Appendix A: Study Details

Contractor

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Objectives

- Research, assess, and evaluate the current status, strategies, policies, and future plans of governments, major energy companies, major motor vehicle manufacturers, and developers of key components of fuel cells designed for use in motor vehicles in countries outside the United States;
- Attempt to measure the technical progress of companies in international markets against DOE's targets and goals; and
- Assess the commercialization plans of companies and government programs to support commercialization and evaluate them against the team's own experience and expertise.

Approach

- Step 1. Review existing and/or ongoing studies and available information on the status of development in major international markets. Define parameters of survey and develop criteria for selecting participants.
- Step 2. Develop lists of potential respondents. Build separate lists for each sector to be surveyed: automobile manufacturers, major component companies, energy corporations, and governments. Divide lists by region (Japan/South Korea, China/Taiwan, Western Europe, Canada, and other).

Divide lists by survey method (site visit, phone interview, mailed questionnaire).

- Step 3. Develop survey instruments/interview guides. Create separate questionnaires for each sector and each method (12 questionnaires total).
- Step 4. Conduct site visits. Form four teams, each led by a consultant accompanied by DOE personnel, to visit top priority companies and government officials in July 2002.
- Step 5. Refine lists and contact phone and mail respondents. Provide up-to-date written DOE briefing to each respondent. Follow up to get maximum participation.
- Step 6. Write draft report.
- Step 7. Produce final report.

Accomplishments

- Literature search was completed. Lists were created by sector and region; survey instruments were developed for each sector and method of contact.
- Site visits were conducted in Germany, the UK, Italy, South Korea, Japan, eastern and western Canada, and China.
- Survey instruments were revised on the basis of site visits. The number of open-ended questions was reduced to make responding by phone or mail easier and less time consuming. A document summarizing current U.S. government activities on fuel cells was created to provide phone and mail respondents with something in return for their participation.
- Phone interviews were conducted and mail surveys distributed and collected, with follow-up calls to assure maximum possible participation.
- Responses from site visits were analyzed.
- Report was produced and circulated.

Time Table

November 2000	DOE issues RFP for
September 2001	Cooperative Agreement signed with BTI
March 2002	Statement of work revised
July 2002	Site visits begin
September 2003	Data collection concludes
September 2003	Statement of work revised to reflect results of questionnaires
December 2003	Report submitted to DOE for approval

Significant contributions to the text were made by Kathryn Schein, Jennifer Gangi, and William Vincent.

Discussion

The Breakthrough Technologies Institute, Inc., entered a cooperative agreement with the U.S. Department of Energy in 2002 to facilitate site visits and conduct a survey of fuel cell vehicle developers, selected energy and component suppliers, and interested government agencies. Our purposes were to:

- Research, assess, and evaluate the current status, strategies, policies, and future plans of governments, major energy companies, major motor vehicle manufacturers, and developers of key components of fuel cells designed for use in motor vehicles in countries outside the United States.
- Attempt to measure the technical progress of companies in international markets against DOE's targets and goals.
- Assess the commercialization plans of companies and government programs to support commercialization.

The goals of the Fuel Cell Vehicle World Survey were revised twice to reflect the results of project outreach activities and the fast-changing fuel cell vehicle landscape. Originally, the goals were quite technical, but as the project progressed, the focus became more strategic.

The result is this snapshot of fuel cell motor vehicle development and major vehicle demonstrations around the globe. We hope it is useful for U.S. policy makers tracking the worldwide race to commercialize fuel cells and for U.S. companies interested in participating in the coming hydrogen economy.

This is an extremely fast-paced arena. New vehicles are being unveiled and component announcements made at an extraordinary rate. We have made every effort to provide timely and up-to-date information. We welcome corrections, additions, and comments.

The project attempted to gather as much information as possible directly from automobile manufacturers, fuel cell component companies, major energy companies, and governments. There are hundreds, if not thousands, of companies throughout the world working on some aspect of vehicular fuel cell development. The number of governments making significant investments in the development of fuel cells is increasing. To help us reach as many companies as possible, BTI contracted with several consultants, each knowledgeable in a particular region of the world. Extensive additional research was required to assure that BTI adequately surveyed the field.

Three survey methods were chosen: site visits, phone interviews and mailed questionnaires. Generally, BTI selected companies that were large enough, well-financed enough, or innovative enough to likely play a significant role in the development and/or eventual commercialization of fuel cell automobiles or buses.

One of the early challenges to the study's success involved motivating potential respondents to participate. BTI, in consultation with DOE, decided that priority participants would appreciate a briefing by DOE officials in conjunction with a site visit. The event would be viewed as an exchange of useful information by all those participating. Site visits were designed to be led by a consultant accompanied by DOE officials.

To encourage the participation of phone and mail respondents, a briefing paper outlining the current U.S. government approach to and initiatives supporting fuel cells for vehicular use was prepared for distribution.

We conducted a total of 53 site visits involving consultants and DOE representatives. Site visits were considered useful to both BTI and DOE personnel and the respondents. Meetings were held in Italy; Germany; the UK; China; Japan; South Korea; and Ottawa and Vancouver, Canada, and averaged two to three hours in length.

We distributed more than 150 questionnaires and made hundreds of telephone calls and additional site visits. Companies responding range widely in capitalization levels and workforce sizes.

Although some companies refused to participate in the study, many respondents were willing to discuss their business activities and their views on fuel cell development and the eventual commercialization of fuel cell vehicles as long as they were assured that their responses were not attributable. There was a greater reluctance to share technical data. We found similar attitudes in our telephone surveys and follow-up consultant visits. Overall, participants were extremely reluctant to share performance data and business projections.

Appendix B: Organizations Visited

Canada

Ballard
Fuel Cells Canada
Hydrogenics Corporation
Membrane Reactor Technology
Methanex
National Research Council
Natural Resources Canada
Questair
SMC Pneumatics
Stuart Energy
Xantrex

Europe

BadenWuerttemburg FC Initiative
BP
Ceres Power
DaimlerChrysler & Evo Bus
Forschungszentrum Julich
FuMa Technology
German Ministry of Economics and Technology
Greater London Authority
Intelligent Energy
Johnson Matthey
Linde
Lombardy regional government
MAN Nutzfahrzeuge
North Rhine Westfalia Fuel Cell Initiative
Nuvera/DeNora
OMG
Schunk Kohlenstofftechnik
SGL Carbon Group
Shell
Stuttgart Regional Economic Development Corporation (WRS)
UK Department of Trade and Industry
UK Department for Transport, Local Government and Regions

Japan

Fuel Cell Commercialization Conference of Japan (FCCJ)/Advancement Association of Japan (ENAA)
Fuel Cell Development Information Center (FCDIC)
Honda R & D Co., Ltd.
Honda Energy Systems Society (HESS)
Hydrogen Energy Systems Society and Engineering
Iwatani Corporation
Japanese Electric Vehicle Association
METI
Osaka Gas
Shell Hydrogen
Shikoku Research Institute

South Korea

Hyundai Motor Company
Korea Electric Power Corporation (KEPCO)
Korea Institute of Energy Research
Korea Institute of Science and Technology
LG Chemical
SK Corporation

Appendix C: Organizations Surveyed via Telephone, E-mail, and/or Mail

Telephone Interviews

Canada

BC Hydro
Cellex Power Products, Inc.
Chrysalix Energy Ltd.
Dynetek
Fuel Maker Corp.
General Hydrogen Corporation
GFI Control Systems, Inc.
Global Thermoelectric
Hera Hydrogen Storage Systems, Inc.
Pathway Design and Manufacturing

Europe

Air Liquide
BMW
"Club PAC"
European Union (special circumstances)
French government: Reseau PACo
Hydrogen Systems/Vandenboore Technologies
Irisbus
Ludwig-Bolkow-Systemtechnik GbmH
Morgan Fuel Cells
Norsk Hydro
Peugeot/Renault
Stat Oil
Sud Chemie
TOTAL/Fina-Elf
Vitrex plc.
Volvo
VW

Japan

Fuji Heavy Industries
Hino Bus — declined
Isuzu Advanced Engineering Center
Japan Steel Works

Japan Metals and Chemicals
Marubeni — spoke with U.S. rep.
Mazda — declined
Mitsubishi Heavy Metal Industries, Ltd. — declined
Mitsubishi Motors – e-mailed; no response
New Energy and Industrial Technology Development Organization — no response
Nippon Mitsubishi Oil — no English
Nissan Motors
Tokyo Gas
Toshiba International Fuel Cells Corporation — declined
Toyota Motor Corporation

E-Mailed Questionnaires

Canada

Canadian Hydrogen Association
Coast Mountain Bus Company — declined
Crystal Graphite Corporation
Energy Visions, Inc.
Greenlight Power Technologies, Inc.
Hydrogen Systems, Inc.
Hydro Quebec Research Institute
Palcan Fuel Cells Limited
Pivotal Power, Inc.
Technologies M4, Inc.
Westaim Ambeon

Europe

BASF
DaimlerChrysler (special circumstances)
Danish Energy Agency
Haldor Topsoe
Helion
Italian Ministry for the Environment
Nedstack BV
Netherlands Agency for Energy and Environment
Proton Motors
P21
Paul Scherrer Institute

Japan

Asahi Glass Co. Ltd.
Asahi Chemical Industry Company
Equos Research Co., Ltd.
Ishikawajima-Harma Heavy Industries
Japan Automobile Research Institute
Kogakuin University-KUCEL
Kosan Company
Mihama Corporation
Suzuki
Three Bond Co., Ltd.
Toho Gas
Tonen
Toray Industries, Inc.
Yamaha Motor Company, Ltd.

South Korea

HankookBEP Co. Ltd.
Korea Automotive Technology Institute
Seoul National University

Both Telephone and E-Mailed Questionnaires

China

Beijing Fuyuan Century Fuel Cell Power, Inc.
Beijing LNpower Company
China Association for Hydrogen Energy
China FAW Group Corporation (Changchun Yiqi)
Dalian Institute of Chemical Physics, Chinese Academy of Sciences
Economic Commission, Shanghai Municipal Government
General Research Institute for Nonferrous Metals
God Power Fuel Cell Corp.
Shanghai Automobile Industry Corp.
Shanghai Chemical Engineering Academy
Shanghai GM Automobile Corporation
Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences
Shanghai Jiaotong University
Shanghai Metallurgical Research Institute
Suzhou Machinery Holding (Group) Co., Ltd.
The Center of Automotive Engineering, Tongji University
The Ministry of Science and Technology (MOST)
The Science and Technology Commission, Beijing Municipal Government
The Science and Technology Commission, Shanghai Municipal Government
Tsinghua University

Taiwan

Asia Pacific Fuel Cell Technology Corporation
China Association for Intelligent Transportation Systems
Chinese Petroleum Corp
Department of Engineering and Applied Science, National Science Council
Energy Commission, The Ministry of Economic Affairs
Environmental Protection Agency
EVT Electrical Scooter Corp.
Industrial Technology Research Institute
Jemmytex International Corporation
Research Institute for Energy and Resources
R.O.C. Transportation Association
San Fu Chemical
Taipei Fuel Cell Foundation
Taiwan Fuel Cell Partnership
Taiwan Intelligent Transport System Association
Taiwan Transportation Vehicle Manufacturers Association

Glossary

ACTIVATION. Chemical. Treatment of a substance by heat, radiation, or other activating reagent to produce a more complete or rapid chemical or physical change. Electrical. The process of treating a cathode to increase its rate of reduction.

AIR. The mixture of oxygen, nitrogen, and other gases that, with varying amounts of water vapor, forms the atmosphere of the earth. Also referring to any or all air for combustion, heating, cooling, ventilation, and other uses as follows:

> Ambient — Air that surrounds the equipment; Atmospheric — Air under the prevailing atmospheric conditions.
>
> Recirculated — Air removed from a space and intended for reuse as supply air; Supply — That air delivered to each or any space in the system or the total delivered to all spaces in the system.

ALKALINE FUEL CELL (AFC). A type of hydrogen/oxygen fuel cell in which the electrolyte is concentrated KOH (35–50%, a liquid) and hydroxide ions (OH^-) are transported from the cathode to the anode. Temperature of operation is typically in the range of 60–90ºC.

ANODE. The electrode in a fuel cell where electrons are produced.

AUXILIARY POWER. Power from an independent source that functions as required to augment/support various performance criteria established for the prime power source.

BALANCE-OF-PLANT. Supporting/auxiliary components, based on site-specific requirements and integrated into a comprehensive power system package centered around the power source.

BIPOLAR PLATES. Conductive plate in a fuel cell stack that acts as an anode for one cell and a cathode for the adjacent cell. The plate may be made of metal or a conductive polymer (which may be a carbon-filled composite). The plate usually incorporates flow channels for the fluid feeds and may also contain conduits for heat transfer.

BLOWER. A fan used to force air and/or gas under pressure.

BRITISH THERMAL UNIT. The mean British Thermal Unit (BTU) is 1/180 of the heat required to raise the temperature of one pound (1 lb) of water from 32ºF to 212ºF at a constant atmospheric pressure. It is about equal to the quantity of heat required to raise one pound (1 lb) of water 1ºF.

BURNER. A device for the final conveyance of the gas, or a mixture of gas and air, to the combustion zone (also see Main Burner).

CATALYST. A chemical substance that increases the rate of a reaction without being Consumed; after the reaction, it can potentially be recovered from the reaction mixture chemically unchanged. The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature.

CATALYST-COATED MEMBRANE (CCM). Term used to describe a membrane (in a PEM fuel cell), the surfaces of which are coated with a catalyst/carbon/binder layer. (See also Membrane Electrode Assembly [MEA].)

CATALYST LOADING. The amount of catalyst incorporated in the fuel cell per unit area. Typical units for PEMFC are mg/cm^2.

CATHODE. The electrode in a fuel cell where electrons are consumed.

COMBUSTION. The rapid oxidation of fuel gases accompanied by flame and the production of heat or heat and light.

COMPRESSOR. A device used for increasing the pressure and density of gas.

CONDENSATE (CONDENSATION). The liquid that separates from a gas (including flue gases) as a result of a reduction in temperature.

CONTROLS. Devices designed to regulate the gas, air, water, or electrical supplies to the controlled equipment. These may be manual, semi-automatic, or automatic.

CONVECTION. Stirring or hydrodynamic transport. Generally, fluid flow occurs because of natural convection (convection caused by density gradients) and forced convection and may be characterized by stagnant regions, laminar flow, and turbulent flow.

CURRENT DENSITY. A vector-point function describing the magnitude and direction of charge flow per unit area, generally expressed in amperes per square meter.

DESULFURIZER. A component for removing sulfur from a fuel mixture.

DIFFUSION. Movement of a species under the influence of a gradient of chemical potential (i.e., a concentration gradient).

DIRECT INTERNAL REFORMING. Production of a desired product (hydrogen) within a fuel cell from a hydrocarbon based fuel (methanol, gasoline, etc.) fed to the fuel cell or stack.

DIRECT METHANOL FUEL CELL (DMFC). A type of fuel cell in which the fuel is methanol (CH_3OH), in gaseous or liquid form. The methanol is oxidized directly at the anode with no reformation to hydrogen. The electrolyte is typically a PEM.

DISTILLATE. A product formed by heating a liquid in a vessel and collecting and condensing the resulting by-product(s).

EFFICIENCY. A measure (usually a ratio) of the useful energy provided by a dynamic system versus the total energy supplied to it during a specific period of operation.

ELECTRICAL EFFICIENCY. The ratio of useful electrical real power output to the total electrical power input.

ELECTRODE. An electric conductor through which an electric current enters or leaves a medium, whether it be an electrolytic solution, solid, molten mass, gas, or vacuum.

ELECTRODE ASSEMBLY. The portion of an automatic ignition system containing the electrode(s) and associated insulators, wire lead terminals, spark gap adjustment means, and mounting brackets.

ELECTROLYTE. A nonmetallic insulating material in which current flow in an external circuit is made possible by the movement of ions through the electrolyte.

EXHAUST HEAT. Waste heat produced by a mechanical, chemical, or electrochemical process.

EXHAUST HEAT RECOVERY. The use of by-product heat as a source of energy.

EXTERNAL REFORMING. The production of hydrogen from a hydrocarbon fuel (methanol, gasoline, etc.) prior to entry to the fuel cell or stack.

FAN. A device consisting of a rotor and housing for moving air or gas at relatively low pressure differentials.

FLUE GASES. Products of combustion plus excess air in appliance flues or heat exchangers.

FLUE LOSSES. The sensible heat and latent heat above ambient temperature of the flue gases leaving gas utilization equipment.

FUEL CELL. An electrochemical device that can continuously convert the chemical energy of a fuel and an oxidant to electrical energy. The fuel and oxidant are typically stored outside of the cell and transferred into the cell as the reactants are consumed.

GAS. Fuel gas, such as natural gas, undiluted liquefied petroleum gases (vapor phase only), liquefied petroleum gas-air mixtures, or mixtures of these gases.

GAS TURBINE. A turbine rotated by expanding gases.

GROSS POWER. The fundamental power output of an energy source prior to any conditioning and losses associated with the production of power suitable for the connected load.

HEAT EXCHANGER. A vessel in which heat is transferred from one medium to another.

HYDROCARBON. A chemical compound of hydrogen and carbon, such as methane, propane, butane, etc.

IMPURITIES. Undesirable foreign material(s) in a pure substance or mixture.

INDIRECT INTERNAL REFORMING. The reformer section is separated, but adjacent to, the fuel cell anode. This cell takes advantage of the close coupled thermal benefit where the exothermic heat of the cell reaction can be used for endothermic reforming reaction.

INTERCOOLER. A heat exchanger for cooling gas between stages of a multistage compressor with a consequent saving in power.

IR LOSS. In an electrolytic cell, the loss equal to the product of the current (I) passing through the cell and the resistance (R) of the cell. Also referred to as IR drop.

I2R LOSS. Power loss due to the current (I) flow through the resistance (R) of a conductor.

LOAD-FOLLOWING. A mode of operation where the fuel cell power plant is generating variable power depending on the AC load demand.

LOW EMISSION VEHICLE (LEV). LEV, Low Emission Vehicle, referring to those light-duty passenger vehicles that meet LEV emission control standards. California's Air Resources Board and the federal EPA set standards for tailpipe emissions and air emissions related to the volatility of fuel used in passenger cars and light trucks. California has established several categories of vehicles, on the basis of the maximum permitted emissions of several pollutants. (See chart below.) In addition, California has a credit program called PZEV (Partial ZEV) designed to stimulate sales of vehicles with Zero Emission Vehicle characteristics. California has also established a fleet-wide emission control requirement.

California LEV II Light-Duty Vehicle Standards			
	Vehicle Emission Category (grams/mile)		
	NMOG	Carbon Monoxide	Oxides of Nitrogen
TLEV	0.156	4.200	0.600
LEV	0.090	4.200	0.070
ULEV	0.055	2.100	0.070
SULEV	0.019	1.000	0.020

MAIN BURNER. A device or group of devices essentially forming an integral unit for the final conveyance of gas or a mixture of gas and air to the combustion zone and on which combustion takes place to accomplish the function for which the equipment is designed.

MANIFOLD. The conduit of an appliance that supplies gas to the individual burner.

MEANTIME BETWEEN FAILURES. The mean exposure time between consecutive failures of a component. It can be estimated by dividing exposure time by the number of failures in that period, provided that sufficient number of failures has occurred in that period.

MEAN TIME TO REPAIR. The time interval (hours) that may be expected to return a failed equipment to proper operation.

MEMBRANE. The separating layer in a fuel cell that acts as electrolyte (a cation-exchanger), as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

MEMBRANE ELECTRODE ASSEMBLY (MEA). Structure consisting of a proton-exchange membrane with surfaces coated with catalyst/carbon/binder layers and sandwiched by two microporous conductive layers (which function as the gas diffusion layers and current collectors).

MOLTEN CARBONATE FUEL CELL (MCFC). A type of fuel cell consisting of a molten electrolyte of Li_2CO_3/Na_2CO_3 in which the species CO_3 2- is transported from the cathode to the anode. Operating temperatures are typically near 650ºC.

NAPHTHA. An artificially produced petroleum or coal tar fraction with a volatility between gasoline and kerosene.

NATURAL GAS. A naturally occurring gaseous mixture of simple hydrocarbon components (primarily methane) used as a fuel for the production of electrical power.

NERNST POTENTIAL. An electrode potential corresponding to the reversible equilibrium between hydrogen gas at a certain pressure and the corresponding level of hydrogen ion activity.

OXYGEN-TO-CARBON RATIO. The ratio of the number of oxygen atoms to the number of carbon atoms in the fuel (e.g., methanol would have a ratio of 1, ethanol would have 0.5).

PARTIAL OXIDATION. Fuel reforming reaction in which the fuel is partially oxidized to carbon monoxide and hydrogen rather than fully oxidized to carbon dioxide and water. This is accomplished by injecting air with the fuel stream prior to the reformer. The advantage of partial oxidation over steam reforming of the fuel is that it is an exothermic reaction rather than an endothermic reaction and therefore generates its own heat.

PHOSPHORIC ACID FUEL CELL (PAFC). A type of fuel cell in which the electrolyte consists of concentrated phosphoric acid (H_3PO_4), and protons (H+) are transported from the anode to the cathode. The operating temperature range is generally 160–220ºC.

POLARIZATION CURVE. Typically a plot of fuel cell voltage as a function of current density (V vs. A/cm^2 or similar units). The curve is obtained under standard conditions so that fuel cell performance can be compared between different cell designs and may be obtained by either a single cell or a stack test.

POWER CONDITIONING. The subsystem that converts the dc power from the (fuel cell) stack subsystem to ac power that is compatible with system requirements.

POWER DENSITY. (kW/liter) In the context of a single cell, the power density is often measured in terms of power/unit area of active cell (e.g., kW/m^2); in the context of a complete cell stack, the power density could also be defined in terms of power/unit stack volume (e.g., kW/m^3).

PREFERENTIAL OXIDATION. A reaction that oxidizes one chemical rather than another. In fuel cells, the reaction is used to preferentially oxidize carbon monoxide from the reformate stream after the water-gas shift reactor and before the fuel cell. Same as selective oxidation.

PRESSURE. The force exerted against an opposing body or the thrust distributed over a surface, expressed in weight per unit of area. Absolute — The pressure above zero pressure, the sum of the atmospheric and gauge pressures. Atmospheric (Standard) — The pressure of the weight of air and water vapor on the surface of the earth at sea level, namely 29.92 inches (760 mm) mercury column or 14.69 pounds per square inch (101.3 kPa). Barometric — The atmospheric pressure as determined by a barometer, usually expressed in inches (mm) of mercury. Gauge — The pressure above atmospheric pressure. Vacuum — Any pressure less than that exerted by the atmosphere.

PROTON EXCHANGE MEMBRANE (PEM). The separating layer in a PEM fuel cell that acts as an electrolyte (which is proton conducting), as well as a barrier film separating the hydrogen-rich feed in the cathode compartment of the cell from the oxygen-rich anode side.

PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC or PEFC). A type of fuel cell in which the exchange of protons (H+) from the anode to the cathode via a membrane is involved in the chemical reaction producing electricity. The electrolyte is a called proton exchange membrane (PEM). The fuel cells typically run at low temperatures (<100ºC) and pressures (< 5 atm).

REACTION RATE. A measure of the speed of a chemical reaction. The reaction rate depends on the rate constant, the number of reactants involved in the reaction, and their concentration. For reactions that are otherwise slow, a catalyst is employed to increase the reaction rate.

REFORMER. A vessel within which fuel gas and other gaseous recycle stream(s) (if present) are reacted with water vapor and heat, usually in the presence of a catalyst, to produce hydrogen-rich gas for use within the fuel cell power plant.

REFORMATE GAS. The fluid that exits the fuel reformer and acts as feed to the fuel cell stack.

REFORMING. The thermal or catalytic conversion of petroleum naphtha into more volatile products with higher BTU ratings.

REVERSIBLE FUEL CELL. A type of fuel cell in which the chemical reactants undergo reversible reactions, such that the cell may be recharged with a separate power source if desired. For example, the hydrogen/oxygen fuel cell may be recharged by providing power for water electrolysis with hydrogen storage. Also called Regenerative Fuel Cell.

SERIES CONNECTION. The connection of electrical cells in a positive to negative pattern such that individual cell voltages are additive.

SHIFT CONVERSION. The reaction of CO and water to hydrogen and carbon dioxide. This process is performed immediately after the reformer and before the preferential oxidizer and reduces CO from approximately 10% down to 0.5% to 0.1% usually through a water-gas shift reaction.

SOLID OXIDE FUEL CELL (SOFC). A type of fuel cell in which the electrolyte is a solid, nonporous metal oxide, typically ZrO_2 doped with $Y2O_3$, and O_2- is transported from the cathode to the anode. Any carbon monoxide (CO) in the reformate gas is oxidized to carbon dioxide (CO_2) at the anode. Temperatures of operation are typically 800–1000ºC.

STACK LIFE. The cumulative period that a fuel cell stack may operate before its output deteriorates below a useful minimum value.

STACK TEST. Experiment where an electrical load is applied to a stack of fuel cells to determine its ability to perform. Normally, the output seeks two pieces of information: First is a current output at a specific cell voltage point; second is a continuous voltage vs. current curve (polarization curve).

STACKING. The process of placing individual fuel cells adjacent to one another to form a fuel cell stack. Normally, the stack is connected in a series.

STEAM REFORMING. A process for separating hydrogen from a hydrocarbon fuel, typically natural gas, in the presence of steam. This is the commonly preferred method of bulk hydrogen generation.

STEAM-TO-CARBON RATIO. The number of moles of water per mole of carbon in either the reformate or the fuel streams. This term is used when steam is injected into the reformate stream for the water-gas shift reaction or into the fuel for steam reforming.

SUBSTACK. Typically a group of stacked fuel cells that makes up the base repetitive unit number of cells per full system stack. Substacks may form an intermediate step in manufacturing and may be used to test new stack concepts prior to scale up to full-size stacks.

TEMPERATURE. A measure of heat intensity. Absolute — The temperature above absolute zero, or temperature plus 273ºC or 459ºF. Ambient — The temperature of the surrounding medium, usually used to refer to the temperature of the air in which a structure is situated or a device operates.

THERMAL EFFICIENCY. Efficiency with which a power source transforms the potential heat of its fuel into work or output, expressed as the ratio of the useful work done by the power source in a given time interval to the total heat energy contained in the fuel burned during the same time interval, both work and heat being expressed in the same units.

THERMAL MANAGEMENT. The directing of heat entering or exiting a system.

TRANSPORTATION. Term applied to the market section that includes light-duty vehicles, buses, heavy-duty vehicles, and off-road vehicles.

TUBULAR CELLS. Fuel cells that are formed in cylindrical fashion and allow fuel and oxidant to flow on the inner or outer surfaces of the pipe.

TURBOCHARGER. A device used for increasing the pressure and density of a fluid entering a fuel cell power plant using a compressor driven by a turbine that extracts energy from the exhaust gas.

TURBOCOMPRESSOR. Machine for compressing air or other fluid (reactant if supplied to a fuel cell system) in order to increase the reactant pressure and concentration.

TURBOEXPANDER. Machine for expanding air or other fluid (reactant if supplied to a fuel cell system) in order to decrease the reactant pressure and concentration. The unit is normally used in conjunction with a compressor to recover unused energy from hot, pressurized gases, thereby reducing the net amount of energy required to power the compressor.

VESSEL, PRESSURE. Containers for the containment of pressure either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or by any combination thereof. Exceptions: vessels having an internal or external operating pressure not exceeding 15 psi (103.4 kPa) with no limitation on size; vessels having an inside diameter, width, height, or cross section diagonal not exceeding six (6) inches (152 mm) with no limitation on length of vessel or pressure.

ZERO EMISSION VEHICLE (ZEV). A vehicle that produces no air emissions from its fueling or operation. California regulations require that in 2003, 10% of the vehicles sold in California by major automakers be ZEV or ZEV-equivalent. California has established a comprehensive program for determining this equivalency. See also LEV.

Conversion Tables

For accuracy, investment and sales figures generally are expressed in local currency. Exchange rates of some major currencies are listed below.

U.S. Dollar Equivalents			
Currency	*Symbol*	*1/1/2003*	*12/1/2003*
One thousand Euro	€	$1,042	$1,196
1 million Yen	¥	$8,420	$9,120
One thousand Canadian Dollars	CAN$	$633	$768
One thousand Australian Dollars	AUS$	$562	$726

Units of Measure
One kilometer (km) = 0.62 miles
One mile (mi) = 1.61 kilometers
One kilogram (kg) = 2.2 pounds
One pound (lb) – 0.45 kilograms
One liter (L) = 0.26 gallons
One gallon (gal) = 3.78 liters

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Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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