Technical Factors Affecting Commercialization of Fuel Cells

Prepared for

PATH

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Washington, DC
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July 16, 2001

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PATH (Partnership for Advancing Technology in Housing) is a new private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve the quality, durability, environmental efficiency, and affordability of tomorrow's homes.

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Acknowledgements
The principal author of this report was Joe Wiehagen with technical and editorial support from Chris Fennell, Bob Fuller, Jamie Lyons and Jeannie Sikora. A special appreciation is extended to the staff of Energy Partners, LLC for their support and review.

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Introduction

The purpose of this report is to identify the technical and building code issues and electric system interconnection choices related to the use of fuel cells in residential buildings. This technical assessment, as a basis for a full residential field evaluation of fuel cell technology, provides background information in the areas of:

- Building codes and standards,
- Home utility supply connections, and
- Options for connection of primary or ancillary electrical supply sources to residential buildings.

Fuel Cell Technology and Types of Fuel Cells[1]

The basic electrical generation concepts used in fuel cells were first discovered in 1839 by Sir William Grove, who concluded in a conversation with Michael Faraday "I cannot but conclude the experiment as an important one…" [October 22, 1842]. Not until the 1960s, however, did the technology undergo serious development for use by the NASA space program. Though many different fuel cell technologies are under development, all are electrochemical devices that convert chemical energy into electrical energy without combustion. Fuel cells can operate using various fuels. When hydrogen and oxygen are used as the primary fuels for the chemical reaction, the byproducts of electrical production are pure water (H_2O) and heat. Fuel cells, which have no moving parts, produce direct current (dc) electricity that may be inverted to alternating current (ac) electricity for use in buildings.

The reactants in the chemical conversion within a fuel cell are hydrogen and oxygen. However, since hydrogen is rarely available in a pure state, it must be extracted from other compounds such as carbon-based fuels like natural gas. In order for fuels other than pure hydrogen (H_2) to be utilized by fuel cells, the fuel must first be processed or reformed into a hydrogen-rich gas mixture. The high-temperature process of reforming produces carbon dioxide and trace amounts of carbon monoxide. These, along with other pollutants, are also produced during combustion of coal, gas or oil for central electricity generation. However, due to the higher efficiency of fuel cell-based power generation, and the ability to locate fuel cells near the load thus avoiding

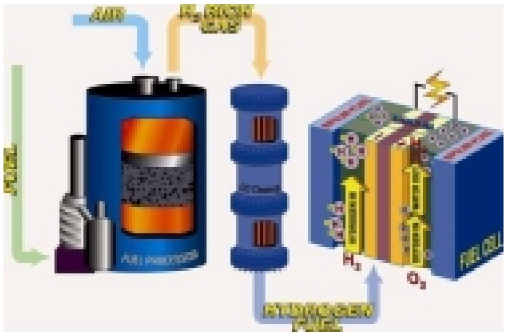

Figure 1: Basic Components of a Fuel Cell

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[1] Descriptions in part from fuel cell manufacturer's internet information sites and the Los Alamos National Laboratory publication, *Fuel Cells – Green Power*.

transmission and distribution losses, the amount of pollutants produced from the reforming process is much less than central generation of electricity.

The primary type of fuel cell being developed for residential buildings is the Proton Exchange Membrane (PEM) fuel cell. PEM fuel cell technology operates at low temperatures and has an efficiency above 40% and often much higher. The basic cell consists of a positive (cathode) and negative (anode) gas diffusion electrode formed by an electrochemically active catalyst layer (typically platinum). The anode and cathode are separated by a solid, ion conducting polymer membrane, which exists in a hydrated state. The electrodes and membrane form a Membrane Electrode Assembly (MEA) which is enclosed between two electrically-conducting, graphite collector plates. Since an individual cell produces less than one volt at full load, cells are stacked in series to produce higher voltage levels. Additional, inactive cells may be added to provide cooling and reactant humidification depending upon the stack's size and application (Figure 1).

Different types of fuel cells are described by their electrolyte and subsequent operating temperature. In the reaction of hydrogen and oxygen in the fuel cell to produce electricity, waste heat is produced. Therefore, the operating temperature is important because the separation of hydrogen from a compound such as natural gas requires high temperature. In some fuel cells, the operating temperature in producing electricity is high enough to simultaneously separate hydrogen from a fuel such as methane. In addition, the higher the operating temperature, the more useful the waste heat, particularly in commercial and industrial applications. Five main types of fuel cells, each suited to particular applications, are being developed:

- Proton Exchange Membrane – Operating at temperatures between 140 °F and 212 °F, this technology has the lowest operating temperatures of any fuel cell system. Applications include stationary and mobile power systems such as for homes and automobiles. Features included a solid electrolyte membrane, quick start-up, and low operating temperatures. Lower temperatures may increase the life of the fuel cell system and require less protective covering than fuel cells that operate at higher temperatures. For homes especially, the waste heat may be used directly.
- Alkaline – These systems use an aqueous electrolyte operating at temperatures slightly higher than PEM units. They are used in outer space applications and feature high performance resulting from a fast chemical reaction time.
- Phosphoric acid – Using a liquid solution of phosphoric acid, these units operate at temperatures between about 350 °F and 400 °F. A primary feature is the option for recovering high temperature waste heat in addition to producing electricity. Waste heat in the form of hot water or steam may be used to generate additional electricity from a turbine (cogeneration).
- Molten Carbonate – The electrolyte combines various elements in solution such as lithium, sodium, or potassium. Operating temperatures range from over 1,000 °F to around 1,800 °F. Primary advantages include the use of high temperature waste heat and the ability to use many different types of fossil fuels directly to extract hydrogen.
- Solid Oxide – Using a solid electrolyte, these units operate with similar temperatures to molten carbonate and have similar benefits. Solid oxide (SO) fuel cells are

generally being developed for larger high-power applications, including buildings, industrial, and large-scale central electrical generation stations. However, smaller units in the 25-kW range are already operating in Japan[2]. Solid oxide fuel cell systems usually employ a hard ceramic material instead of a liquid electrolyte, allowing operating temperatures to reach 1,800 °F. Power generating efficiencies alone can reach 60%, higher efficiencies are possible with the recovery of the high-grade waste heat.

For most fuel cells, the primary fuel is hydrogen. Though abundant, obtaining "free" hydrogen (H_2) is difficult. Hydrogen can be separated from water by electrolysis, or it can be obtained from fossil fuels such as natural gas, methanol, ethanol, propane, or gasoline through a chemical process of reforming. The "reformer" may be an integral part of the fuel cell or a separate component.

Fuel cell technology is developing so rapidly that advances are changing both traditional applications and certain fuel cell operating characteristics such as temperature and pressure. Also, new technologies to extract hydrogen from fossil fuels in the reformer are being implemented. These new technologies make even low temperature fuel cells capable of using two or three different fuel sources.

Residential Fuel Cell Systems

PEM fuel cell technology is viewed as a prime option for use in homes because it has a low operating temperature compared to other fuel cell technologies and is capable of using reformed natural gas as a fuel source. Properties that make PEM fuel cells attractive for residential use include their operation at relatively low temperatures (about 200 °F), a high power density[3], and their ability to handle a rapidly variable output, such as would occur in homes. According to the U.S. Department of Energy (DOE), "[PEM fuel cells] are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries in video cameras."[4] Several manufacturers have developed prototype residential PEM fuel cells that operate on natural gas. This technology is being designed in the range of 2 to 10 kW; typical sizes that match the power needs of residences.

Fuel cell characteristics such as operating temperature, use of fossil fuels, air flow requirements, and byproduct removal are all issues of particular interest when applying fuel cells to residential buildings and therefore must comply with building codes and standards.

Residential fuel cell installation requirements could involve issues, such as:

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[2] Ibid.

[3] Power Density is the power available across an area of fuel cell membrane. Since the membrane must pass the available ions (positive charge) from one side of the membrane to the other (while the negatively charged electron travels through the circuit producing work) the membrane is a limiting factor on how much electricity can be produced.

[4] Extracted from the Fuel Cells 2000 website information (http://216.51.18.233/fctypes.html).

- Operating temperature of components,
- Storage of explosive or combustible fuel, either within the unit or in a separate container or location in or near the home,
- Use of ancillary energy sources, such as batteries,
- Requirements for process air and/or ventilation,
- Requirements for exhaust gases,
- Byproducts of fuel processing (water and heat) and electrical generation,
- Use of electronic equipment to convert electrical output to a form compatible with the building electrical system, and
- Interconnection with other sources of electrical power, such as the utility grid.

These issues are independent of electrical performance issues that involve start-up time, peak load supply, maintenance, service, and replacement.

Overview of Building Codes and Standards[5]

Virtually all regions of the United States are covered by a legally enforceable building code that governs the design and construction of buildings, including residential dwellings. Although building codes are legally a state police power, most states allow local political jurisdictions to adopt or modify national building codes to suit their specific needs or, in a few cases, to write their own code. Usually, jurisdictions adopt one of the major model building codes by legislative action instead of writing their own code.

There are three major model building codes in the United States that are comprehensive; that is, they cover all types of buildings and occupancies–from a backyard storage shed to a high-rise office building or sports complex. These three building codes and contact information for the code writing organizations are:

National Building Code (NBC)
Building Officials and Code Administrators International, Inc. (BOCA)
4051 West Flossmoor Road
Country Club Hills, IL 60478-5795
708-799-2300
www.bocai.org

Standard Building Code (SBC)
Southern Building Code Congress International, Inc. (SBCCI)
9800 Montclair Road
Birmingham, AL 35213-1206
205-591-1853
www.sbcci.org

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[5] Portions of this section are from the *Residential Structural Design Guide*, published by HUD, April 2000.

Uniform Building Code (UBC)
International Conference of Building Officials (ICBO)
5360 Workman Mill Road
Whittier, CA 90601-2298
562-699-0541
www.icbo.com

Although the three model codes have historically competed for adoption by state and local jurisdictions, up until recently they generally served distinct regions, as indicated in Figure 2. Through their development, the model codes tended to address conditions typical of the geographic area in which they were applied. For example, the NBC tends to address conditions indigenous to the northeastern quarter of the United States (e.g., frost), while the SBC focuses on conditions in the southeastern quarter of the United States (e.g., hurricanes), and the UBC addresses conditions common to the western half of the United States (e.g., earthquakes).

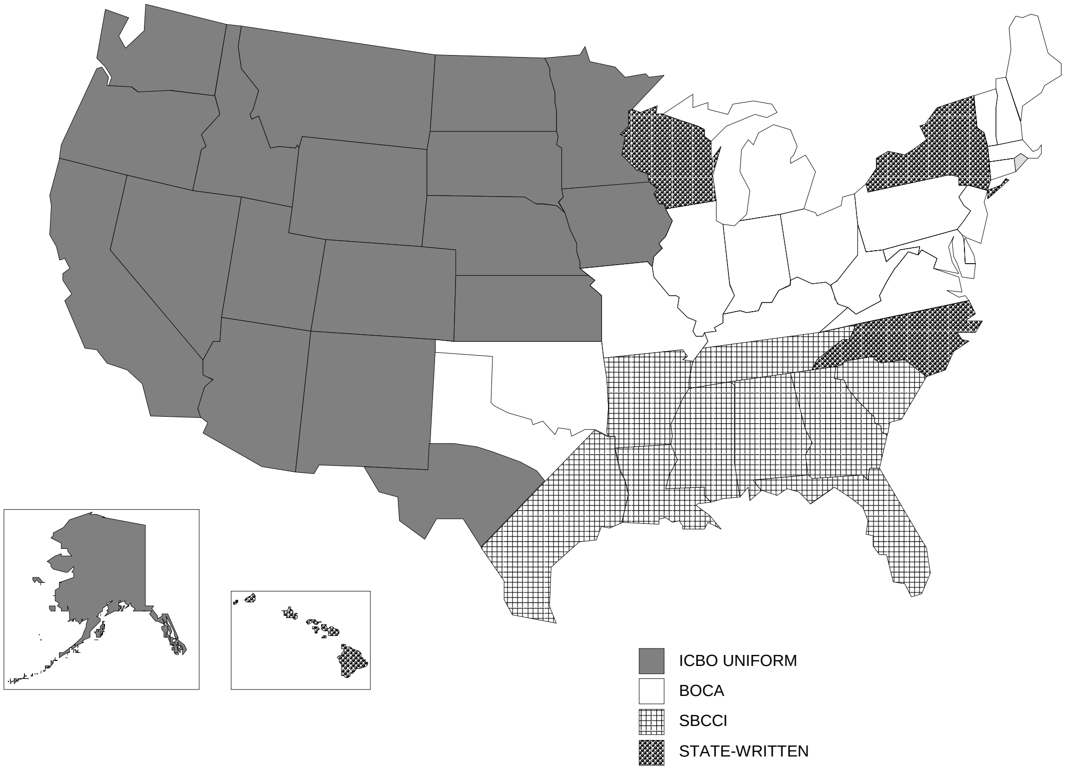

Figure 2: Use of Building Codes in the United States

To help resolve the problem of disunity among the three major building codes, the model building code organizations in 1996 entered into a joint effort, under the auspices of the International Code Council or ICC, to develop a single comprehensive building code called the *International Building Code* (IBC). The IBC draws heavily from the previous codes but includes updated requirements for seismic design and other vital subject areas. The new code was published in March 2000, although several years may pass before the

2000 IBC is widely adopted. In addition, another code-writing body, the National Fire Protection Association (NFPA), is developing a competitive model building code.

While the major model codes include some "deemed-to-comply" prescriptive requirements for conventional house construction, they focus generally on performance (i.e., engineering) requirements for more complex buildings across the whole range of occupancy and construction types. To provide a comprehensive, easier-to-use code for residential construction, the three major code organizations participated in developing the *One- and Two-Family Dwelling Code* (OTFDC) by the Council of American Building Officials (CABO) and first published in 1972, and now evolved into the *International One- and Two-Family Dwelling Code* (ICC, 1998). Presented in logical construction sequence, the OTFDC is devoted primarily to simple prescriptive requirements for single-family detached and attached (townhouse) homes, although more performance and design standards are being introduced. Many state and local jurisdictions have adopted the OTFDC as an alternative to a major residential building code. Thus, designers and builders enjoy a choice as to which set of requirements best suits their purpose.

The major code organizations, under the auspices of the ICC have developed a replacement for the OTFDC in conjunction with the IBC. Called the *International Residential Code for One- and Two-Family Dwellings* (IRC), it draws on earlier editions of the OTFDC and is recently available. The IBC references the IRC as applicable to one- and two-family buildings.

The International Code Council (ICC) also developed other code documents applicable to various “sub-systems” in the building, such as the mechanical or plumbing systems. The model code organizations listed previously also have plumbing and mechanical codes which may or may not be applicable on a local or state level. In some jurisdictions, for example, the plumbing code will be promulgated by the local water authority. However, just as there are building codes applicable to most structures, there are plumbing and mechanical codes applicable to sub-systems installed in buildings.

The ICC set of codes includes:

- International Building Code,
- International Fire Code,
- International Residential Code,
- International Mechanical Code,
- International Fuel Gas Code,
- International Energy Conservation Code,
- International Property Maintenance Code,
- International Plumbing Code,
- International Private Sewage Disposal Code,
- ICC Electrical Code, and the
- International Zoning Code

The ICC Electrical Code is primarily administrative, and references the National Electrical Code (NEC) for detailed electrical provisions. The National Fire Protection Association (NFPA) promulgates the NEC, which is maintained (updated) every three years. Most jurisdictions throughout the United States also use the NEC for installation of electrical systems and components.

Though not technically a code, the Minimum Property Standards (MPS) establish certain minimum standards for buildings constructed under Housing and Urban Development (HUD) housing and lender programs. New single-family homes and multi-family housing among others are covered under these provisions. In the past these standards were applied separately to housing but since the 1980's, HUD has accepted the model building codes, including many referenced standards, and local building codes, in lieu of separate HUD standards. A major difference in the MPS resides in the area of component performance.

“However, there is one major area of difference between the MPS and other model building codes: durability requirements. Homes and projects financed by FHA-insured mortgages are the collateral for these loans and their lack of durability can increase FHA's financial risk in the event of default.

More specifically, the model codes do not contain any minimum requirements for the durability of such items as doors, windows, gutters and downspouts, painting and wall coverings, kitchen cabinets and carpeting. The MPS includes minimum standards for these, and other items, to ensure that the value of an FHA-insured home is not reduced by the deterioration of these components.”[6]

Also, FHA approved mortgages require that homes meet one of the nationally recognized building codes, and even in areas where no building code is specified.

Standards in the Building Codes

Model building codes do not provide detailed specifications for all building materials, products and systems but rather refer to established industry standards. Standards typically applicable to residential construction are promulgated by the American Society for Testing and Materials (ASTM), the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI), Underwriters Laboratories (UL), and others. A standard is primarily a “referenced authoritative resource” and becomes a mandatory requirement only to the extent that it is referenced by a building code[7]. Currently, over 600 material and testing standards are referenced in the building codes used in the United States.

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[6] Refer to the web site, http://www.hud.gov/fha/sfh/mhs/mhsmpsp.html for more details specific to the MPS.

[7] Refer to *A Guide to the Use of Standards in the ICC International Codes*, see introduction.

For products and processes not explicitly recognized in a model code or standard, the model building code organizations, at the request of manufacturers, provide a special, fee-based code evaluation service. This evaluation service provides reports on products and investigates such areas as fire, structural or other performance characteristics. By issuing an evaluation report, they provide the building official with a basis for approving new products previously unused or minimally used in buildings. While the National Evaluation Service, Inc. (NES) provides a comprehensive evaluation relative to the three model codes[8]; each model code organization also performs evaluations independently for its specific code.

Implication for Residential Fuel Cells

The National Evaluation Service (NES) has published a White Paper to support the development of a National Evaluation protocol leading to a National Evaluation Report (NER) for stationary fuel cell systems. The primary purpose of the effort is "…to facilitate [fuel cell] acceptance by building regulatory authorities…"[9]. The proposed protocol appears to include requirements for labeling (e.g., UL listing) fuel cell equipment and installed systems. The proposed guidelines include items such as "In Situ Evaluation Criteria" that would include the installation of the system [3 Ibid., p18]. Specific site evaluation areas include building, thermal, and electrical integration with the home.

The use of a new technology in residential construction may require compliance with either the building code or requirements in a standard directly referenced by the building code. In the case where a technical standard applies to the use of a technology, a building code may adopt the standard by reference[10]. Building codes rely on the technical requirements of a standard to ensure the proper use or application of the material, system, or device. Numerous standards and codes may apply to fuel cells and their application in buildings.

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[8] Recently ICBO has separated from other code bodies in issuing its own proprietary evaluation report.

[9] Refer to the National Evaluation Service web site, www.nateval.org, for a copy of the White Paper, "National Evaluation Protocol for Stationary Fuel Cell Power Plants", June 5, 2000.

[10] Standards setting bodies include organizations such as the American Society for Testing and Materials (ASTM), Underwriters Laboratory (UL), and many others.

Implication for Residential Fuel Cells

Several standards exist or are under development whose scope encompasses the performance of fuel cell technology. These standards including ANSI Z21.83 “Fuel Cell Power Plants,” ASME PTC 50 “Performance Test Code for Fuel Cell Power Systems,” IEEE P1547 “Distributed Resources Interconnected with Electric Power Systems,” and UL 1741 “Static Inverters and Charge Controllers.”[11] Other standards related to hydrogen technologies through the International Electrotechnical Commission are under development as well. Refer to subsequent sections in this report for a description of various codes and standards.

HOUSE UTILITY SUPPLY CONNECTION SUMMARY

Electric Supply

Most homes in the U.S. are connected to an electric supply grid that provides alternating current (ac) power at a nominal 120/240 volts. Electric service, using a grounded neutral conductor, can supply a nominal 240 volts line-to-line or 120 volts nominal line-to-neutral. The electrical current rating of an individual service is limited by the size of the electric service feeder cable and the rating of the main service panel or main disconnect over-current device(s). Due to the widespread use of the National Electrical Code (NEC), the basic electrical system installation is virtually the same in most residential applications.

However, there are minor residential electrical system installation differences evident, such as:

- Location of the main panel (breaker or fuse) box,
- Location of the utility metering equipment,
- Use of dedicated utility disconnect equipment, and
- Use of three-wire circuits[12]and dedicated circuits.

Because many building code requirements vary by jurisdiction, when using fuel cells in residential applications, these differences need to be resolved on an individual (city, county, state) basis. The primary technical issue for interconnection of fuel cells is the electrical connection with the house and utility electrical supply grid. The resolution of these electrical interconnection and supply issues are greatly influenced by various fuel cell design attributes, including:

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[11] Information obtained from *Fuel Cell Summit*, Volume 1, Issue 2, Published by the DOE, Office of Power Technologies.

[12] A three-wire circuit uses two ungrounded (hot) conductors to supply two different circuits while sharing one neutral conductor. This wiring method is used primarily for cost savings.

- Fuel cell power output relative to the building electrical demand,
- Capability of the fuel cell inverter output to interact with the utility system,
- Fuel cell operation independent of the utility connection, and
- Intended purpose of the fuel cell system (primary power, backup power, etc.).

Particular issues of fuel cell connection and operation relative to the house electrical supply are also influenced by utility concerns of interconnection to the utility grid of distributed generation equipment. A discussion of these issues is in the NAHB Research Center report, *Institutional Factors Affecting Commercialization of Fuel Cells* (December 2000). The utility interconnection regulatory issues may exert more influence on the design of a fuel cell system than the above options allow.[13]

Codes and Regulations Regarding Fuel Gas Supply

The use of fuel cells in residences also needs to consider the technical requirements regarding the use of fuel gas, which is a primary source of hydrogen for fuel cells. Fuel gas is commonly available in homes in many regions of the United States. The local fuel gas (natural gas) supplier, along with any applicable state and federal regulations, generally governs the supply of fuel gas to homes. The local distribution of fuel gas, and hence the technical issues of supply capacity, pressure, and quality should be considered on an individual gas utility basis.

Inside a residential structure, however, the fuel gas supply may be governed by one or more building codes, depending on local adoption. Along with local adaptations, there are three major fuel gas codes that may be adopted in a given locale. These are the:

- International Fuel Gas Code published by the International Code Council (excerpts are found in the IRC),
- National Fuel Gas Code (NFPA 54) published by the National Fire Protection Association (NFPA), and
- Uniform Plumbing Code published by the International Association of Plumbing and Mechanical Officials (IAPMO).

NFPA 54 is also an American National Standards Institute (ANSI) standard with the designation ANSI Z223.1. It is generally used as the base document for all other gas codes.

RESIDENTIAL WIRING SYSTEMS AND THE NEC

The National Electrical Code (NEC) requirements for building wiring systems discussed in this document are applicable to one- and two-family buildings including attached

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[13] One example concerns the fuel cell operation that allows sending power back to the utility. A particular utility may restrict this option given certain utility system design limitations.

housing such as townhouses; other electrical installations are not within the scope of this discussion.

The NEC generally covers the premises wiring system, starting from the service drop[14] and including all downstream wiring. Systems, equipment, and wiring under the purview of the utility are excluded from the provisions of the NEC, as stated in section 90:

> "[Not covered in the NEC are:] Installations, including associated lighting, under the exclusive control of the electric utilities for the purpose of communications, metering, generation, control, transformation, transmission, or distribution of electric energy. Such installations shall be located in buildings used exclusively by the utilities for such purposes; outdoors on property owned or leased by the utility; on or along public highways, streets, roads, etc.; or outdoors on private property by established rights of easements."[15]

For residential single-family buildings, the premises wiring is generally considered to extend from the aerial service drop or underground service lateral to all outlets. Thus premise wiring includes the portion of the electrical system from the service entrance conductors extending from the service drop to the main service equipment or distribution panel and beyond.

Listing and Labeling

Listed and labeled equipment, devices, and materials are those that have been tested or otherwise evaluated by a Nationally Recognized Testing Laboratory (NRTL) such as Underwriter's Laboratories (UL), Canadian Standards Association (CSA), Intertek Testing Services (ITS),[16] and the National Electrical Manufacturers Association (NEMA) and shown to perform within their intended purpose. Organizations, acceptable to the Authority Having Jurisdiction (AHJ), may periodically test or evaluate products to determine that they continue to perform as intended. Products are usually tested in accordance with a standard developed by an approved standards organization.

Section 110-3 of the NEC gives options that manufacturers may use for product design purposes. Section 110-3 does not explicitly require listing or labeling, although other sections of the NEC specifically require listed or labeled products. However, the electrical section of the *International One- and Two-Family Dwelling Code* requires equipment, materials, devices, etc., to be listed for the application and labeled by an "approved" agency, as well as installed and used according the manufacturer's instructions.

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[14] The service drop is the overhead cable from the utility to the house. Service lateral is the underground cabling from the utility to the house.

[15] Refer to Section 90-2 (b) (5), 1999 NEC

[16] Formerly known as Electrical Testing Laboratories (ETL)

Residential Service Requirements

The minimum size of the electrical supply system (service rating) for single family dwellings is 100 amps[17] but not less than the load to be served. Article 220 of the NEC designates the sizing method for residential services and includes a standard calculation method or an optional calculation method.[18] However, the optional method may only be used for dwelling units with services of at least 100 amps.

Proposed NEC Article 692, Fuel Cell Systems

A new NEC Article 692 has been proposed that covers the installation of fuel cell power systems. It is similar to Article 690 that covers the installation of solar photovoltaic (PV) systems. [19] The scope of the proposed article includes both utility independent and utility interactive systems with or without battery storage.

The proposed Article 692, as modified by the review panel for this section of the NEC, addresses circuit sizing, disconnecting methods, wiring methods, connection to the house electrical system, grounding, use of a transfer switch, and requirements for systems that are interactive with another power system.

NEC Article 690, Solar Photovoltaic Systems

Similarities exist between Article 692 and Article 690,[20] especially concerning the inverter connection to the building power supply. The portions of Article 690 that deal with the dc side of the PV system may be applicable, but PV-supplied circuits perform quite differently from the dc side of a fuel cell circuit. A more appropriate comparison may be with Section 690-6, AC (Photovoltaic) Modules. AC modules are PV modules that produce ac electricity directly from sunlight.[21] These devices must be (parallel) connected to the utility supply to operate and they have no accessible dc circuits. Fuel cell system designs may or may not have accessible dc circuits that must be considered separately in the NEC. Deciding issues include the capacity of the battery storage and its accessibility and maintenance requirements as well as its proximity to the fuel cell system power connections.

Portions of Article 690 are relevant to the inverter output from a fuel cell connected to the building supply. Issues such as the amperage rating of the main breaker that is fed by an inverter circuit, disconnecting methods, and specific wiring methods may be similar to that of fuel cell inverter output. NEC code issues related to interconnection with other power sources may also be applicable to residential fuel cell systems located within the

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[17] 1999 NEC Section 230-79 (c)

[18] 1999 NEC Article 220

[19] The proposal, 3-206, was submitted as a new article 691. The Technical Correlating Committee advised that the article be renumbered as new article 692.

[20] Refer to the National Electrical Code, 1999, published by the NFPA.

[21] AC Modules have an inverter incorporated either on or very near each individual PV module.

building and supplying building power. Section H of Article 690 includes a number of provisions related to battery storage in PV systems which may help in understanding the use of battery storage for fuel cell systems.

NEC Article 480, Storage Batteries

Article 480 of the NEC covers installation of stationary batteries used in a building. The provisions of this section include battery voltage limitations, battery location, venting of cells, and battery support structures. As mentioned in the previous section, Article 690 on PV systems also includes some requirements for stationary batteries.

> Implication for Residential Fuel Cells
>
> Battery use in fuel cell systems will likely be limited to periods when house demand exceeds fuel cell capacity at a particular moment. At all other times, batteries will be fully charged. The use of batteries in a fuel cell system is substantively different from battery use in PV systems—in which batteries are used frequently to provide power during periods of low sunlight. In PV systems with a large battery storage system, there are separate design requirements for the battery system and the PV system. Batteries used in fuel cells may be evaluated as part of the fuel cell system rather than independently for a given installation depending on the intended purpose of the batteries and the overall capacity of the battery system. However, for fuel cell systems, treatment of the storage battery component separate from the fuel cell may have advantages if the battery storage capacity is large or requires frequent maintenance. If the battery compartment were separate from the fuel cell system itself, the requirements of NEC Article 480 would most likely take precedence over other sections of the code.

INTERNATIONAL FUEL GAS CODE

A brief review of the International Fuel Gas Code (IFGC) provides a general guideline for installation of fuel gas appliances in homes. The IFGC was developed from the *International Mechanical Code*, the *International Plumbing Code*, the *Standard Gas Code*, and the *National Fuel Gas Code* (ANSI Z223.1), in conjunction with the gas industry.[22]

Definition of Appliance and Labeling

The IFGC defines an appliance (or equipment) as "[a]ny apparatus that utilizes gas as a fuel or raw material to produce light, heat, power, refrigeration, or air conditioning."[23]

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[22] Refer to the preface to the *International Fuel Gas Code* (IFGC).

[23] See Chapter 2 of the IFGC.

This definition may be interpreted to include those devices that produce electricity, such as a generator or fuel cell.

Section 301.3 provides information concerning listing[24] and labeling[25] of equipment, appliances, or materials. Listed and labeled equipment is required under the IFGC unless otherwise approved by the local jurisdiction or inspector.

The IFGC is explicit in its intent not to inhibit the installation of new materials or the use of new methods of construction as long as they satisfy the intent of the code. Equipment and methods that are not formally listed/labeled but that are equivalent to the code intent must be found to have sufficient "…quality, strength, effectiveness, fire resistance, durability, and safety."[26]

Gas Appliance Location and Combustion Air

The IFGC restricts the location of gas appliances, especially in cases where combustion air is drawn from inside the building shell. The location of equipment in, and the use of combustion air from, certain rooms in the house such as bedrooms is prohibited. Exceptions are allowed for direct-vent appliances where all combustion air is supplied from outdoors; some vented room appliances where safety requirements are met; and appliances in a dedicated enclosure (with restrictions).

Section 304 of the IFGC describes techniques for providing an adequate supply of combustion, ventilation, and dilution air for gas appliances. The requirements are specific and depend on access to sufficient air supply for proper operation of equipment. In reference to sufficient air supply in homes, the term "unusually tight construction" is used and is specifically defined in chapter 2, definitions.[27] Typical residential construction techniques may cause many new homes to fall into this category.

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[24] "Listed" is defined as inclusion in a list by a Nationally Recognized Testing Laboratory (NRTL). NRTLs are concerned with product evaluation, inspection, testing, production, etc.

[25] "Labeled" refers to a marking applied to the equipment, appliance, or material by a NRTL.

[26] Refer to section 105.2 of the IFGC

[27] The concept of "unusually tight construction" is defined by the IFGC, and includes elements such as a continuous vapor barrier, storm windows or weather seals, and extensive use of caulking.

Implication for Residential Fuel Cells

Location of fuel cell equipment may depend, in part, on the amount of air required for the fuel cell's chemical reactions, including the air volume required for cooling, ventilation or removal of output products, and purging of fuel cell components. Specific air volume or flow rate requirements dictate, in part, the location of the fuel cell within the house envelope. If insufficient air volume is available inside the envelope (e.g. in a tight house), the fuel cell may be more easily installed outside of the envelope in an adjacent enclosed space. This space may or may not be conditioned, depending on the requirements of the fuel cell. The IFGC provides requirements for vent or duct areas, materials and installation methods pertaining to combustion air. New designs are under development that may eliminate venting concerns because the entire fuel cell unit will be installed outdoors, much like an outdoor air conditioning condenser.

Many new homes are constructed using methods and materials that limit the natural air infiltration into the home, and are referred to as "tight" homes. Some energy codes effective in specific areas limit the amount of natural infiltration and then specify requirements for mechanical ventilation. In these homes, especially when combustion appliances are present, provisions are made to ensure adequate air supply to the appliance even to the point of using a direct exterior vent near the combustion appliance.

In some cases, the house foundation type and availability of garage or attic space will guide the location of a fuel cell. Foundation systems include basement spaces (either conditioned or unconditioned), crawl spaces (primarily vented), slab-on-grade, or a combination. A fuel cell may be located in an adjacent enclosure constructed specifically for the equipment or in an existing attached space such as the garage or an attic. For garage or attic installations however, special precautions may be required such as installation of pillars, ventilation, and lighting. In the case of attic installations, requirements will specify minimum attic access sizes.

Other sections of the IFGC Chapter 3 contain provisions for the installation, access and service, condensate removal, and clearances for fuel gas equipment. Creation of appliance installation methods is generally the responsibility of the manufacturer and is typically in accordance with the appliance listing. The IFGC contains provisions for installation of unlisted equipment but references manufacturer's installation requirements.

Implication for Residential Fuel Cells

Specific requirements and modifications to manufacturer's requirements for clearances above and adjacent to combustible materials are covered in Section 308 of the IFGC. These equipment clearance requirements may be applicable to fuel cells particularly in view of the operating temperature of the fuel cell. The specified clearances to combustible materials may be modified depending on the wall construction material, coverings, and air spaces provided.

Provisions for condensate removal must be provided when using an appliance with liquid combustion byproducts, such as condensing furnaces. The liquid produced by a fuel cell in the chemical reaction will need to be disposed of using any number of methods. When the home is connected to the public sewer, methods of condensate disposal depend on the requirements of the local water purveyor and may include:

- Direct flow or pump to a sanitary or storm drain,
- Direct flow or pump to out-of-doors, or
- Direct flow or pump to a drainage system.

Implication for Residential Fuel Cells

The maximum flow rate of liquid byproduct needs to be specified by the fuel cell manufacturer. Requirements for drain size, drain line slope, or pumping rates may also need to be specified or recommended.

Gas Piping and Venting

Chapter 4 of the IFGC concerns, in part, the design and installation of gas piping systems. Requirements for pipe materials are available in Section 403. Pipe installation requirements are listed in Sections 404, 405, and 407 through 410. Appliance connection requirements such as use of listed and labeled connectors, disconnects, or flexible connectors are in Section 411.

Appliance manufacturer specifications concerning fuel gas demand determine the total connected hourly load for a building. The maximum hourly load is based on the rated volume of gas required to supply all connected appliances simultaneously operating at full capacity. The estimated hourly load may be decreased if the loads are shown to not operate simultaneously during the entire hour.[28] The supply of gas to a specific appliance must be available at pressures above the minimum required by the appliance, accounting for pressure drop in the supply line, and demand from other appliances on the same line.

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[28] This concept is known as load diversity and assumes that many appliances either cycle, as in a furnace, or have a limited period of operation, as in a range.

Implication for Residential Fuel Cells

For some fuel cells, there may be an efficiency gain by supplying fuel gas at higher pressures. However, fuel gas piping in buildings is generally limited to a maximum of 5 psig. Exceptions for welded pipe or ventilated protected pipe enclosures may allow for higher delivered pressures to a fuel cell. For higher fuel gas pressure, the local Authority Having Jurisdiction responsible for inspection of a fuel gas system may require and/or allow specific connection methods including dedicated piping to the fuel cell. Special metering devices easily installed by the fuel gas supplier may also be necessary.

Chapter 5 of the IFGC contains extensive requirements for venting of gas appliances. Specific requirements for venting of gas appliances are in Sections 501-503. Specific sizing requirements for vents are contained in Section 504. Venting requirements are generally based on the category of the appliance:

- Category I – non-positive vent pressure with vent gas temperature not capable of excessive condensate production,
- Category II – non-positive vent pressure with vent gas temperature capable of excessive condensate production,
- Category III – positive vent pressure with vent gas temperature not capable of excessive condensate production, and
- Category IV – positive vent pressure with vent gas temperature capable of excessive condensate production.

Requirements for venting include acceptable materials, clearances, cleanouts, and capacity, among others. Proximity to building openings, such as windows and to other building air intake openings, are also considered. Venting requirements may be specified with the appliance listing.

INTERNATIONAL MECHANICAL CODE

The International Mechanical Code (IMC) regulates the design, installation, maintenance, alteration and inspection of permanently installed mechanical systems that control the environmental conditions and related processes in buildings.[29] The IMC may specify requirements for appliances not covered by the International Fuel Gas Code. Many of the provisions of the IFGC discussed above are applicable in the IMC and pertain to equipment not specifically covered by the IFGC.

Chapter 9 of the IMC includes requirements for specific appliances. Section 924, Stationary Fuel Cell Power Plants contains one provision that references fuel cells directly and is new to the IMC 2000 edition.

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[29] Refer to Chapter 1 of the International Mechanical Code (2000).

Implication for Residential Fuel Cells

Section 924.1 of the IMC states: "Stationary fuel cell power plants having a power output not exceeding 1,000 kW, shall be tested in accordance with ANSI Z21.83 and shall be installed in accordance with the manufacturer's installation instructions."

FUEL CELL CONNECTION TO A RESIDENTIAL BUILDING ELECTRIC SUPPLY

Various options exist for the connection of fuel cell power plants to residential power systems. For example, the ac electrical output of a residential PV system may be used directly in the home power system in conjunction with a utility supply or alone using battery storage. Likewise, the fuel cell system may be incorporated as a stand-alone device, albeit without battery storage, or interactive with another power source such as the utility. Various supply options may be used depending on electrical supply availability and cost, the size of connected loads, or consumer preference.

FUEL CELL INTERCONNECTION WITH OTHER ENERGY SOURCES

Because current proposed residential fuel cell systems rely on fossil fuel sources such as natural gas for hydrogen supply, it is unlikely that fuel cells would be used to supply power to the utility grid.[30] Instead, electricity generated by a fuel cell would fully or partially supply the building loads only. On the other hand, distributed generation systems discussed within the IEEE P1547 standard, for example, are primarily concerned with direct connection of a distributed resource to a utility grid, e.g. distributed generation. Distributed generation equipment is typically considered in terms of small generators located at a remote site and supplying electricity to a facility, device or area. This is done in parallel to the utility grid so that interconnection with the utility grid is assumed and necessary. However, in many cases when the distributed generation, as in a PV system or fuel cell, is sited at the point of use, feedback into the utility grid may not be desirable. However, the fuel cell system would need to parallel with the grid whenever the load was shared since each system would provide some portion of the load. Typically in this parallel connection, the distributed generation supply would supply the load up to its maximum output with any additional load requirements being supplied by the utility grid.

Furthermore, utility interconnection for PV systems is often more important than for fuel cells since the output from PV systems is variable and dependent on sunlight intensity unlike other types of generation that have a consistent fuel source 24 hours per day. The amount of power available to the load from a PV system, unless matched with the load, will be either larger or smaller than the connected load. Since PV systems use a renewable resource, the effort to minimize periods when the PV system is intentionally

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[30] On a residential basis, the purchase of natural gas to make electricity in the fuel cell to supply back to the electric utility will most likely be uneconomic or not permitted in the regulatory environment. The economics may change in specific locations where the price of natural gas is low and the value of electricity output of the fuel cell is high.

disabled when it is capable of producing power, is critical.[31] Therefore, PV systems are often interconnected with another power source, such as the utility, simply to achieve the goal of maximum use of the PV output. Stand-alone PV systems are an exception where the PV output may be disabled if the load is satisfied and the connected battery storage is fully charged.

Distributed generation applications have a unique set of issues that potentially involve both state and federal regulations. In addition, ownership, maintenance, and metering issues complicate the installation and use of a fuel cell system. However, as utility deregulation unfolds and utility grid reliability and energy costs become an increasingly important issue, the use of distributed generation will be much more relevant. In this discussion, however, the use of fuel cells as distributed generation (supplying power to the electric utility system) will not be considered further.

Residential Energy Use

Residential energy use varies widely both daily and seasonally.[32] Even hourly energy use varies dramatically depending on the number of people in the home and the amount of time the house is normally occupied. Demand for electricity varies with the type of appliances used and type of fuel the appliances use. All-electric homes experience a demand that depends greatly on water heating and space conditioning equipment operation. Homes with natural gas, oil, or other fuel for water heating and/or space conditioning generally have a lower overall electric demand than all-electric homes. In summary, the demand for electricity and other energy sources in homes depends in part on the:

- Type of fuel used for space conditioning, water heating, and clothes drying,
- Efficiency of the heating and cooling equipment,
- Insulation levels in the exterior walls, floor, and ceiling,
- Infiltration losses,
- Duct losses,
- Orientation of the home, especially the windows,
- Size of the home,
- Number of occupants,
- Number of appliances and the frequency of use,
- Age of the appliances,
- Climatic conditions,
- Set-points for heating and cooling system operation, and
- General occupant behavior.

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[31] Generation from a renewable resource is preferred over sources of generation that consume fuel or produce pollution in the generation process. Therefore, full utilization of generation from renewable sources is warranted whereas periods of non-use of other non-renewable generation may be acceptable.

[32] Refer to NAHB Research Center Report, *Review of Residential Electrical Energy Use Data for the*, May 2001.

Occupant behavior accounts for everything from cooking, bathing, and laundry habits to use of lighting and window shades to opening of windows.

Since being established in 1977, the United States Energy Information Administration (EIA) has developed an extensive database of energy consumption and production data. Their Residential Energy Consumption Survey (RECS), initiated in 1978, evaluates energy use in residential buildings and is a primary source for analyzing residential energy use in the U.S.

From 1978 to 1997, residential energy use per household has decreased 27 percent from 138 Mbtu to 101 MBtu.[33] This decrease primarily occurred from 1978 to 1987, and energy use has remained approximately level since then. The largest relative decrease by end-use was in space heating energy consumption, which decreased from 66 to 51 percent of total energy consumption. Cooling energy, as a percentage of total energy use, remained essentially unchanged. As a result of the decrease in heating energy requirements, water heating energy as a portion of the total energy consumed, increased by 27 percent. In addition, appliance and lighting energy consumption as a portion of the total energy increased by 59 percent over two decades.

For both single-family attached (SFA) and single-family detached (SFD) homes, the use of air-conditioning has grown dramatically. Now, half of the housing stock has central air-conditioning and nearly three-quarters of all single-family homes have some air-conditioning. Electricity is used for heating in about a third of all households, which includes multifamily and manufactured housing units. In addition, 61 percent of all homes use natural gas for at least one appliance.[34]

Implication for Residential Fuel Cells

Residential fuel cells, located at the home, may supply electricity for use in the home only, or may be designed to interact with the utility supply to provide electrical power to the utility or other grid network. Additionally, fuel cells may be designed to supply the entire house demand or only a portion of the load. The chosen approach may be influenced by the ownership of the fuel cell (utility, homeowner, etc.), the method of metering, or the cost of electrical supply from other competing sources.

FUEL CELL SYSTEM APPLICATION OPTIONS IN RESIDENTIAL BUILDINGS

There are several options for how fuel cells could be used in residential buildings. The choice of system depends on the intended purpose of the fuel cell. As a distributed electric resource (as opposed to a central electric resource), fuel cells may be used as one part of the basic infrastructure of utility supply. For example, one large fuel cell could supply multiple homes in a neighborhood. Residential developments, from a few homes

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[33] MBtu (million Btu) or 1,000,000 Btu, and is measured at the site where the energy is used.

[34] Statistics as part of the EIA publication, *A Look at Residential Energy Consumption in 1997*, November 1999.

to hundreds of homes, could incorporate fuel cell technology to provide electricity to a set of homes similar to a utility transformer that services a set of homes from a main utility line.

Another option is to design a fuel cell to supply an entire home's electrical demand. In this scenario, the connection to the electric utility grid may not be used at all, or may be used only as back-up supply in case of fuel cell failure.

A third option is to use the fuel cell to supply a portion of the home's electrical load, with the remaining load serviced by the electric utility system. With this option, the fuel cell may be used to supply a separate sub-panel with 120-volt loads only, thereby simplifying the fuel cell design, installation, and operation.

Based on an individual home, a fuel cell system can be designed to supply 120 volt or 120/240 three wire electrical supply to a residential electrical system through various methods:

- A stand-alone system, supplying all of the home's electrical demand.
- A parallel and interactive system with the electric utility supply.
- A parallel and non-interactive system with the electric utility supply.
- As part of an electric supply system involving multiple sources of electrical supply.

A Stand Alone System Supplying All of a Home's Electrical Demand

A fuel cell system may be connected to a residential electrical service to supply all of a home's electricity needs. This type of fuel cell system needs to satisfy peak demand as well as very low demand when the only loads are from such devices as digital clocks and "instant-on" circuitry in media equipment. The range of electrical demand may be two to ten times as much for an all-electric house than for a home that uses gas for its major appliances.

Actual and estimated electricity demand is vitally important to the application of a fuel cell system. The projected electric demand guides the size of the fuel cell and any required electric storage capability. The capacity of the fuel gas connection is also important if the home's major appliances and the fuel cell operate from the same source of fuel gas.

In a stand-alone application, the connection to the home's electric system may be made at the main service panel. This installation would most likely be governed by the National Electrical Code and any local electric codes in effect in the jurisdiction where the fuel cell is used. Fuel cell design would most likely include the capability to supply all 120/240-volt loads rather than 120 or 240 volt loads only since both voltage levels are used commonly in homes. Changes in the building's electrical system design, layout, and operation would not be necessary in a stand-alone system.

With a stand-alone system in which the fuel cell output is used only in the home, the homeowner would be responsible for maintaining, repairing, and monitoring the fuel cell although the utility may be responsible for supplying fuel to the cell. This is a change from the typical electric utility-homeowner relationship where the homeowner depends on the utility to resolve any electric supply or maintenance problems.

There are many existing examples of stand-alone electric systems. Solar PV and wind systems and hybrid systems that couple PV or wind with engine generators have been used successfully throughout the United States and the world. In many cases, especially with solar PV and wind-based systems, the electric supply capacity is matched closely with house demand to ensure that the load is served while not installing excessive, expensive generation capacity. This attention to system design helps to limit the overall system cost and to ensure a consistent supply of electricity. Many homes with stand-alone electric systems use very efficient lighting and appliances and more efficient building techniques and materials. In addition, many of these homes reduce electric demand through use of non-electric appliances where feasible.

The benefits of a stand-alone system include:

- Higher electric supply efficiency to the overall building (when compared with central generation),
- Potentially less influence from natural disasters such as storms or accidents to utility infrastructure,
- Use of a less polluting fuel source and method of electrical generation, and
- Potentially lower costs for the electric energy consumed.

A Parallel and Interactive System with the Electric Utility Supply

Fuel cell systems may be connected to the house electric supply in parallel with a standard utility supply. An interactive, parallel connection is capable of electricity flow between systems and may even be programmed to supply a specified capacity, if desired. For example, the fuel cell may be limited to feeding up to a certain amount of power back into the utility grid or limited to feeding power to the grid only at certain times of the day. In this connection scheme, the fuel cell system can be sized to supply any portion of the home’s electrical demand with the utility connection supplying the remainder. The fuel cell system may also be designed to supply back-up power under specific conditions such as a loss of utility supply. Other specific conditions might warrant the use of a back-up fuel cell system to:

- Limit the peak demand of the building to avoid special demand charges,[35]
- Limit the peak demand on the utility system to avoid power outages or problems,
- Avoid certain power quality problems,
- Use the lowest cost fuel for electricity at any given period,

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[35] Demand rates are additional electricity charges based on the peak electricity use in a building (usually based on 15-minute peak demand).

- Allow consumer choice, or
- Optimize a combination of the above.

A parallel connection option also allows the fuel cell to operate at some minimum level regardless of the house electric demand at any moment. Conversely, the fuel cell may not need to operate until some minimum level of demand is required. In either case, the fuel cell can supply power back to the utility grid either when necessary or required through the operation of the electronic control in the fuel cell. With this flexibility the fuel cell system may be optimized for best performance.[36]

Sizing a fuel cell in a parallel connection is less critical than in a stand-alone system since, in a parallel connection, the utility is available for electrical supply when needed. Therefore, a fuel cell system design may be based on optimizing the fuel cell operation rather than on the house demand.

Some benefits of a parallel system connection include:

- Fuel cell sizing independent of the building loads,
- An optimized fuel cell operation regime,
- Potentially higher overall efficiency of the fuel cell system,
- Back-up power capability for some electrical loads,
- Use of a less polluting fuel source,
- Higher reliability of electricity supply, and
- Potentially lower electricity costs.

Particular attention must be paid to the utility connection in a utility-interactive design. The electrical output of the fuel cell must be compatible with the utility supply, and particular safeguards must be in place to protect inadvertent feedback to the utility at times when the utility line is de-energized. Interconnection requirements complicate the overall fuel cell design. However, standards are available that detail the basic safety requirements and equipment capable of this level of performance. Inverters used in utility-interactive PV systems are an example of a successful interconnection option for residential and other distributed power systems.

A Parallel and Non-Interactive System with the Electric Utility Supply

As with the parallel and interactive connection, a non-interactive parallel system permits the use of utility supply coupled with fuel cell output to supply the electrical needs of a home. The primary difference is that a non-interactive system cannot supply electricity back to the utility grid. This option simplifies the design of the fuel cell system's electric output and avoids issues related to inadvertent utility grid feedback.

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[36] The fuel cell control may be designed to supply power back to the utility grid at times when the utility supply is more expensive or is in a capacity shortage.

A parallel non-interactive fuel cell system serves all of the building load using power from both the fuel cell and the utility. However, to reduce costs, the fuel cell inverter is not designed to place power back onto the utility grid. To reduce these costs, the inverter is designed to supply ac power to the home but is not matched precisely to the utility ac signal. Therefore, to use the utility power, it must be converted to dc then re-inverted to ac for use in parallel with the fuel cell power. In other words, instead of matching the fuel cell output to the utility, the utility is matched to the fuel cell output. This simplifies the fuel cell connection to the utility and to the home. However, in the event that the utility supply is lost, the fuel cell may continue to service its portion of the building load only. Although, care must be taken to ensure that the load does not exceed the capacity of the fuel cell which would cause the fuel cell to either shut down or malfunction. For example, dedicated circuits may be supplied by the fuel cell only in case of a utility outage.

In homes with low electric demand, a fuel cell may easily handle most of the loads except possibly for larger loads such as a central air-conditioner. Sensing electronics in the fuel cell or elsewhere and programming may be necessary to disable certain loads if the utility supply is lost.

Some benefits of a parallel, non-interactive system connection option include:

- Fuel cell sizing independent of the building loads,
- A simpler, less costly fuel cell electric output design,
- A potentially optimized fuel cell operation regime,
- Higher efficiency of fuel cell system electricity supply,
- Potential back-up for some electrical loads,
- Use of a less polluting fuel source, and
- Potentially lower electricity costs.

The design of a fuel cell system, including the electronics to supply 120/240-volt electric output to the building, is simplified in a non-interactive system since the fuel cell does not feed back energy to the utility. However, there is generally an efficiency penalty due to the conversion of the utility power to dc and back again to ac through the fuel cell inverter electronics.[37]

Fuel Cells as Part of a Hybrid Electric Supply System that has Multiple Sources of Electrical Supply

A fuel cell in combination with other sources of electrical supply is another connection option to service the electrical demand of a home. Sources of electrical supply can be either ac or dc. For example, a set of batteries may be used to supply dc energy in

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[37] In this system, the utility power is converted to dc and then reinverted to ac through the inverter in parallel with the fuel cell. This system simplifies the electronic design of the equipment to convert dc power to ac power.

parallel to the fuel cell dc output prior to the electronics that converts dc to ac power. Renewable energy supplies, such as PV or wind are used in a similar manner.

The use of another generation method, such as an engine generator, may be used in parallel with the ac output of a fuel cell. This option is common in many stand-alone renewable energy systems. The generator may be used to supply ac to some loads or to charge a battery supply. A generator may supply power to specific intermittent loads large enough to warrant the use of a generator to supplement the capacity of the fuel cell. For example, an engine generator might be used to power a compressor, while the fuel cell system supplies other loads.

Alternatively, a fuel cell could be used to supply specific loads only, while another supply source serves all other loads. For example, the fuel cell might be used to supply essential loads such as a refrigerator, furnace blower, and some lighting and outlets. In case of a utility outage, the fuel cell would continue to serve these specific loads. However, if a problem with the fuel cell system arises, utility power, or another source can be switched over to supply all of the loads.

The benefits of a hybrid electric system include:

- Fuel cell sizing independent of the building loads,
- A simpler, less costly fuel cell electric output design compared to a utility interactive design,
- System design flexibility and potential for a modular approach,
- Higher efficiency of fuel cell system electricity supply,
- Potential back-up for some electrical loads,
- Use of a less polluting fuel source, and
- Potentially overall lower electricity costs.

The electrical connection may be more costly in this system design than any of the others since additional electrical distribution equipment to separate certain loads is necessary. However, proper sizing of the distribution equipment may make such additional costs relatively minor.

ENERGY CODES AND PROGRAMS

The *International Energy Conservation Code* (IECC) 2000 edition has developed from and replaced the Model Energy Code as a single document that sets out minimum requirements for energy efficient building construction methods and materials. Energy conservation programs, such as utility programs or the federal ENERGY STAR program, also influence the energy use in homes. These codes and programs are designed to bring about energy conservation through use of higher levels of insulation, efficient windows, high efficiency equipment, and other means. All of these efforts are geared toward reducing the use of non-renewable energy sources. Renewable energy sources, with some qualifications, are used to decrease the consumption of non-renewable resources at the meter. Issues related to energy production at the site where it is used (site energy) versus utility energy that is centrally generated and transmitted (source energy) are not addressed in the IECC. Fuel cell systems and other forms of distributed generation that use non-renewable energy sources are not credited with decreased non-renewable energy consumption by the codes or programs when sited within a building.

> Implication for Residential Fuel Cells
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> Buildings trying to meet energy codes may not receive credit for using a fuel cell supplied by natural gas. This is because, in a home energy analysis, there is no calculation of source energy used. Therefore, the use of electricity from a central generation plant that has experienced efficiency losses in generation, transmission and distribution (source losses) is not differentiated from electricity generated on-site that does not include those efficiency losses.

STANDRDS RELATED TO DISTRIBUTED GENERATION (PV AND OTHERS)

Distributed Generation (DG) is defined as an integrated or stand-alone use of (modular) electrical generation close to the point of use.[38] Although primarily considered on an industrial or commercial scale, DG technologies are making their way into the residential market. For instance, the use of photovoltaic systems in homes is growing, with over 23,000 "solar-equipped" buildings installed in 1999.[39] For years, off-grid homes have used DG in the form of generators, photovoltaics, and wind power for electrical supply to homes. Recently, especially with the advent of net-metering[40] regulations, the interconnection of distributed PV systems in parallel with the utility grid has become more common. For a more detailed discussion of issues related to utility deregulation, see the NAHB Research Center Report, *Institutional Factors Affecting Commercialization of Fuel Cells.*

Because of the increasing use of net metering, the development of codes and standards directly related to the installation of distributed PV systems, primarily on buildings, has dramatically expanded. The parallels between distributed PV systems and fuel cell systems may serve as a precedent for and support the implementation of fuel cell technology in residential buildings. The following PV standards may apply to fuel cells:

IEEE Standards:

- 929-1988 *IEEE Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic Systems*: Covers issues of power quality, equipment protection, and safety. Also revision project to update the standard, designation P929.

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[38] Refer to *Distributed Generation: System Interfaces*, a white paper by Arthur D. Little, Inc., 1999.

[39] See http://www.eren.doe.gov/millionroofs/benchmark.html for information related to the installation of solar systems under the Federal *Million Solar Roofs Program*.

[40] Net-metering allows the energy sent back to the utility through the meter to be valued at the same rate at which the energy is purchased from the meter.

- 519-1992 *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*: Generally applicable to commercial and industrial systems, covers issues of power quality. See also P519 for revisions.
- 928-1986 *IEEE Recommended Criteria for Terrestrial Photovoltaic Power Systems*: Covers general performance issues for terrestrial PV systems. Some subsystem component performance requirements are included.
- 937-1987 *IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic Systems*: Covers procedures and design considerations for use of lead-acid batteries including location, maintenance, and ventilation issues. Also revision project P937 available in 1998.
- 1013-1990 *IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic Systems*: Covers sizing techniques including iterative methods for optimizing costs. Also revision project P1013 available 1998. In addition, revision project P1361 for selection, testing, and analysis of lead-acid batteries for stand-alone applications. Nickel-cadmium technology installation and sizing recommendations are in standards IEEE 1145-1990 and 1144-1996, respectively.
- P1373 Revision Project, *Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems*: New project underway.
- 1374-1998 *IEEE Guide for Terrestrial Photovoltaic Power System Safety*: Covers the electrical safety of PV systems from design to equipment applicability.
- P1547 *Standard for Interconnecting Distributed Resources with Electric Power System*: New standard project. Covers the interconnection with the electric power system and provides requirements for performance, safety, testing, maintenance, etc.

As the list above demonstrates, there is ample technical design and safety information relating to the use of various types of energy conversion, energy storage, and safety equipment for distributed generation equipment. Most of the information is equipment related and is not referenced directly by the building codes.

National Fire Protection Association (NFPA)

The NFPA is developing a standard pertaining to the installation of stationary fuel cell systems. NFPA 853, titled, “Standard for the Installation of Stationary Fuel Cell Power Plants,” applies to fuel cell systems exceeding 50 kW. This relatively large size is not directly applicable to residential systems but the provisions may provide some guidance when installing a fuel cell inside a building.

Chapter 3 of NFPA 853 presents general installation and interconnection guidelines for a fuel cell system. Based on these provisions the installation of a fuel cell system may be required to:

- Keep exhaust gas from the indoor environment,
- Prevent unauthorized access to the unit,
- Implement procedures for a permanent installation,
- Protect the unit from damage, and

- Provide fire separation from other indoor spaces.

Electrical interconnection with other building systems is governed by the National Electrical Code (NEC). The National Fuel Gas Code (NFPA 54) governs any fuel gas connections. For the remaining sections of NFPA 853, Chapter 4 covers different fuel supplies, and Chapter 5 covers ventilation and exhaust issues. Chapter 6 provides requirements for fire protection and detection.

NFPA 853 remains in the proposal stage. Comments on proposals were due in 1999 and an update on the status has not been issued as of late 2000.

Long Island Power Authority

The New York Public Service Commission has issued an order "…Adopting Standard Interconnection Requirements for Distributed Generation Units" including Appendix B applicable to residential solar electric systems of 10 kW or less.[41] Inverter electrical design requirements for the interface with an electrical utility system include:

- Testing by a Nationally Recognized Testing Laboratory (NRTL),
- Automatic disconnection within 6 cycles if less than 60 volts (120 volt base),
- Automatic disconnection within 2 seconds if voltage over 132 or less than 104 volts (120 volt base),
- Automatic disconnection within 2 cycles if the voltage rises above 180 volts (120 volt base),
- Automatic disconnection within 6 cycles if the frequency exceeds 60.5 hertz or falls below 59.3 hertz,
- Reconnection following an automatic disconnection after 5 minutes of acceptable established voltage and frequency,
- Voltage and current set points are not field settable (factory set),
- Certification (test report) of proper performance required[42],
- A manual external disconnect switch required,
- The disconnect switch is to be located within 10 feet of the utility meter,
- The disconnect switch must be readily available to the utility personnel,
- The disconnected switch must be clearly marked,
- A dedicated distribution transformer may be required,
- The electrical output must meet the latest requirements for power quality, [43]
- A system-commissioning test is required upon initial installation or at the time of any changes to the system. The test may utilize software routines to simulate system performance to demonstrate the operation of safety devices. The tests are to be performed by a qualified contractor, and

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[41] State of New York, Public Service Commission, Case 94-E-0952, including Appendix B- "Photovoltaic Interconnection Standards For Residential Solar Electric Power Producing Facilities of 10 kW or Less" Revised: December 1999.

[42] The performance is to meet or exceed requirements listed in ANSI/IEEE Standards C37.90.1 and 929.

[43] Power quality requirements as specified in IEEE Standard 519 and ANSI C84.1.

- The utility may require the owner to test the system controls.

Testing Laboratories

Many jurisdictions require that any electrical or fuel consuming appliance be listed or labeled by a Nationally Recognized Testing Laboratory (NRTL). Underwriters Laboratory (UL), Canadian Standards Association (CSA), and other laboratories provide technical standards, testing, and product evaluation, including quality control, that lead to the labeling and listing of products for use in buildings. Fuel cells would be listed and/or labeled once the product satisfactorily met the performance specified in one or more standards.

UL, for example, maintains standard UL 1741, *Static Inverters and Charge Controllers for use in Photovoltaic Power Systems*. This standard covers equipment that converts dc power, i.e. from PV systems, to ac power, and battery charge controllers with a PV power source. The standard is being expanded to cover other power equipment that utilize inverters such as fuel cells or PV systems, individual converters such as stand-alone and utility interactive inverters, and battery chargers. In addition, utility requirements for disconnection upon loss of power and synchronization issues will be evaluated in this standard.

PHOTOVOLTAIC EXAMPLES AND LESSONS

For years, the use of PV systems has provided performance and interconnection experience with distributed generation that supplies all or part of building loads. This experience has led to continued development of standards and, in some cases, legislation to govern the implementation of distributed generation systems. In the case of PV, over a dozen states have required utilities to interconnect the ac output of the PV systems using qualified inverters with the utility electric system.

However, the interconnection effort has not been without challenges as described in a U.S. Department of Energy report, *Making Connections: Case Studies of Barriers to Interconnection of Distributed Power*. The report found that in most of the 65 cases examined there were significant barriers to the implementation of distributed generation projects including utility-related, regulatory, technical and business barriers resulting in higher costs and extended project periods. [44]

Many institutional issues covering the implementation of distributed generation are reviewed in "*Institutional Factors Affecting the Commercialization of Fuel Cells*" published by the NAHB Research Center.

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[44] For brief synopses refer to the Photovoltaic Insiders Report (ISSN 0731-4671), July 2000, editor: Richard T. Curry.

SUMMARY AND CONCLUSIONS

This report reviews the building codes and standards primarily related to building energy supply with the purpose of siting a fuel cell system within the home and the options for interconnecting a fuel cell with the home power system. Due to its unique ability to supply electrical power from a fuel such as natural gas, the fuel cell system cannot be considered as analogous to a gas appliance, for example, a gas range.

The fuel cell system operates at elevated temperatures, has exhaust requirements, and produces by-products, while supplying ac power to the home. However, the fuel cell system produces electricity without combustion and at higher efficiencies than most centrally generated electricity. In addition, the waste by-products are water and heat, both of which may be reused in the home or fuel cell system itself.

The building codes regulating the deployment of fuel cell systems are developing rapidly but as of yet, the experience with siting, operating and maintaining fuel cell systems is limited. The specific applications and methodologies for connecting the fuel cell system to the home are also varied and developing, often dependent on an individual consumer's particular needs.

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