.

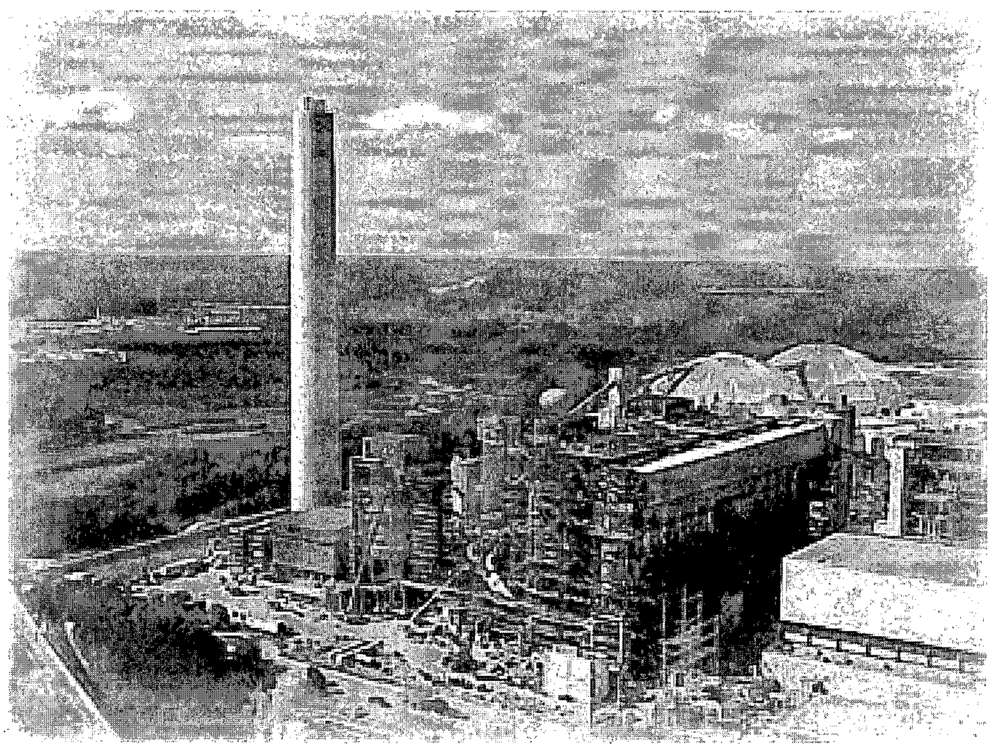
The goal of the CCT Program is to furnish the marketplace with a number of advanced, more efficient coal-based technologies that meet strict environmental standards. Use of these technologies is intended to minimize the economic and environmental barriers that limit the full utilization of coal.

To achieve this goal, beginning in 1985, a multi-phased effort consisting of five separate solicitations was administered by the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL). Projects selected through these solicitations have demonstrated technology options with the potential to meet the needs of energy markets while satisfying relevant environmental requirements.

Part of this Program is the demonstration of advanced electric power generation technologies, including circulating fluidized bed combustion (CFB). This report discusses the JEA Large-Scale CFB Combustion Demonstration Project which is testing the CFB concept using inexpensive feedstocks such as high sulfur coal and coal fuel blends.

The project is being conducted at the Northside Generating Station of JEA (formerly Jacksonville Electric Authority) in Jacksonville, Florida, and JEA is the project Participant. Foster Wheeler Energy Corporation, the technology supplier, is an additional team member.

To date, the JEA Project has operated CFBs to generate electricity at a scale larger than previously demonstrated. The boilers at the Northside Station are the largest CFBs in the world. Power production on coal feed meets the target goal of 297.5 MWe gross (265 MWe net). Emissions of atmospheric pollutants are below the stringent limits set for this project. A two-year demonstration test program is planned to evaluate the operational and environmental performance of the CFB system.



**JEA plant with CFB boilers in center and fuel storage domes in background**

# The JEA Large-Scale CFB Combustion Demonstration Project

## Background

The Clean Coal Technology (CCT) Demonstration Program, sponsored by the U.S. Department of Energy (DOE) and administered by the National Energy Technology Laboratory (NETL), has been conducted since 1985 to develop innovative, environmentally friendly coal utilization processes for the world energy marketplace.

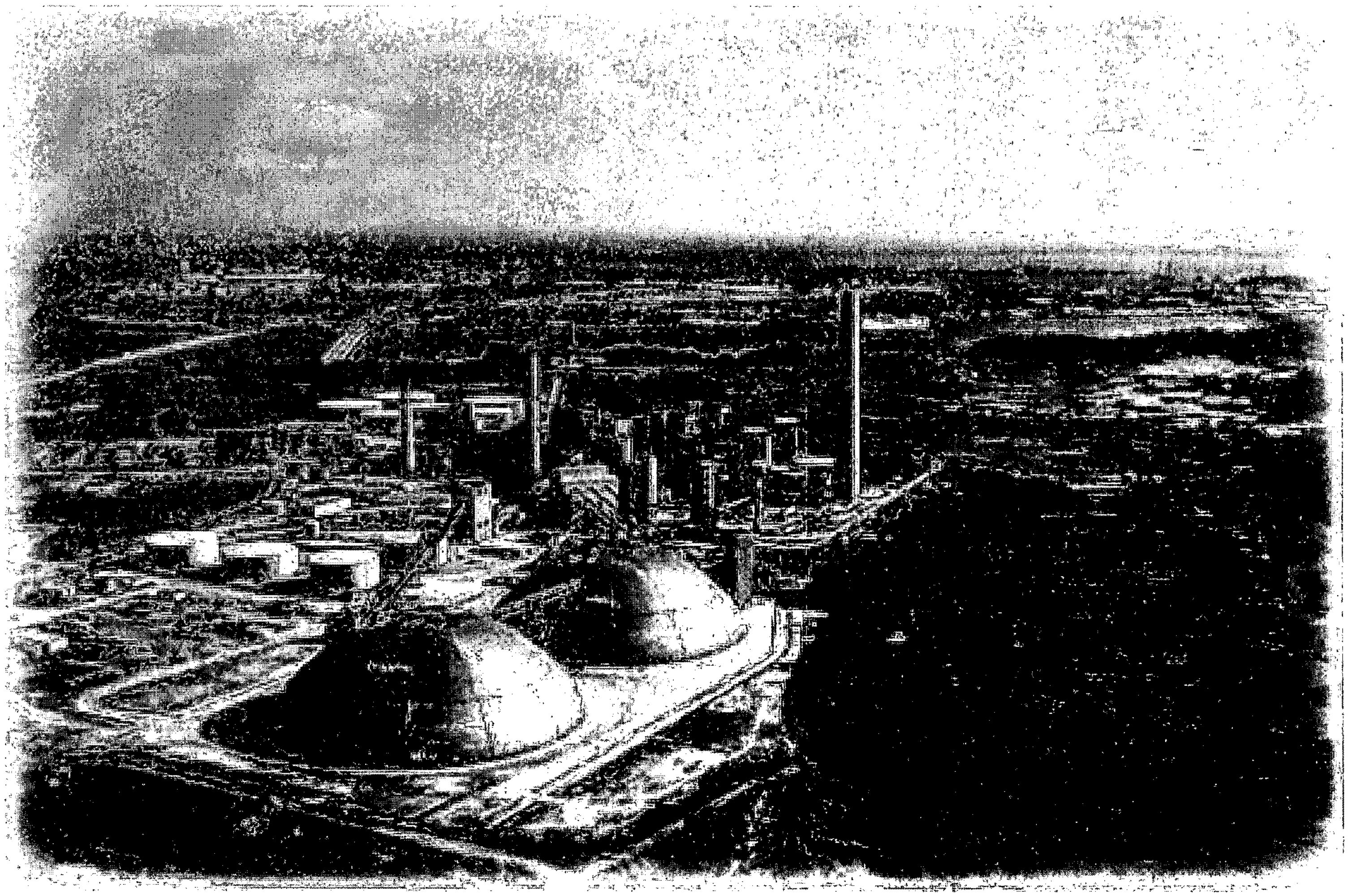
The CCT Program, which is co-funded by industry and government, involves a series of demonstration projects that provide data for design, construction, operation, and technical/economic evaluation of full-scale applications. The goal of the CCT Program is to enhance the utilization of coal as a major energy source.

### *Fluidized Bed Combustion*

Among the technologies being demonstrated in the CCT Program is fluidized bed combustion (FBC). FBC is an advanced electric power generation process that minimizes the formation of gaseous pollutants by controlling coal combustion parameters and by injecting a sorbent (such as crushed limestone) into the combustion chamber along with the fuel. In the JEA project described in this report, the fuel is coal or a blend of coal and petroleum coke. Crushed fuel mixed with the sorbent is fluidized on jets of air in the combustion chamber. Sulfur released from the fuel as sulfur dioxide ($SO_2$) is captured by the sorbent in the bed to form a solid compound that is removed with the ash. The resultant by-product is a dry, benign solid that can be disposed of easily or used in agricultural and construction applications. More than 90% of the sulfur in the fuel is captured in this process.

An additional environmental benefit of FBC power plants results from their relatively low operating temperature, which significantly reduces formation of nitrogen oxides (NOx).

Five FBC demonstration projects are included in the CCT Program under Advanced Electric Power Generation: (1) the JEA Large-Scale CFB Combustion Demonstration Project, (2) the Nucla CFB Demonstration Project, (3) the Tidd PFBC Demonstration Project, (4) the McIntosh Unit 4A PCFB Demonstration Project, and (5) the McIntosh Unit 4B Topped PCFB Demonstration Project. This Topical Report describes the JEA project.



**Panoramic view of JEA site**

# *Project Description*

The JEA Large-Scale CFB Combustion Demonstration Project consists of installing a new 300-MWe (297.5-MWe nameplate) atmospheric circulating fluidized bed (ACFB) boiler in conjunction with an existing turbine generator at JEA's Northside Generating Station (Unit 2) in Jacksonville, Florida. In parallel with this project, JEA replaced the Unit 1 oil/gas fired boiler with an identical ACFB unit. Unit 1 continues to use its existing turbine generator.

These boilers are designed to burn fuel blends consisting of coal and petroleum coke, thereby greatly reducing plant fuel costs and maintaining fuel flexibility while meeting stringent emissions limits. These units are the world's largest ACFB boilers.

In this project, the existing Unit 2 turbine generator was upgraded, and other existing balance-of-plant (BOP) equipment and systems were either upgraded or replaced. The existing turbine building and some piping systems were re-utilized.

Steam from the combustor is used in an existing General Electric 297.5-MWe (nameplate) turbine to produce electric power. With parasitic power consuming 32.5 MWe, net power output is 265 MWe.

## JEA Large-Scale CFB Combustion Demonstration Project

### Project Participants and Responsibilities

*JEA*

- Overall project and construction management
- Funding ($234 million)
- Environmental permitting

*U.S. DOE*

- Funding ($75 million)
- Technology support/dissemination

*Foster Wheeler Energy Corporation (Clinton, NJ)*

- Design and supply of CFBs
- Engineering/procurement/construction for the extended boiler island, including CFBs, scrubbers, fabric filters, stack, and fuel and limestone preparation facilities

*Black & Veatch (Kansas City, MO)*

- Design of BOP and materials handling systems

*Zachry Construction Corporation (San Antonio, TX)*

- Procurement and construction of BOP system upgrades and replacements, including condensate, feedwater, and circulating water systems; water and wastewater treatment systems; distributed control system; station electric distribution system; and substation equipment

*Fluor Global Services (Irvine, CA)*

- Upgrade/uprate of turbine/generators
- Procurement and construction of materials handling systems, including continuous ship unloader (purchased by JEA), pier, conveyors, fuel storage domes, and fuel and limestone reclaim equipment

### *Project Participant*

The Participant is JEA, who provided the host site. An additional team member is Foster Wheeler Energy Corporation (FWEC), who supplied the ACFB technology.

### *Fuel Supply*

Coal feed is an Eastern bituminous coal having a sulfur content of 3.39 wt%. Petroleum coke having a sulfur content as high as 8% also serves as feed, either alone or in combination with coal.

### *Project Scale*

The JEA project represents a scale-up of previous ACFB installations. The Nucla project, completed in 1992, had a capacity of 100 MWe (net) and the Tidd project, completed in 1995, had a capacity of 70 MWe (net). The McIntosh Unit 4A project (currently on hold) is designed for a capacity of 137 MWe (net), and the McIntosh Unit 4B project (also on hold) has a design capacity of an additional 103 MWe (net). At a nominal design capacity of 300 MWe gross (265 MWe net), the JEA project is the largest scale demonstration of FBC technology to date.

## Jacksonville

A half century after Ponce de Leon claimed Florida for Spain, Frenchman Jean Ribault sailed into the St. Johns River to establish Fort Caroline for French Huguenot settlers. Within several years, Spanish forces from the military garrison at St. Augustine would destroy this small settlement.

In 1821, Spain ceded Florida to the United States, and one year later Isaiah D. Hart surveyed the village. He named it Jacksonville for General Andrew Jackson, the territory's first military governor.

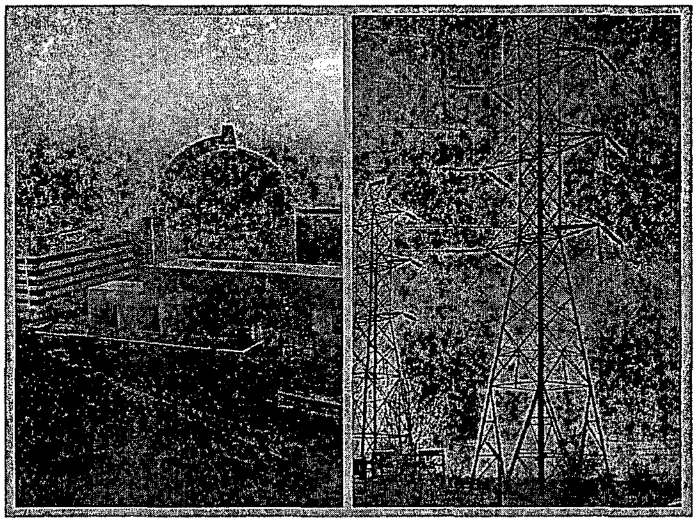
Today, located at the crossroads of two transcontinental highways, Jacksonville is one of the Nation's largest cities in land area (841 square miles), a major port, site of Navy bases, and home of the NFL Jacksonville Jaguars, a Mayo Clinic medical center, and the Jacksonville Zoological Gardens. The area boasts beautiful beaches and numerous waterways for over 700,000 residents.

# The University of Chicago

# "The Economic Future of Nuclear Power"

## August 2004

# THE ECONOMIC FUTURE OF NUCLEAR POWER



A Study Conducted at The University of Chicago

August 2004

## Table 1-1: Summary Worksheet for Busbar Cost Comparisons, $ per MWh, with Capital Costs in $ per kW, 2003 Prices

| Technology | Sandia Model GenSim | | SAIC Model Power Choice | | | Scully Capital Report | | | EIA – AEO 2004 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | r=10% | r=15% | Debt r = 8%; Disc r = 8% | Debt r =10%; Disc r = 8% | Debt r =10%; Disc r = 10% | r = 8% | r = 10% | r = 10% | Debt r =10%; Eq = 15%; Disc r = 10% | Debt r =8%; Eq = 10%; Disc r = 10% |
| Nuclear | 51 | 83 | | | | | | | | |
| (capital cost) | (1,853) | (1,853) | | | | | | | | |
| Legacy Nuclear | | | 65 | 70 | 77 | | | | | |
| (capital cost) | | | (2,000) | (2,000) | (2,000) | | | | | |
| EIA Reference Case, New Nuclear | | | | | | | | | 63 to 68 | |
| (capital cost) | | | | | | | | | (1,752 to 1,928) | |
| EIA Advanced Technology Case, New Nuclear | | | | | | | | | 43 to 53 | |
| (capital cost) | | | | | | | | | (1,080 to 1,555) | |
| ABWR | | | 53 | 50 | 55 | | | | | |
| (capital cost) | | | (1,600) | (1,600) | (1,600) | | | | | |
| AP 1000 | | | 49 | 46 | 51 | 36 | 40 | 44 | | |
| (capital cost) | | | (1,365) | (1,365) | (1,365) | (1,247) | (1,247) | (1,455) | | |
| Pebble Bed Modular Reactor (PBMR) | | | 40 | 41 | 45 | | | | | |
| (capital cost) | | | (1,365) | (1,365) | (1,365) | | | | | |
| Gas-Turbine Modular Helium Reactor (GT-MHR) | | | 39 | 39 | 43 | | | | | |
| (capital cost) | | | (1,126) | (1,126) | (1,126) | | | | | |
| Advanced Fast Reactor (AFR) | | | 57 | 57 | 64 | | | | | |
| (capital cost) | | | (1,126) | (1,126) | (1,126) | | | | | |
| Coal | 37 | 48 | 43 | 44 | 49 | | | | | 38 |
| (capital cost) | (1,094) | (1,094) | (1,350) | (1,350) | (1,350) | | | | | (1,169) |
| Gas Turbine Combined Cycle | 35 | 40 | 38 | 38 | 40 | | | | | 41 |
| (capital cost) | (472) | (472) | (590) | (590) | (590) | | | | | (466) |
| Gas Combustion Turbine | 56 | 68 | | | | | | | | |
| (capital cost) | (571) | (571) | | | | | | | | |
| Solar-Photovoltaic | 202 | 308 | | | | | | | | |
| Solar-Thermal | 158 | 235 | | | | | | | | |
| Wind | 55 | 77 | | | | | | | | |

# Chapter 5. FINANCING ISSUES

## Summary

As a prelude to considering energy scenarios for the future, which will be the capstone of the study in Chapters 9 and 10, this chapter develops the basic financial model used to analyze nuclear energy economic viability. Features of the U.S. tax system are introduced. Risk is considered in some depth. To provide a benchmark for the energy scenarios for the future that will contemplate alternative nuclear energy policies, the model is used to estimate the sensitivity of economic viability to uncertainties in the no-policy case.

Taxes

Recognition that nuclear energy plants will be owned and operated by utilities or other private providers requires introducing tax treatment of debt and equity, deduction of depreciation from taxable income with effects of different allowed depreciation schedules, effects of special tax provisions, and effects of inflation on taxes.

Risk

The perceived risk of investments in new nuclear facilities is widely appreciated to contribute to the risk premium on any new nuclear construction. Principal sources of risk are the possibilities that new plants will exceed original cost estimates and that construction delays will escalate costs. In this chapter guidelines from the corporate finance literature are used to specify likely relationships between project risk and risk premiums for corporate bonds and equity capital. Risk premiums have an important influence on the economic competitiveness of nuclear energy. A 3 percent risk premium is used for the first few plants.

No-Policy Scenarios

In using the financial model to study sensitivity to uncertainties, an overnight cost range for new nuclear plants of $1,200 to $1,800 per kW is used, based partly on the three technologies discussed as being realistic in Chapter 3. Given the capital cost range, the LCOE of new nuclear plants in the absence of policies is from $53 to $71 per MWh, with a 7-year construction time. The range is lower at $47 to $62 per MWh with a 5-year construction time. Costs remain outside the range of competitiveness with coal and gas, which have LCOEs of $33 to $41 per MWh and $35 to $45 per MWh, respectively.

The nuclear LCOE for the most favorable case, $47 per MWh, is close but still above the highest coal cost of $41 per MWh and gas cost of $45 per MWh. Longer debt terms and longer plant life span reduce nuclear LCOEs, but still do not bring them into the competitive range. The impact of construction delays is large, particularly if a 2-year delay occurs after all outlays have been made—capable of making the nuclear LCOE range from $61 to over $76 per MWh. These no-policy results provide benchmarks indicating the extent to which policies to be considered in Chapters 9 and 10 are needed to reduce nuclear LCOEs.

# U.S. Department of Energy
# National Energy Technology Laboratory

# "Combustion - Fluidized-Bed Combustion, Program Overview"

**(no date)**

National Energy Technology Laboratory

Site Map GO

THE ONLY U.S. NATIONAL LABORATORY DEVOTED TO FOSSIL ENERGY TECHNOLOGY

ABOUT NETL

KEY ISSUES & MANDATES

ONSITE RESEARCH

TECHNOLOGIES

Oil & Natural Gas Supply
Coal & Power Systems
Clean Coal Demonstrations
Environmental & Water
Gasification
Turbines
Combustion Technologies
Fuel Cells
FutureGen
Advanced Research
Contacts
Carbon Sequestration
Hydrogen & Clean Fuels
Technology Transfer

ENERGY ANALYSES

SOLICITATIONS & BUSINESS

CAREERS & FELLOWSHIPS

NEWSROOM

CONTACT NETL

## Combustion - Fluidized-Bed Combustion

Program Status

- FBC Overview
- FBC Goals
- FBC Status
- FBC Roadmap
- FBC Benefits

**Advanced FBC Technology Demonstrations**

Two Clean Coal Technology Demonstration Program projects are providing valuable information: one at Jacksonville, Florida, which is demonstrating circulating atmospheric FBC by 2000; and the other expected to be sited soon, which will demonstrate commercial-scale advanced GFBCC technology.

**Pressurized Fluidized-Bed Combustion System**

First-generation PFBCs are operated with 100 percent of the solid fuel conversion happening in the fluidized bed. Since PFBCs have a maximum operating temperature around 870°C (1600°F), the gas turbine operates at a relatively inefficient temperature rating.

Depending on the manufacturer and/or site-specific conditions, the fluidized bed could be either the circulating- or bubbling-bed type. First-generation PFBC systems now undergoing commercial demonstration are capable of achieving efficiencies up to 42 percent.

Pressurized circulating fluidized bed (PCFB) partial gasifiers used in CHIPPS and GFBCC have been tested in pilot scale.

**Topping Combustor**

Second-generation APFBC systems require the development and demonstration of a commercially viable topping combustor with suitable fuel flexibility, flame stability, and NOx emissions. These need to accept hot APFBC syngas, and hot vitiated air. Tests of a multi-annular swirl burner (MASB) have demonstrated good flame stability and NOx performance. Systems testing of the MASB was performed at the Wilsonville Power Systems Development Facility (PSDF) during 1998. With the integration of building-block technologies under development --hot gas cleanup, advanced gasifier technology, and turbine systems-- efficiencies for PFBC systems will eventually exceed 50 percent.

CHIPPS and GFBCC systems use moderate-temperature syngas, and ordinary gas turbine combustion air. Any gas turbine already developed for syngas operations should work.

**Combustion By-Products Utilization**

FBC economics improve as combustion by-products are reduced or high-value uses are found. The goal is to reduce solid by-products from FBC systems without compromising sulfur capture or producing in-bed sintering. Variability of limestone will be assessed as a factor in the volume of solid by-products from FBC systems without compromising sulfur capture or producing in-bed sintering. Variability of limestone will be assessed as a factor in the volume of solid by-products, and a limestone utilization model will be developed to optimize sulfur capture and minimize the volume of solid by-products. Expanding markets for FBC by-products will reduce net operating costs and landfill requirements. FBC ash will be characterized for conventional applications, such as agriculture, mine remediation, and structural fill, and high-value uses of solid by-products from FBC systems will be developed.

**Hot Gas Filtration**

In APFBC systems, ceramic filters are used that operate in the 1400°F to 1550°F temperature range to filter both syngas and vitiated air. Ceramic filter element durability, filter-ash bridging, and system costs are critical development issues being addressed. The challenge of producing candle-filter elements able to operate for more than three years is being met by enhancing monolithic filter elements made of various materials, such as clay-bonded silicon-carbide, porous-sintered metal, and alumina-mullite oxide. A number of composite-type ceramic and iron aluminide-type filter elements are also undergoing development. Filter cost can be reduced by 25 percent through optimized design of the system; filter vessel cost is about 75 percent of the total system cost.

CHIPPS and GFBCC use moderate temperature metallic syngas filters which have been successfully demonstrated.

**Solids Transfer**

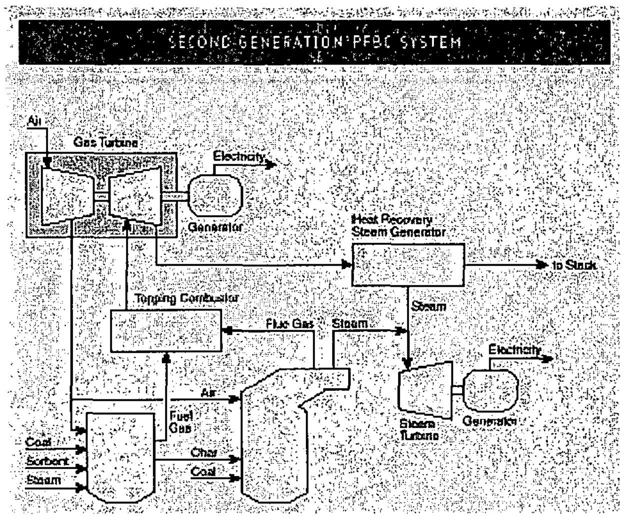
Improved handling of hot-solids material --feed and withdrawal, flow control, and fines removal-- can achieve cost reduction and reliability improvement. A feasibility study of a rotary high-pressure dry-solids feeder will evaluate the system's potential for reducing capital and operating costs. An advanced system for simpler and more reliable transfer of hot char from the carbonizer to the fluid-bed combustor will be tested for its ability to decrease materials flow and handling-related downtime by at least 50 percent.

**Sulfur/Alkali Removal**

Alkali in hot-gas streams can limit gas turbine life and reliability. The severity of the alkali problem must be determined. Gas turbine tolerance to alkali, the amount of alkali released, the effect of filter-cake characteristics, and the ability to control alkali will be assessed. Also, experiments to determine sulfur removal and trace-contaminant levels in the gas stream during integrated demonstration will be conducted.

**Cofiring of Biomass and Industrial By-Products**

Existing fluidized beds are suitable for cofiring, but to date, only 8 of the 100 units in the U.S. cofire material. Cofiring of biomass and industrial by-products could evolve into a standard practice as a near-term means to reduce $CO_2$ emissions. R&D data on heavy metals are needed so that environmental approval and permits for cofiring projects are not any more difficult to obtain than for single-fuel solid-combustion units.




In a second-generation PFBC system, the coal is partially gasified in a pressurized fluidized-bed carbonizer. The carbonizer produces a low-Btu gas and a char. The char is burned in a PFBC. Both gases are cleaned by hot-gas filtration, and the carbonizer's syngas is burned in a topping combustor to heat the PFBC flue gas. This hot flue gas drives a gas turbine to generate power. The flue gas leaving the gas turbine then generates steam in a heat recovery steam generator, which is used to generate additional power. At the Wilsonville Power Systems Development Facility (PSDF), an advanced second-generation PFBC now demonstrates high efficiency at pilot scale.

Second-generation PFBC is also called "advanced circulating pressurized fluidized bed combined cycle," or "APFBC."

# Gasification Technologies Conference
# San Francisco

# "The Reliability of Integrated Gasification Combined Cycle (IGCC) Power Generation Units"

## October 2005

# The Reliability of Integrated Gasification Combined Cycle (IGCC) Power Generation Units

Christopher Higman, Syngas Consultants Ltd.

Sal DellaVilla and Bob Steele, Strategic Power Systems, Inc. (SPS)

Gasification Technologies Conference,

San Francisco, October 11th, 2005

**Introduction**

The Integrated Gasification Combined Cycle (IGCC) has for many years been regarded as a technology with considerable potential for power production from coal and other fuels at high energy efficiency and with greatly reduced emissions in comparison with conventional combustion technologies. The inherent ability to capture $CO_2$ with substantially reduced energy and cost penalties has increased the focus on IGCC in the context of various $CO_2$ reduction strategies.

Beginning in the mid-1990's, a number of IGCC plants were built and operated so that a base of experience has begun to develop. These plants have confirmed the exceptionally low ($SO_x$, $NO_x$, particulate matter and, if required, mercury) or less toxic (waste water and slag) emissions from these plants. They have also confirmed the expectations of improved thermal efficiency, even if parallel advances in other technologies have not allowed this to be translated into the competitive advantage originally contemplated.

However, the reliability and availability of demonstration IGCC's has not been as high as desired by the power industry or as actually achieved by gasification plants operating in the chemical and other industries. The success of IGCC in realising its potential is therefore also dependant on establishing the reasons for this reduced reliability and taking appropriate steps to improve it.

This paper presents two interlinked projects aimed at supporting the improvement of IGCC reliability. The one project comprises the extension of SPS's existing ORAP (Operational Reliability Analysis Program) reliability, availability and maintainability (RAM) tracking technology from its existing base in natural gas open and combined cycle operations into IGCC.

The other project is using the extended ORAP database to evaluate performance data from existing plants. The initial work has concentrated on evaluating public domain data on the performance of gasification based power and chemical plants. This is being followed up by plant interviews in some 20 plants to verify and expand the database on current performance.

The paper will report on the current status of the projects and present analysis of some important issues already recognized.

## 1. Current Perceptions

### 1.1 The Importance of Reliability

Reliability is every bit as important to the economic success of a plant as the capital and operating expenditure (CAPEX and OPEX). This is illustrated in Figure 1. The cost of electricity (COE) was calculated for a base case (100%) and then sensitivities for the efficiency, the CAPEX and the availability performed. The efficiency has been plotted as heat rate and the availability as outage so that all plots have a positive slope. The graph shows that the cost of electricity is more sensitive to availability and CAPEX than to the heat rate. Note that that all calculations were made with a constant fuel price.

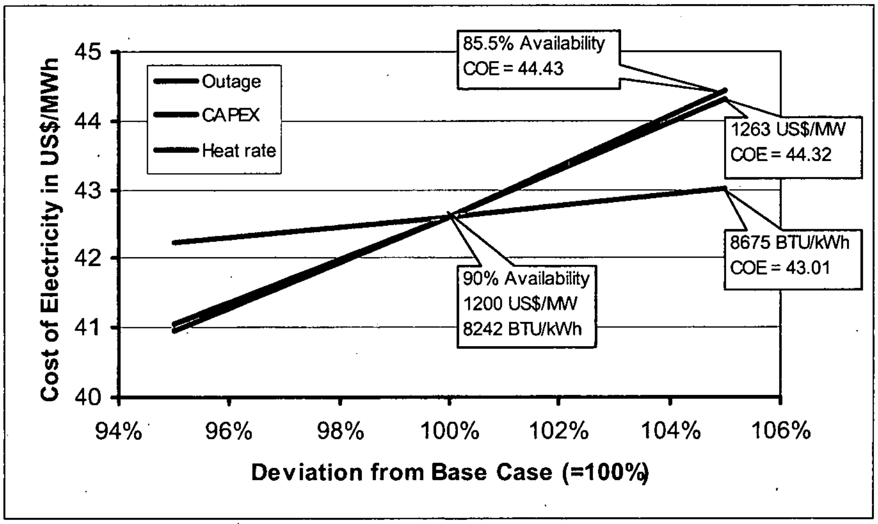



**Figure 1** **Relative Influence of Availability, Investment and Efficiency on the Cost of Electricity**

The data in Table 1 shows availability and capacity factors for various type of power plant in North America over the period 1998 to 2002. The data has been gathered through the Generating Availability Data System (GADS) operated by the North American Electricity Reliability Council (NERC). As can be seen from these figures, availabilities for conventional PC boilers run just below 87%, natural gas fired CC plant at just under 90%.

**Table 1** **NERC GADS Data 1998-2002 [from DellaVilla, 2004]**

| | Service Factors (%) | Capacity Factors (%) | Availability Factor (%) |
|---|---|---|---|
| Gas-fired boilers | 46.7 | 28.9 | 86.3 |
| Oil-fired boilers | 42.2 | 27.6 | 86.3 |
| Coal-fired boilers | 82.3 | 69.9 | 86.9 |
| Aero-derivatives | 4.6 | 2.9 | 91.9 |
| Single Cycle GTs | 5 | 4.3 | 91.1 |
| Combined Cycle GTs | 61.3 | 49.9 | 89.9 |

Looking at Table 2, which shows data evaluated from the ORAP database, one can see that the best performing group of natural gas fired combustion turbines achieve an availability of 94.5%. These figures put the 90% target typically required for IGCCs into perspective. This target is clearly ambitious, which as a development goal is certainly correct. On the other hand the data from existing plants operating with conventional technologies shows that it may not be an absolute criterion for every application.

# U.S. Department of Energy
# Energy Information Administration

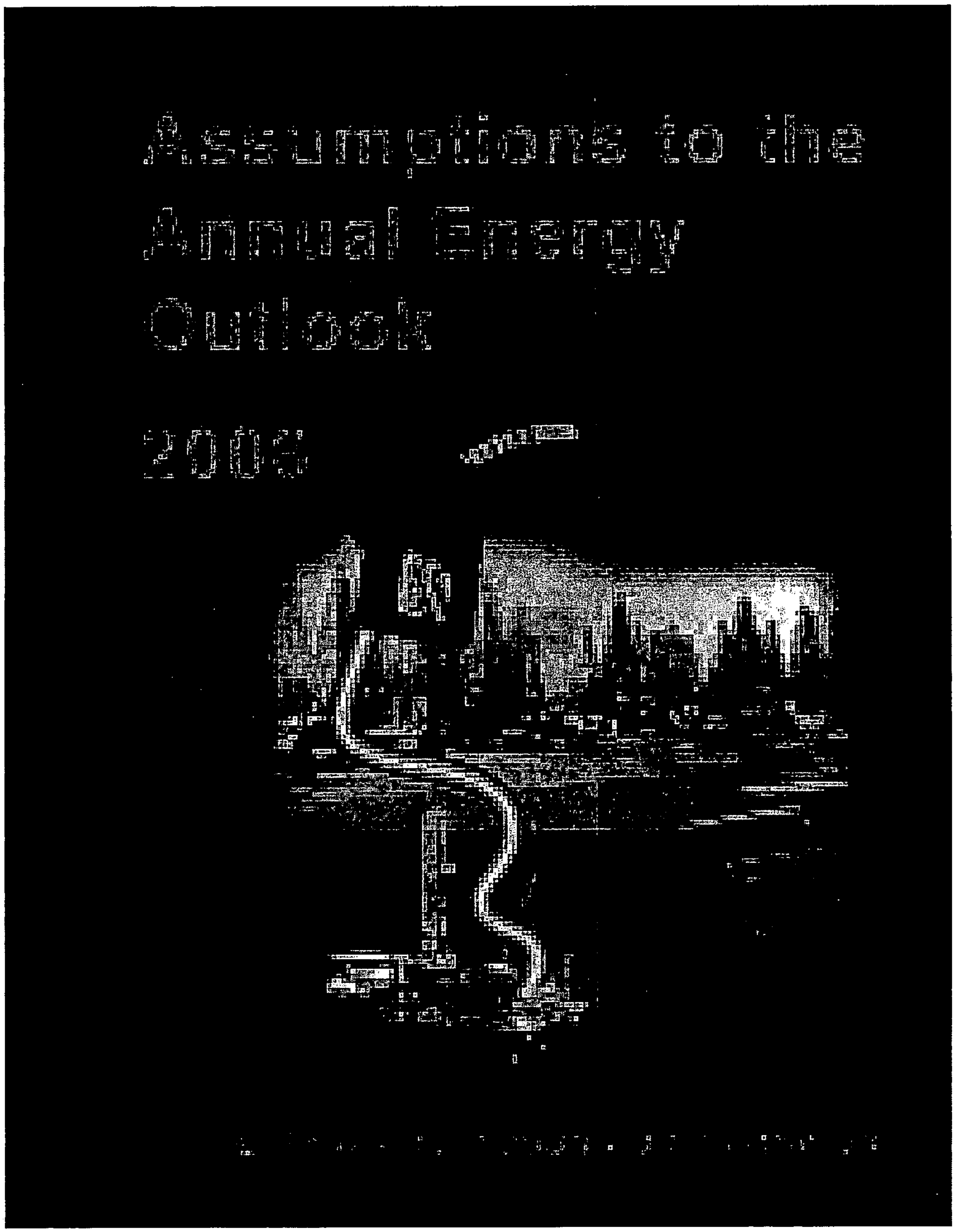
# "Assumptions to the Annual Energy Outlook"

# DOE/EIA-0554(2006)

# (Cover Page and Page 73)

## March 2006

Report #:DOE/EIA-0554(2006)
Release date: March 2006
Next release date: March 2007



## Table 38. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies

| Technology | Online Year[1] | Size (mW) | Leadtimes (Years) | Base Overnight Costs in 2005 ($2004/kW) | Contingency Factors: Project Contingency Factor | Contingency Factors: Technological Optimism Factor[2] | Total Overnight Cost in 2005[3] (2004 $/kW) | Variable O&M[4] ($2004 mills/kWh) | Fixed O&M ($2004/kW) | Heatrate in 2005 (Btu/kWhr) | Heatrate nth-of-a-kind (Btu/kWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scrubbed Coal New[7] | 2009 | 600 | 4 | 1,167 | 1.07 | 1.00 | 1,249 | 4.18 | 25.07 | 8,844 | 8,600 |
| Integrated Coal-Gasification Combined Cycle (IGCC)[7] | 2009 | 550 | 4 | 1,349 | 1.07 | 1.00 | 1,443 | 2.65 | 35.21 | 8,309 | 7,200 |
| IGCC with Carbon Sequestration | 2010 | 380 | 4 | 1,873 | 1.07 | 1.03 | 2,065 | 4.04 | 41.44 | 9,713 | 7,920 |
| Conv Gas/Oil Comb Cycle | 2008 | 250 | 3 | 556 | 1.05 | 1.00 | 584 | 1.88 | 11.37 | 7,196 | 6,800 |
| Adv Gas/Oil Comb Cycle (CC) | 2008 | 400 | 3 | 532 | 1.08 | 1.00 | 575 | 1.82 | 10.65 | 6,752 | 6,333 |
| ADV CC with Carbon Sequestration | 2010 | 400 | 3 | 1,021 | 1.08 | 1.04 | 1,147 | 2.68 | 18.12 | 8,613 | 7,493 |
| Conv Combustion Turbine[5] | 2007 | 160 | 2 | 388 | 1.05 | 1.00 | 407 | 3.25 | 11.03 | 10,842 | 10,450 |
| Adv Combustion Turbine | 2007 | 230 | 2 | 367 | 1.05 | 1.00 | 385 | 2.89 | 9.59 | 9,227 | 8,550 |
| Fuel Cells | 2008 | 10 | 3 | 3,787 | 1.05 | 1.10 | 4,374 | 43.64 | 5.15 | 7,930 | 6,960 |
| Advanced Nuclear | 2013 | 1000 | 6 | 1,744 | 1.10 | 1.05 | 2,014 | 0.45 | 61.82 | 10,400 | 10,400 |
| Distributed Generation -Base | 2008 | 2 | 3 | 791 | 1.05 | 1.00 | 831 | 6.49 | 14.60 | 9,650 | 8,900 |
| Distributed Generation -Peak | 2007 | 1 | 2 | 951 | 1.05 | 1.00 | 998 | 6.49 | 14.60 | 10,823 | 9,880 |
| Biomass | 2009 | 80 | 4 | 1,659 | 1.07 | 1.02 | 1,809 | 3.13 | 48.56 | 8,911 | 8,911 |
| MSW - Landfill Gas | 2008 | 30 | 3 | 1,443 | 1.07 | 1.00 | 1,544 | 0.01 | 104.03 | 13,648 | 13,648 |
| Geothermal[6,7] | 2009 | 50 | 4 | 2,100 | 1.05 | 1.00 | 2,205 | 0.00 | 75.00 | 32,173 | 35,460 |
| Conventional Hydropower[6] | 2009 | 500 | 4 | 1,320 | 1.10 | 1.00 | 1,452 | 3.20 | 12.72 | 10,338 | 10,338 |
| Wind | 2008 | 50 | 3 | 1,091 | 1.07 | 1.00 | 1,167 | 0.00 | 27.59 | 10,280 | 10,280 |
| Solar Thermal[7] | 2008 | 100 | 3 | 2,589 | 1.07 | 1.10 | 3,047 | 0.00 | 51.70 | 10,280 | 10,280 |
| Photovoltaic[7] | 2007 | 5 | 2 | 3,981 | 1.05 | 1.10 | 4,598 | 0.00 | 10.64 | 10,280 | 10,280 |

[1]Online year represents the first year that a new unit could be completed, given an order date of 2005.

[2]The technological optimism factor is applied to the first four units of a new, unproven design, or regulatory structure. It reflects the demonstrated tendency to underestimate actual costs for a first-of-a-kind unit.

[3]Overnight capital cost including contingency factors, excluding regional multipliers and learning effects. Interest charges are also excluded. These represent costs of new projects initiated in 2005.

[4]O&M = Operations and maintenance.

[5]Combustion turbine units can be built by the model prior to 2007 if necessary to meet a given region's reserve margin.

[6]Because geothermal and hydro cost and performance characteristics are specific for each site, the table entries represent the cost of the least expensive plant that could be built in the Northwest Power Pool region, where most of the proposed sites are located.

[7]Capital costs are shown before investment tax credits are applied.

Sources: The values shown in this table are developed by the Energy Information Administration, Office of Integrated Analysis and Forecasting, from analysis of reports and discussions with various sources from industry, government, and the Department of Energy Fuel Offices and National Laboratories. They are not based on any specific technology model, but rather, are meant to represent the cost and performance of typical plants under normal operating conditions for each plant type. Key sources reviewed are listed in the 'Notes and Sources' section at the end of the chapter.

# Instituto Nacional de Investigaciones Nucleares
# México

# "Levelized Costs for Nuclear, Gas and Coal for Electricity, under the Mexican Scenario"

## (3 Pages - Not Consecutive)

## 2004

# Levelized costs for nuclear, gas and coal for Electricity, under the Mexican scenario.

Javier C. Palacios, Gustavo Alonso, Ramón Ramírez, Armando Gómez, Javier Ortiz, Luis C. Longoria.
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**ABSTRACT**

In the case of new nuclear power stations, it is necessary to pay special attention to the financial strategy that will be applied, time of construction, investment cost, and the discount and return rate. The levelized cost quantifies the unitary cost of the electricity (the kWh) generated during the lifetime of the nuclear power plant; and allows the immediate comparison with the cost of other alternative technologies.

The present paper shows levelized cost for different nuclear technologies and it provides comparison among them as well as with gas and coal electricity plants. For the calculations we applied our own methodology to evaluate the levelized cost considering investment, fuel and operation and maintenance costs, making assumptions for the Mexican market, and taking into account the gas prices projections.

The study also shows comparisons using different discount rates (5% and 10%), and some comparisons between our results and an OECD 1998 study. The results are in good agreement and shows that nuclear option is cost competitive in Mexico on the basis of levelized costs.

## 1- The Mexican Scenario

The globalization and liberalization processes that are taking place in the most advanced economic systems are establishing new behavior rules in the energy systems and, in particular, in the electricity market. The energy policy continues being defined by the smallest cost, considering the limits established by the environmental norms and regulations. However, the experiences registered in pioneer countries in the liberalization of the electric market have granted a great relevance to other objectives, among those that highlight the guarantee and supply quality and the stability of the production costs, and they have been the cause of important modifications in the current strategic valuation of the different energy sources, especially the nuclear.

The operation of the nuclear power stations has been improving until reaching marks of excellence that transforms them into a valuable asset for the electric systems. This technology has incorporated improvements coming from developments in other areas (computer science, materials) and a very solid infrastructure of legislation. Several countries have been developed new programs and designs in order to increase the nuclear capacity of the current operating nuclear power stations. Enlarging the useful life of the plants from 40 to 60 years and increasing their generation capacity from 100% to 105% (this is the case of Mexico) and in some cases up to 120%.

Currently, Mexico has one nuclear power plant located in Laguna Verde, in the state of Veracruz Mexico, starting comercial operation in 1990. This NPP has 2 BWR units with a combined capacity of 1365 MWe. This power represents 3.08% as of March 2004 of the total installed capacity in the country [1]. The Mexican government through Comisión Federal de Electricidad (CFE; Electricity Commission), is the utility owning and operating the nuclear power reactor. This power plant produced in the first three months of 2004 5.23% of the total electricity in the country. Figure 1 shows the distribution of the electricity production in Mexico as of March 2004.

Although in the past the nuclear option was no competitive in Mexico, at present this situation is changing, due to different factors. One of them is the high price of fossile fuel in Mexico mainly

In Figure 2 we present the total energy generation cost for all the scenarios considered in this paper.

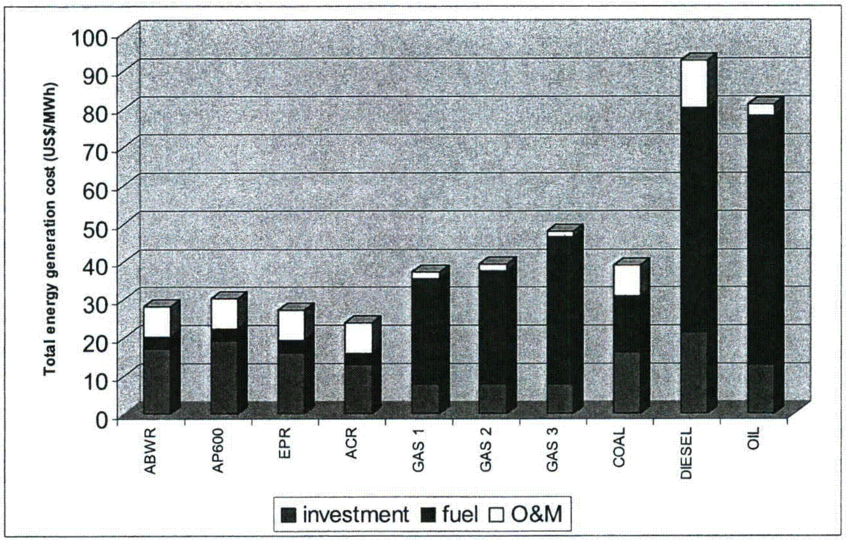



Figure 2. Total energy cost for Nuclear, Gas and Coal Plants

As was discussed in section 3, the variation in the total cost of electricity generation of the different plants as a function of the variation of fuel price is more drastic in the case of gas, and coal fuel compared with uranium. As an example, we can see from figure 3 that if the fuel prices increase 100%, this would result in a 16.21% increase in the cost of nuclear generation, 55.44% in the case of coal generation and 79.01% for natural gas.

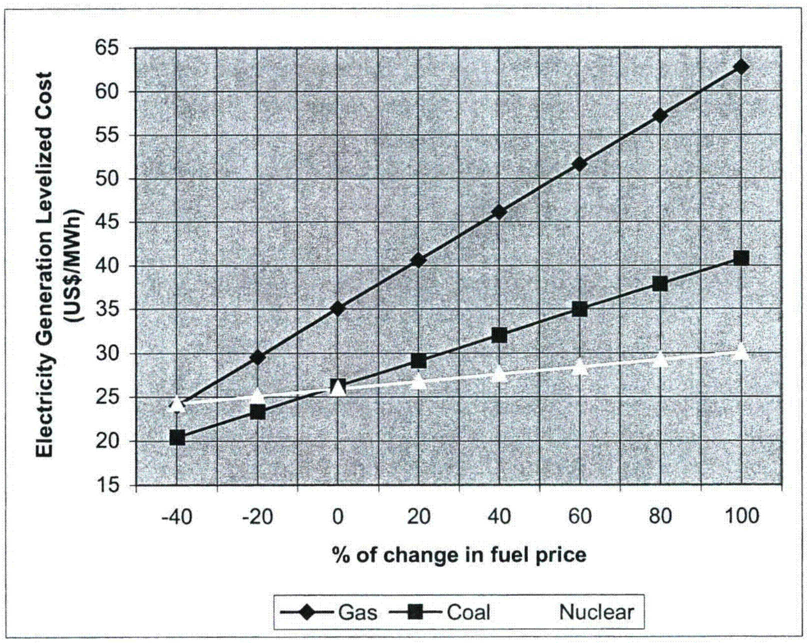
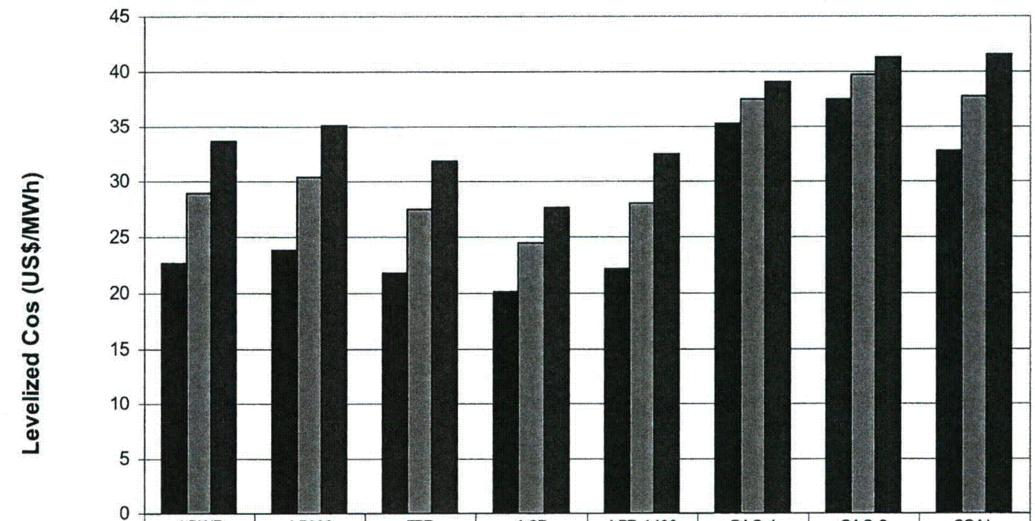



Figure 3. Variation in the total cost of electricity generation as a function of the variation of fuel price

Finally in figure 5 we show the results for the levelized cost of electricity generation at different discount rates.




| | ABWR | AP600 | EPR | ACR | APR-1400 | GAS-1 | GAS-2 | COAL |
|---|---|---|---|---|---|---|---|---|
| Discount Rate 5% | 22.66 | 23.9 | 21.77 | 20.06 | 22.12 | 35.34 | 37.57 | 32.82 |
| Discount Rate 8% | 28.98 | 30.48 | 27.59 | 24.48 | 28.11 | 37.49 | 39.72 | 37.78 |
| Discount Rate 10% | 33.69 | 35.21 | 31.93 | 27.66 | 32.58 | 39.09 | 41.32 | 41.53 |

Figure 4. Levelized cost at different discount rates for electricity generation.

**5. Comparison between ININ results and OCDE and Finish studies.**

As we mentioned in section 2 we use two recent studies to compare the obtained levelized costs. The first of them was carried out in 1998 and it was elaborated by the OECD [2], which projected the generation costs for the period 2005-2010. The second study was elaborated by the Finnish government in 2002 [3] to compare the electricity generation costs by means of gas, coal and nuclear.

For comparison purposes we use a discount rate of 5%. From the results obtained in this study and those reported by the OECD and Finland, we can observe the reduction of the levelized cost since the OCDE results. Also we can see that in the three studies it is demonstrated that the most economic option in generation for levelized cost is the nuclear one. The results of the comparison are shown in figure 5.

**6. Final Discussion**

The investment cost of the nuclear power stations could seem relatively high, but they can be redeemed in a reasonable time due to their variable costs (especially that of fuel) is reduced and is not vulnerable in front of fluctuations of the market. With these characteristics, the nuclear power stations are good to produce load-base electricity, it means, working the 24 hours of every day of the year.

ATTACHMENT K3
CALIFORNIA ENERGY COMMISSION
"MOSS LANDING POWER PLANT PROJECT"
AUGUST 1, 2007

# California Energy Commission

# "Moss Landing Power Plant Project"

## August 1, 2007

Welcome to the California Energy Commission

**PROJECT INFO**

Project Fact Sheet

Project Location (Maps)

Project Photos

**COMPLIANCE PROCEEDINGS**

Announcements, Documents, Notices & Other Info Relating to the Compliance Proceeding (Updated: 8/7/7)

Docket Log

**ORIGINAL PROCEEDINGS**

Announcements, Hearings, Orders, Notices & Workshops (Updated: 3/20/01)

Documents, Decisions and Transcripts In This Siting Case (Updated: 8/13/01)

Docket Log

Schedule For This Case

Proof of Service List

List of Reviewing Agencies

Commission News Releases

**PARTICIPATION**

Public Adviser's Office

Guide to Public Participation In Siting Cases

# MOSS LANDING POWER PLANT PROJECT

Docket Number: 99-AFC-4C (Compliance Proceeding)
99-AFC-4 (Application For Certification)

Committee Overseeing This Case:

William J. Keese, Chairman
Presiding Member

Michal C. Moore, Commissioner
Associate Member

Hearing Officer: Gary Fay

**ANNOUNCEMENTS**

August 1, 2007
Possible approval of a petition to amend the existing certificate to permit the addition of a temporary pilot desalination plant to the project site.
**(See the Petition on Compliance Page)**

## Key Dates

- October 25, 2000 -- Energy Commission approves project.
- August 11, 1999 -- AFC deemed "data adequate" by the Energy Commission.
- May 7, 1999 -- Application for Certification (AFC) filed with Energy Commission.

## General Description of Project

On May 7, 1999, Duke Energy Moss Landing LLC filed an Application for Certification (AFC) seeking approval from the California Energy Commission (Energy Commission) to construct and operate the proposed 1,060-megawatt (MW) Moss Landing Power Plant Project. The project is proposed to be located at the existing Moss Landing Power Plant site that was previously operated by PG&E for about 50 years. This site is located at the intersection of Highway 1 and Dolan Road, east of the community of Moss Landing near the Moss Landing Harbor.

The project, as proposed by Duke Energy, consists of replacing the existing electric power generation Units 1-5, (a total of 613 MW built in the 1950s and shut down in 1995), with two 530 MW, natural gas-fired, combined cycle, units. Each combined cycle unit consists of two natural gas fired combustion turbine generators (CTGs), two unfired heat recovery steam generators (HRSGs) and a reheat, condensing steam turbine generator (STG). Each combined cycle unit will use seawater for once-through cooling. Duke Energy also proposes to upgrade each of the existing Units 6 and 7 by 73 MW.

Duke also plans to remove eight 225-foot stacks and ten large oil tanks.

Link to Duke Energy's (project proponent) Web site.

## Energy Commission Facility Certification Process

The Energy Commission is the lead agency under the California Environmental Quality Act (CEQA) and has a certified regulatory program under CEQA. Under its certified program, the Energy Commission is exempt from having to prepare an environmental impact report. Its certified program, however, does require environmental analysis of the project, including an analysis of alternatives and mitigation measures to minimize any significant adverse effect the project may have on the environment.

### For Questions About This Siting Case Contact:

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Internet E-Mail List Server will be available at:
mosslanding @ energy.ca.gov
(See List Server Page for subscription info.)

### For Questions About Participation In Siting Cases Contact:

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Page Updated: July 20, 2007.

ATTACHMENT L
BIG STONE II
“PLANT PROJECT OVERVIEW”
2006

# Big Stone II

# “Plant Project Overview”

# 2006

# Big Stone II

Home [ ] Search

Power plant» Transmission line» News/Media» Public meetings» Participants» Contact us»

## Plant project overview

Power plant project > Project overview

**Power plant project**

- Project overview
- Environmental impact
- Economic impact
- Project timeline
- Questions and answers about the plant

**Transmission project**

**Seven local utilities have signed agreements to build a second electric generating unit on the site of the existing Big Stone Plant near Milbank, South Dakota.**

Based on increasing demand and studies that point to a potential energy shortfall, seven companies began working together in 2003 to resolve their mutual need for baseload energy. Studies included:

- a cost and performance comparison of state-of-the-art coal combustion and emissions technologies in various size ranges,
- estimates of air emission rates, and
- an evaluation of designs to provide a reliable quantity of cooling water from Big Stone Lake while minimizing impacts and costs.

The result of these efforts was an agreement to develop an electric generating plant that would be:

- approximately 630 megawatts;
- coal-based;
- designed with the best available emission-control technologies at the time of purchase, and
- available to serve the customers of the investing utilities.

**The seven utilities**
Based in Minnesota, North Dakota, and South Dakota, the seven participating electric utilities serve more than 2.3 million customers in five states in the Upper Midwest.

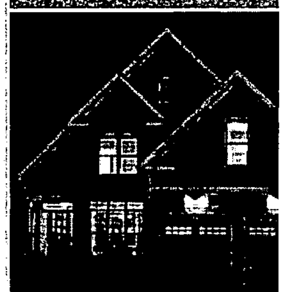
Otter Tail Power Company, lead developer
Central Minnesota Municipal Power Agency
Great River Energy
Heartland Consumers Power District
Missouri River Energy Services
Montana-Dakota Utilities Co
Southern Minnesota Municipal Power Agency

**Project timeline**
While plant construction is contingent on approval of all necessary permits, this is the proposed timeline:

- Initial announcement - October 2004
- Permitting and public comment - Early 2005 through third quarter 2006
- Construction begins - Mid-2008
- Plant commercially available - Mid-2011 to mid-2012

**Project impact**
Big Stone II represents the largest investment of private and public capital ever made in South Dakota. The electricity it produces will flow to customers in Minnesota, North Dakota, South Dakota, and Iowa. During its four-year construction period, the plant would employ an average of 625 construction workers, with a peak workforce of 1,500. Once online, Big Stone II would likely employ 35 to 40 operational workers at the site. Learn more about the project's economic impact.






**Project cost**
Early cost estimates for the power plant were at about $1 billion, with an

additional $200 million for the transmission line project. These costs estimates have increased, however, largely due to higher costs for construction materials and labor. Other factors include market pricing by vendors as well as design changes made by project participants to increase output and improve efficiency. Based on the most recent design refinements, the project, including transmission, is expected to cost $1.6 billion. Efforts continue to maximize efficiencies and minimize costs.

**Advantages of the proposed site**

The South Dakota site has important economic advantages. Otter Tail Power company has operated Big Stone Plant, which it owns jointly with Montana-Dakota Utilities and NorthWestern Energy, for more than 25 years. The site contains much of the expensive infrastructure needed to support a second unit. A well-trained staff is in place, as are a railroad line and a water supply. In addition to having some existing transmission corridors, it's close to load centers where demand is high.

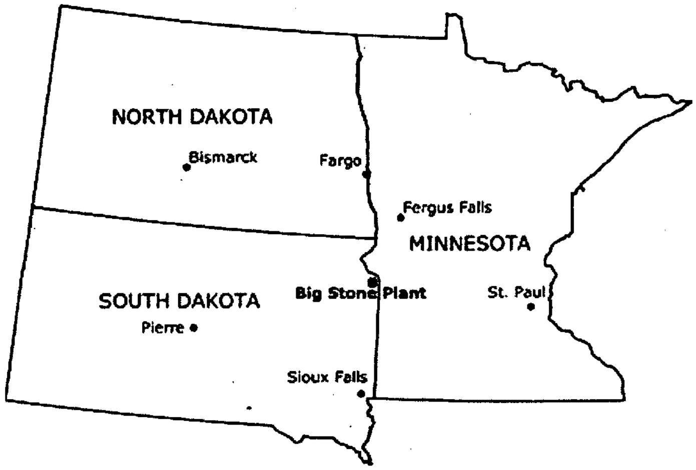
This reduces—by tens of millions of dollars—the expense of building additional transmission from sites farther removed from load centers. Some transmission upgrades or new construction will be necessary to deliver the power generated by the proposed new plant at Big Stone. Also, it is possible that the transmission upgrades could provide opportunities for the development of renewables, such as water, wind, and biomass. The transmission studies will first determine what is needed for the plant, and then what would be available for renewable or other generation. For the transmission project, two corridor options now appear most beneficial. In addition, while Big Stone II's primary fuel source would be Powder River Basin coal, biomass is also being investigated.

The Big Stone site was selected after Burns & McDonnell conducted a study to identify a preferred site, along with alternate sites, for a new coal-fired generating unit.

**Site details**

The existing Big Stone Plant is two miles northwest of Big Stone City, which is near Milbank, South Dakota. The new generator will be located adjacent to the 450-megawatt Big Stone Plant, which began operating in 1975 on the 2,200-acre site.

**Location map:**




**Preliminary artist's rendering:**

ATTACHMENT M1
HILL & ASSOCIATES
"ECONOMIC BENEFITS OF A COAL-FUELED POWER PLANT"
(REPORT PREPARED FOR PEABODY ENERGY)
(NO DATE)

# Hill & Associates

# "Economic Benefits of a Coal-Fueled Power Plant Compared to Natural Gas" (report prepared for Peabody Energy)

## (no date)

# ECONOMIC BENEFITS OF A COAL-FUELED POWER PLANT COMPARED TO NATURAL GAS

**PREPARED FOR**

**PEABODY ENERGY**

# Economic Benefits of a Coal-Fueled Power Plant Compared to Natural Gas

## Summary

Peabody Energy has requested Hill & Associates, Inc to evaluate the potential economic benefits of constructing and operating a large coal-fueled power plant in the Midwest, compared to developing and operating a plant of similar size fueled by natural gas. This report presents the results of our analysis, which shows that coal has a much more favorable economic impact. The numbers presented are representative of the state-wide economic impacts that would be associated with development of a new power plant in any of the several mid-western states that produce coal.

The construction and operation of a coal-fueled power plant in a coal-producing state will bring major economic benefits in terms of jobs created and sales for regional businesses. Constructing a coal-fueled power plant and the associated mine will increase business volume at the state level by $4.5 billion dollars and result in over 20,000 job-years of new employment. Operating the mine and plant over the estimated 40 – 50 year life will lead to an additional $439 million dollars of business volume in the state each year and create almost 2,300 permanent jobs. Much of the economic activity and many of the new jobs will be created indirectly as a result of the expenditures made directly at the power plant and mine.

By contrast, a new gas-fueled power plant of the same size would have only about one third of coal's favorable impact on the economy and regional employment during the construction phase. Gas would also have a less favorable impact during the operating life of the plant because most of the dollars spent for operating the gas plant would probably go out-of-state for purchases of the natural gas. New jobs created by operation of the gas plant would amount to only 38% of the jobs created by the new coal plant and mine.

In addition to the advantages coal offers in terms of project-related spending and employment, the use of coal for power generation also provides broader economic benefits. Because fuel is a major element in the cost of electricity and coal is so much cheaper than gas, the use of coal-fueled generation provides a secure base of low-cost generation for all of the consumers and businesses in the region. Furthermore, low electricity costs will help attract other new business. Appendix A shows the current cost of coal to a mine-mouth power plant in the Midwest is likely to be about $0.70 per million Btu. Based upon the typical performance pattern of an underground mine, these costs are expected to remain approximately constant over the life of the mine. Also, the annual forecast of U.S. steam coal prices prepared by Hill & Associates, Inc. predicts declining coal prices in the Midwest. In contrast, gas prices have recently been higher and are expected to remain far above coal. According to the 2002 edition of the Annual Energy Outlook of the U.S. Energy Information Agency (EIA), the average price for natural gas delivered to U.S. utilities during 2000 and 2001 was almost $4.50 per million Btu. Because the EIA and others forecast the price of gas will average around $3.50 per million Btu (in constant dollars) over the next 20 years, it appears that coal will continue to be a much lower cost fuel than natural gas. These fuel price differences account for the fact that states generating power from gas have the highest electricity prices and states using coal have the lowest electricity prices.

There will also be non-economic benefits derived from a new coal plant. While gas generally offers environmental advantages over coal, it should be noted that a modern coal plant with a high thermal efficiency and equipped with state-of-the-art pollution control equipment will, because of its low operating costs, displace the output of old, small and less well-controlled coal plants that can be significant sources of pollution. The UFEM/NPM model used by Hill & Associates to model coal use and electricity dispatch across the U.S. consistently shows that modern coal plants in the Midwest will force some of the smaller/older plants to be shut down. Thus the environment will gain along with the economy.

## Background and Approach to the Study

This study was prepared by Hill & Associates, Inc., a consulting firm specializing in energy industry economics and markets, with the assistance of the University of West Virginia's Bureau of Business and Economic Research. The two options analyzed were:

1. A 1,500 megawatt coal-fueled power plant equipped with the latest technology for emissions control. The coal for this plant would be supplied by a new mine sited near the power plant.

2. A plant of the same size burning natural gas and utilizing combined cycle technology. In all likelihood, a plant of this size would have to use gas produced outside the region and piped in via the interstate pipeline system.

The study team developed estimates of power plant construction and operating costs and employment from sources such as the Department of Energy, the International Energy Agency, the Electric Power Research Institute and internal company files of mine costs and staffing. These cost estimates were then fed into the IMPLAN model, a widely-used model that provides estimates of the full statewide impact of changes in economic inputs. The IMPLAN model calculates direct, indirect and induced economic activity. These measures capture the "ripple" effect that occurs when one element of new economic activity creates new employment and spending in related areas as well as additional employment and spending in economic sectors not directly related to the one where the initial new expenditures are made. The cost and staffing estimates used as inputs to the IMPLAN model are summarized in Appendix A.

## Estimates of Economic Impacts

The results of the IMPLAN model analysis are shown in Tables 1 - 6 below. Tables 1 and 2 show the economic impacts of a coal-fueled power plant and the mine needed to supply the coal. Tables 3 and 4 show a similar analysis for a gas-fueled plant of the same size. Tables 5 and 6 summarize the differences. In each case, the first table of a pair shows the total life-of-project numbers for the impact of the construction work and the second table shows the annual impacts (in millions of dollars per year and in equivalent jobs) of plant operations.

Before discussing the results as presented in the tables, it will be useful to review a few definitions of the major terms used in the study. These are:

- *Direct Economic Impacts* – The first round of spending on the project.
- *Indirect Impacts* – The second and later rounds of spending by the contractors and sub-contractors.
- *Induced Impacts* – Later rounds of business volume related to the consumption spending by the construction and operating employees of the project.
- *Business Volume* – Sales (or spending).
- *Employment* – Permanent jobs in the operation phase and "Job-years" during the construction phase (a job-year being one person employed for 12 months, two employed for 6 months, etc.)
- *Employee Compensation* – Wages and salaries plus employers' contributions for social security, unemployment insurance, workers' compensation, medical insurance, etc.

A review of the tables below shows the economic benefits of a coal-fueled plant are much greater than gas for the following three reasons:

1. The construction cost for a coal-fueled plant is almost three times that of a plant of the same size fueled by natural gas.
2. Employment at a coal plant and the mine that supplies it will be more than six times the employment at a gas plant.
3. Most of the money spent on fuel supply, which is a power plant's largest operating cost, stays in-state for a coal plant but goes out of the state for a gas plant.

## Table 1
## Economic Impact of a 1500 Mw Coal-Fueled Plant & Mine - Construction Phase

| Type of Impact | Direct Impact | Indirect and Induced Impacts | Total Impact |
|---|---|---|---|
| Business Volume (Sales in millions) | $2,113 | $2,411 | $4,524 |
| Employment (Job-Years) | 6,240 | 14,060 | 20,300 |
| Employee Compensation (millions) | $624 | $391 | $1,015 |
| Assorted State Taxes (Based on Kentucky – in millions) | -- | -- | $57.7 |

## Table 2
## Economic Impact of a 1500 Mw Coal-Fueled Plant & Mine - Operations Phase

| Type of Impact | Direct Impact | Indirect and Induced Impacts | Total Impact |
|---|---|---|---|
| Business Volume (Sales in million $/year | $153.7 | $285.7 | $439.4 |
| Employment (Jobs) | 538 (1) | 1,735 | 2,273 |
| Employee Compensation (million $/yr) | $11.4 | $57.3 | $68.7 |
| Assorted State Taxes (millions) | -- | -- | $4.0 |

1. The 395 employees needed at the coal mine are included here in the "direct impact" column because the power plant and mine will be built and operated together as part of a new business venture.

## Table 3
## Economic Impact of a 1500 Mw Gas-Fueled Plant - Construction Phase

| Type of Impact | Direct Impact | Indirect and Induced Impacts | Total Impact |
|---|---|---|---|
| Business Volume (Sales in millions) | $750 | $855 | $1,605 |
| Employment (Job-Years) | 1,350 | 4,620 | 5,970 |
| Employee Compensation (millions) | $135 | $136 | $271 |
| Assorted State Taxes (millions) | -- | -- | $15.5 |

**Table 4**
**Economic Impact of a 1500 Mw Gas-Fueled Plant - Operations Phase**

| Type of Impact | Direct Impact | Indirect and Induced Impacts | Total Impact |
|---|---|---|---|
| Business Volume (Sales in million $/year) | $52.2 (1) | $92.3 | $144.5 |
| Employment (Jobs) | 78 | 790 | 868 |
| Employee Compensation (million $/year) | $5.8 | $23.3 | $29.1 |
| Assorted State Taxes (millions) | -- | -- | $1.7 |

Note 1. If the majority of expenditures on the natural gas plant were spent in-state, the direct economic impact of the gas plant would be $327.4 million per year. However, an estimated $275.2 million is likely to be spent out-of-state for natural gas, an expenditure that will have no impact within the state.

**Table 5**
**Additional Impacts of Coal (Compared to Gas) - Construction Phase**

| Type of Impact | Direct Impact | Indirect and Induced Impacts | Total Impact |
|---|---|---|---|
| Business Volume (Sales in millions) | $1,363 | $1,556 | $2,919 |
| Employment (Job-Years) | 4,890 | 9,440 | 14,330 |
| Employee Compensation (millions) | $489 | $255 | $744 |
| Assorted State Taxes - millions | -- | -- | $42.2 |

**Table 6**
**Additional Impacts of Coal (Compared to Gas) - Operations Phase - Excluding Out-of-State Purchases of Natural Gas**

| Type of Impact | Direct Impact | Indirect and Induced Impacts | Total Impact |
|---|---|---|---|
| Business Volume (Sales in million $/year) | $101.5 | $193.4 | $294.9 |
| Employment (Jobs) | 460 | 945 | 1,405 |
| Employee Compensation (million $/year) | $5.6 | $34.0 | $39.6 |
| Assorted State Taxes – million $/year | -- | -- | $2.3 |

In summary, these tables show that:

# APPENDIX A

## POWER PLANT and LOCAL COAL MINE COST SUMMARY

| | COAL-FUELED PLANT (PC with wet scrubber) | | | GAS-FUELED PLANT (Combined Cycle) | |
|---|---|---|---|---|---|
| SIZE (MW) | | 1,500 | | | 1,500 |
| CAPACITY FACTOR | | 90.00% | | | 90.00% |
| ANNUAL GENERATION - MWHrs | | 11,826,000 | | | 11,826,000 |
| **TOTAL CAPITAL COST (Millions)** | | $2,000.0 | | | $750.0 |
| OF WHICH: | | | | | |
| Equipment Purchase | 45.00% | $900.0 | | 60.00% | $450.0 |
| Labor & Material | 34.00% | $680.0 | | 23.00% | $172.5 |
| Buildings, Eng.,Land | 14.00% | $280.0 | | 8.00% | $60.0 |
| Sales Taxes, Interest, Other | 7.00% | $140.0 | | 9.00% | $67.5 |
| **Total Coal Plant Capital** | 100.00% | $2,000.0 | **Total Gas Plant Capital** | 100.00% | $750.0 |

**POWER PLANT OPERATING COSTS:**

| | | $/MWHr | $/Year (Millions) | | $/MWHr | $/Year (Millions) |
|---|---|---|---|---|---|---|
| Fuel | @$0.70/mmBtu * | $7.00 | $82.8 | @$3.50/mmBtu | $24.64 | $291.4 |
| O&M, Labor,Services, Other | | $6.00 | $71.0 | | $4.67 | $55.2 |
| **Total Coal Plant Oper. Cost** | | $13.00 | $153.7 | **Total Gas Plant Oper. Cost** | $29.31 | $346.6 |

*$12.52 cost + $4.00 Depreciation and return on capital = $16.52/ton profitable price = $0.70/mmBtu

## APPENDIX A – (Continued)

**COAL REQUIREMENT**

| | |
|---|---|
| Tons/yr Required | 5,011,017 |

**COAL MINE CAPITAL AND PRODUCTION COSTS**

| | | | |
|---|---|---|---|
| **TOTAL CAPITAL COST (Millions)**<br>**At $25/annual ton** | | $125.3 | |
| OF WHICH: | | | |
| Equipment Purchase | 50.00% | $62.6 | 50% in-state |
| Labor | 39.00% | $48.9 | |
| Engineering & Land | 2.00% | $2.5 | |
| Sales Taxes, Interest, Other | 9.00% | $11.3 | |
| Total | 100.00% | $125.3 | |

**COAL MINE PRODUCTION COSTS (all coal supplied by local mine):**

| | **$/Ton** | **$/Year (Millions)** |
|---|---|---|
| Labor & Benefits | $4.15 | $20.8 |
| Supplies & Parts | $4.20 | $21.0 |
| State & Local Taxes, Royalties | $1.92 | $9.6 |
| Admin. Costs | $0.95 | $4.8 |
| Fed Taxes | $1.30 | $6.5 |
| Total | $12.52 | $62.7 |

| **EMPLOYMENT:** | **COAL:** | | | **GAS:** |
|---|---|---|---|---|
| | **PLANT** | **MINE** | **TOTAL** | **PLANT** |
| Construction (Job-Years)<br>(at $100,000/const. Worker yr) | 5800 | 439 | 6239 | 1350 |
| Operations (No. Employees) | 143 | 395 | 538 | 78 |

# Portland General Electric

# "Frequently Asked Questions about Port Westward Power Plant"

# 2005



# Port Westward

**Announcements and progress reports about construction of Port Westward Power Plant**

- **Construction update**

Construction is near completion at PGE's new Port Westward Generating Plant, which will begin commercial operations in spring of 2007. It will be the most efficient natural gas-fired generator of its type in the West, providing enough electricity to power about 300,000 homes.

Port Westward will be powered by a Mitsubishi "G1" class combustion turbine, which is more efficient than the more common "F" class technology.

The new Port Westward Power Plant is Columbia County's first major industrial construction project in recent years. At the height of construction in the summer of 2006, up to 400 people were working at the site, many of them residents of nearby communities.

- **Project timeline**
- **Construction firms working on Port Westward**
- **Photo and video gallery**
- **"Frequently Asked Questions"**

The Port Westward site is located at 81566 Kallunki Road in Clatskanie. As we continue with construction, you may have questions, so PGE has created a special phone line just for this project. Feel free to call our toll-free number, 866-337-9905 any time of day, and a staff person will call you back as soon as possible.

### *Port Westward*

Port Westward will be the most efficient plant of its type in the West.

It will produce enough power for about 300,000 homes.

Commercial operations will begin in spring of 2007.

Port Westward is sited next to PGE's Beaver Generating Plant, which has been in operation since 1974.

A new radial or generation lead has been built to PGE's Trojan switchyard to move the power to PGE's distribution system.

Port Westward will provide about 17 permanent jobs.

Port Westward is just one part of PGE's overall resource strategy in its Integrated Resource Plan.

ATTACHMENT M3
PORTLAND GENERAL ELECTRIC
NEWS ROOM
"PORTLAND GENERAL ELECTRIC ANNOUNCES PORT WESTWARD PLANT
AVAILABLE FOR COMMERCIAL GENERATION"
(JUNE 12, 2007)

# Portland General Electric

# News Room

# "Portland General Electric Announces Port Westward Plant Available For Commercial Generation"

# June 12, 2007

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# News Room

June 12, 2007

**Portland General Electric Announces that its Port Westward Plant is Available for Commercial Generation**

Portland, Ore. — Portland General Electric Company (NYSE: POR) today announced that its Port Westward Generating Plant, a new 400 megawatt natural gas-fired power plant located near Clatskanie, Ore., is available for commercial generation. The plant is owned and operated by PGE, and is the first major new generating plant placed into service by the company since 1995. It has the capacity to serve approximately 300,000 homes.

"Port Westward is an important resource that will help meet our customers' current and future energy needs," said Peggy Fowler, CEO and President of PGE. "We're extremely pleased to have brought it online, on-budget and just in time to help meet customer demand during the hot summer months."

Fowler noted that the project required close collaboration between PGE, Black & Veatch Construction, Inc., Mitsubishi Power Systems, Inc., and Oregon regulators. Black & Veatch served as general contractor for the project. Mitsubishi Heavy Industries, Ltd. manufactured and supervised installation of the plant's turbines.

Port Westward will help reduce PGE's dependence on power purchases in the wholesale energy market. The plant serves as an important component of the company's diversified portfolio of energy resources, complementing new wind generation that PGE expects to bring online later this year with completion of the first phase of its Biglow Canyon wind farm in Sherman County. The Port Westward plant's state-of-the-art G-class turbine makes it one of the most efficient combined-cycle natural gas-fired generating plants in the United States.

The plant was completed on budget under fixed-price contracts, with final construction costs expected to be between $280 million and $290 million. Certification of commercial availability came just one month later than the May 2007 date that was initially projected when contracts were signed and engineering work started in October 2004. The plant successfully completed all required performance and functional testing before PGE took possession.

Earlier this year, the Oregon Public Utility Commission approved a price increase of 2.8 percent, to take effect when Port Westward became fully operational. The increase covers capital and operating costs of the new plant. PGE has submitted a tariff filing with the OPUC requesting that the increase be effective June 15, 2007.

###

About Portland General Electric

Portland General Electric, headquartered in Portland, Ore., is a fully integrated electric utility that serves more than 796,000 residential, commercial and industrial customers in Oregon.

Safe Harbor Statement

Statements in this news release that relate to future plans, objectives, expectations, performance, events and the like may constitute "forward-looking statements" within the meaning of the Private Securities Litigation Reform Act of 1995, Section 27A of the Securities Act of 1933, as amended, and Section 21E of the Securities Exchange Act of 1934, as amended.

Portland General Electric Company based these forward-looking statements on its current expectations and projections about future events in light of its knowledge of facts as of the date of this current report and its assumptions about future circumstances. Forward-looking statements in this news release include statements regarding the ability of Port Westward to help meet customer demand and reduce the company's dependence on power purchases in the wholesale energy market and statements regarding the expected effective date of the rate increase. Investors are cautioned that any such forward-looking statements are subject to risks and uncertainties, including actions by the OPUC and changes in power market conditions. As a result, actual results may differ materially from those projected in the forward-looking statements. The Company assumes no obligation to update any such forward-looking statement. Prospective investors should also review the risks and uncertainties listed in the Company's most recent Annual Report on Form 10-K and the Company's reports on Forms 8-K and 10-Q filed with the United States Securities and Exchange Commission, including Management's Discussion and Analysis of Financial Condition and Results of Operation and the risks described therein from time to time.

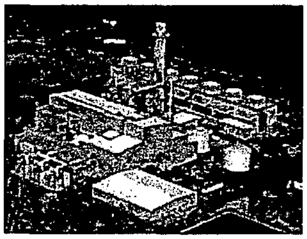
POR-F

Source: Portland General Electric Company

For more information, contact:
Steve Corson, PGE, 503-464-8444

# Port Westward

**Port Westward Plant serves more than 300,000 homes.**



Video: Watch the plant get built in 51 seconds. Windows Media Player

PGE's natural gas-fired power plant in Columbia County went online June 2007. A key part of PGE's diverse mix of generating resources, it produces enough energy to serve about 300,000 homes. About 17 workers operate the plant.

Powered by a state-of-the-art Mitsubishi G-class combustion turbine, the 400-megawatt Port Westward Generating Plant is one of the most efficient combined-cycle natural gas-fired generating plants in the world.

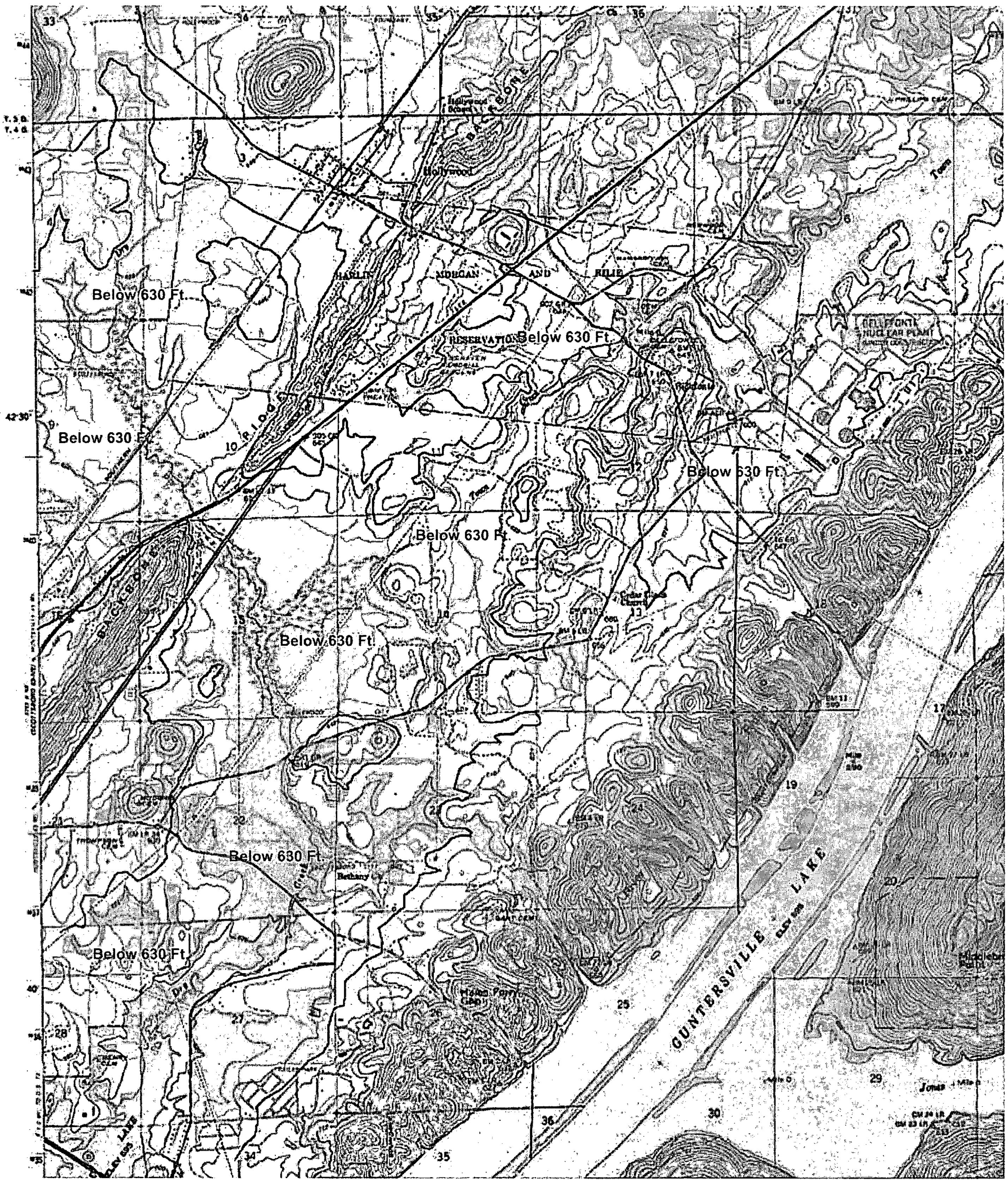
Port Westward emission levels for nitrous oxide and carbon monoxide are below the strict requirements of the Oregon Department of Environmental Quality.

Thanks in part to fixed-bid construction contracts, Port Westward was completed on budget. It is owned and operated by PGE. Check out **photos of the plant**.

# Tennessee Valley Authority

# Topographical Map Showing Dry Creek Basin and 630 Ft. Elevation Contour

## May 2008




**Topographical Map Showing Dry Creek Basin and 630-Ft. Elevation Contour**