UTC Power
A United Technologies Company

MODEL 400
PureCell® System

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PRODUCT DATA AND APPLICATIONS GUIDE

The PureCell® Model 400 Energy Solution

PureCell®

energy
Reinvented

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The Model 400 is designed to provide safe and reliable service when operated within design specifications, according to all applicable instructions, and with the appropriate operating materials. When operating this equipment, use good judgment and follow safety precautions to avoid damage to equipment and property or injury to personnel. Be sure to understand and follow the procedures and safety precautions contained in all applicable instructions, operating materials, and those listed in this manual.

All information in this document is as of 16 May 2011.

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CONTENTS

Section ***Page***

DISCLAIMER ii

1. PRODUCT DESCRIPTION 1-1

1.1 System Overview 1-1

1.2 Performance Overview 1-1

1.3 Powerplant Description 1-2
1.3.1 Subsystem Descriptions 1-2
1.3.1.1 Fuel Processing System 1-3
1.3.1.2 Power Supply System 1-4
1.3.1.3 Thermal Management System/Water Treatment System 1-5
1.3.1.4 Electrical System Module 1-6
1.3.1.5 Air Processing System 1-6
1.3.2 Cooling Module 1-7

1.4 Remote Monitoring System 1-7

1.5 Product Certification 1-8

1.6 Product Life 1-8

1.7 Storage Requirements 1-8

1.8 Component Sizes 1-9

1.9 Transportation and Rigging Information 1-9

1.10 Hazardous Materials 1-9
1.10.1 Shipping of Hazardous Material 1-10
1.10.1.1 Integrated Low Shift Converter 1-10
1.10.1.2 Cell Stack Assembly 1-10
1.10.1.3 Integration into Fuel Cell Powerplant 1-10
1.10.2 Servicing of Product with Hazardous Material Present 1-10
1.10.3 Hazardous Waste 1-10

1.11 Safety Hazard Analysis 1-10
1.11.1 Fire Detection and Protection 1-10
1.11.2 Gas Leak 1-10
1.11.3 Hydrogen 1-11
1.11.4 Phosphoric Acid 1-11
1.11.5 Fluid Leak 1-11

2. PERFORMANCE DATA 2-1

2.1 Electrical 2-1
2.1.1 Net Power Rating 2-1
2.1.2 Start-Up and Parasitic Power 2-1
2.1.3 Grid-Connect Electrical Characteristics 2-1
2.1.4 Grid-Independent Electrical Characteristics 2-2
2.1.5 Efficiency, Fuel Consumption 2-3

Section **Page**

2.2 Part Power Operation ... 2-4

2.3 Heat Recovery ... 2-4
  2.3.1 Use of Powerplant Heat ... 2-4
  2.3.2 Heat Recovery Characteristics & Heat Exchanger Pressure Drop ... 2-5
    2.3.2.1 Low Grade Heat Available ... 2-5
    2.3.2.2 High Grade Heat Available ... 2-7
    2.3.2.3 Secondary Low Grade Heat Available ... 2-9
    2.3.2.4 External Mixing of Low-Grade and High-Grade Heat ... 2-9
    2.3.2.5 Heat Recovery Tables ... 2-10
    2.3.2.6 Pressure Drop Curves ... 2-11
  2.3.3 Absorption Chiller ... 2-12

2.4 Emissions ... 2-12

2.5 Noise ... 2-12

3. SITE DESIGN GUIDELINES ... 3-1

3.1 Environment Conditions ... 3-1

3.2 Natural Gas ... 3-1

3.3 Make-Up Water ... 3-2

3.4 Nitrogen Purge System ... 3-2

3.5 Electrical Interfaces ... 3-3
  3.5.1 Grid-Connected (3-Wire) ... 3-3
  3.5.2 Grid-Independent (3-Wire) ... 3-3
  3.5.3 Grid-Independent (4-Wire) ... 3-4
  3.5.4 Grid-Independent Load Control and Sequence of Operations ... 3-5
    3.5.4.1 Grid-Independent Performance Ratings ... 3-5
    3.5.4.2 Guidelines for GI Sequence of Operations ... 3-6
    3.5.4.3 Example Sequence of Operations for Grid-Independent Load Pickup ... 3-7
  3.5.5 Multi-Unit Load Share ... 3-9

3.6 Controls Interfaces ... 3-9
  3.6.1 Normal Shutdown ... 3-9
  3.6.2 Fast (Emergency) Shutdown ... 3-9
  3.6.3 Grid Circuit Breaker Enable ... 3-9
  3.6.4 Power Output Set Point (kW Dispatch) ... 3-9
  3.6.5 Load Following Control (Zero Power Export) ... 3-10
  3.6.6 High Grade Heat Remote Temperature Control ... 3-10
  3.6.7 External Ventilation Fan Control and Sensing ... 3-10
    3.6.7.1 External Heat Recovery Pump Start/Start Signal or BMS Fuel Cell Operation Status Signal ... 3-10
  3.6.8 Purge Gas Supply Pressure Switch ... 3-10

3.7 Remote Monitoring System ... 3-11
  3.7.1 Heat Recovery Monitoring ... 3-11
  3.7.2 Building Management Interface ... 3-12

3.8 Utility Interconnection Components Data ... 3-12

Section **Page**

- 3.8.1 Powerplant Interconnection Circuit Breaker MCB001 3-12
- 3.8.2 Main Disconnect Switch MDS001 (Part of Powerplant) 3-12
- 3.8.3 Optional Site-Installed Protection Equipment 3-12

3.9 Siting Options.... 3-13
- 3.9.1 Building Roof Siting 3-13
- 3.9.2 Indoor Siting 3-15
  - 3.9.2.1 Key Requirements....3-15
  - 3.9.2.2 Accessibility....3-16
  - 3.9.2.3 Powerplant Ventilation Requirements....3-16
  - 3.9.2.4 Testing Requirements....3-19

3.10 Central Cooling Option 3-19

3.11 Guide Specification.... 3-20

APPENDIX A — FC 1 REFERENCED STANDARDS A-1

FIGURES

Figure **_Page_**
1-1. Process Overview 1-1
1-2. PureCell® System Model 400 Installation Example....................1-2
1-3. Five Subsystems of the PureCell® System Model 400 1-3
1-4. Fuel Cell Repeat Element 1-4
1-5. Four Fuel Cell Stack Configuration....................1-5
1-6. Model 400 Inverter 1-6
1-7. Air Cooling Module 1-7
1-8. RMS Architecture 1-8
2-1. Model 400 Performance Vs. Operating Hours 2-3
2-2. Model 400 Performance Vs. Power Output....................2-4
2-3. Powerplant Heat Recovery Interfaces 2-5
2-4. Total Average Heat Available at 400 kWe Output Vs. Inlet (Cold Side) Temperature 2-6
2-5. Total Heat Available at 400 kWe Output Vs. Inlet (Cold Side) Temperature....................2-8
2-6. LG HEX Pressure Drop Vs. Flow, Customer (Cold) Side....................2-11
2-7. High Grade Heat Exchanger Pressure Drop Vs. Flow, Customer (Cold) Side....................2-11
3-1. Grid-Connect Only Configuration 3-3
3-2. Grid-Connect With Grid-Independent Back-up Power Configuration (3-Wire) 3-4
3-3. Grid-Connect With Grid Independent Back-up Power Configuration (4-Wire) 3-5
3-4. Optional HRM Architecture 3-11
3-5. Indoor Ventilation Schematic....................3-17
3-6. Fuel Cell Conceptual Central Heat Rejection Design....................3-20

TABLES

Table ***Page***

1-1. Powerplant Performance 1-2

1-2. Component Sizes....................1-9

2-1. Grid-Connected Electrical Characteristics 2-1

2-2. Grid-Independent Electrical Characteristics....................2-2

2-3. Exit Temperatures from LG HEX as a Function of Inlet Temperature and Flowrate....................2-10

2-4. Exit Temperatures from HG HEX as a Function of Inlet Temperature and Flowrate 2-10

2-5. Exit Temperatures from LG HEX as a Function of Inlet Temperature and Flowrate....................2-10

2-6. PureCell® Model 400 Emissions Data 2-12

3-1. Allowable Gas Composition....................3-1

3-2. Allowable Make-Up Water Composition....................3-2

3-3. General RO Specification....................3-2

3-4. Purge Gas Specification 3-3

3-5. Nominal Power Module Exhaust Conditions....................3-17

3-6. Ventilation Flows 3-18

ACRONYMS

	A
AC	Alternating Current
APS	Air Processing System
ATS	Automatic Transfer Switch
	B
BMI	Building Management Interface
BMS	Building Management System
BOL	Beginning of Life
	C
CARB	California Air Resources Board
CHP	Combined Heat and Power
CSA	Cell Stack Assembly
	D
DC	Direct Current
DG	Distributed Generation
DOT	Department of Transportation
	E
EOL	End of Life
ESM	Electrical System Module
	F
FPS	Fuel Processing System
	H
HG	High Grade
HRM	Heat Recovery Monitoring
	I
ILS	Integrated Low-Temperature Shift Converter
IMDG	International Maritime Dangerous Goods
	L
LG	Low Grade
	M
MSDS	Material Safety Data Sheets
MTS	Manual Transfer Switch
MULS	Multi-Unit Load Share
	P
PAFC	Phosphoric Acid Fuel Cell

PCS	Power Conditioning System
PPC	Powerplant Controller
PSS	Power Supply System
	R
RMS	Remote Monitoring System
RO	Reverse Osmosis
	S
SCF	Standard Cubic Feet
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
	T
TDS	Total Dissolved Solids
TMS	Thermal Management System
	U
UN	United Nations
	W
WTS	Water Treatment System

1. PRODUCT DESCRIPTION

1.1 SYSTEM OVERVIEW

The PureCell® system Model 400 is a stationary phosphoric acid fuel cell (PAFC) powerplant intended for distributed generation (DG) and combined heat and power (CHP) applications. It is capable of producing 400 kW of continuous, reliable electric power while generating useable waste heat. This heat can be used for space heating, hot water applications, and for driving an absorption chiller to provide cooling. The Model 400 can also provide backup power when the electric utility service fails. As long as natural gas is available, electric power and heat can be generated.

Figure 1-1 shows the basic operation of the system. Natural gas is first converted to hydrogen in the fuel processing system (FPS) through a process known as catalytic steam reformation. Hydrogen and air are then supplied to four phosphoric acid fuel cell stacks, in which hydrogen and oxygen combine electrochemically to produce direct current (DC) electricity, heat, and water. Finally, alternating current (AC) electricity is produced through an on-board DC to AC inverter. Heat generated in the fuel cell process generates steam, which is returned to the FPS for use in the steam reformation process. Useable heat is delivered to a customer-supplied water source through on-board heat recovery heat exchangers.

Figure 1-1. Process Overview

1.2 PERFORMANCE OVERVIEW

Table 1-1 summarizes the performance characteristics of the Model 400 system. Detailed performance information is provided in Section 2 of this guide.

Table 1-1. Powerplant Performance

Characteristic	***Performance***
Net Power Output	400 kW/471 kVA, 480 V, 60 Hz, 3-wire
Electrical Efficiency, LHV	>40% initial >38% 10-year average
Fuel Consumption, HHV	3.79 MMBTU/hr initial 3.99 MMBTU/hr 10-year average
Recoverable Heat	1.73 MMBTU/hr initial 1.88 MMBTU/hr 10-year average
Overall System Efficiency, LHV	Up to 90%

1.3 POWERPLANT DESCRIPTION

The Model 400 is a factory-assembled and tested fuel cell powerplant rated for outdoor service, which is composed of two main components: a power module and a cooling module. The power module is an assembly of five subsystems that are assembled and tested as a complete unit at UTC Power's manufacturing facility. The power module is delivered to a site with no additional assembly required. A factory-supplied cooling module is typically required and can be positioned at the installation site along with site-specific equipment, wiring, and plumbing. ***Figure 1-2*** shows each component at a typical site installation.

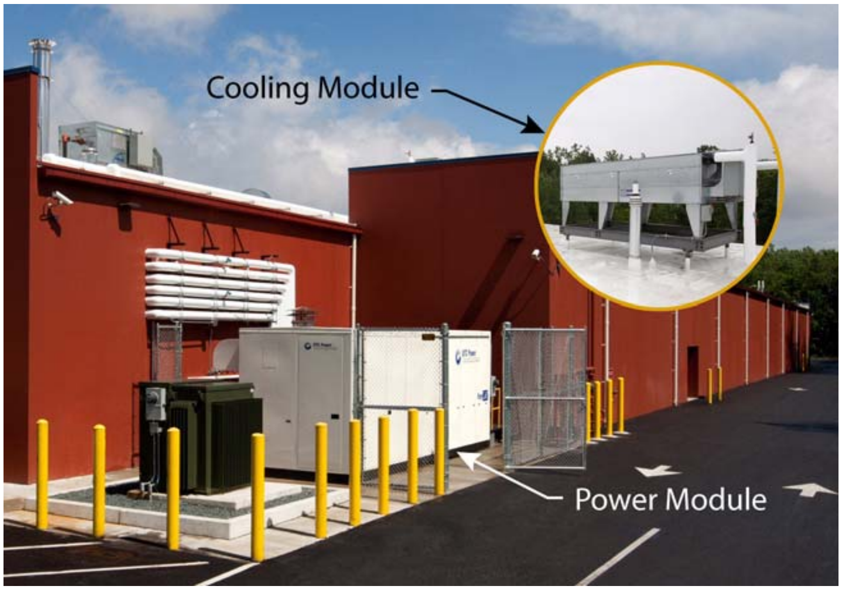

Figure 1-2. PureCell® System Model 400 Installation Example

The Model 400 is a derivative of a 200 kW fuel cell powerplant, the PureCell® system Model 200, that was in production from 1991 to 2008 and has been installed at over 260 sites worldwide. With over 9 million operating hours and more than 1.5 billion kWh of electricity generated, UTC Power's fleet of phosphoric acid fuel cells has demonstrated world-class reliability and durability. These attributes continue to be the guiding principles of UTC Power's stationary fuel cell business.

1.3.1 Subsystem Descriptions

The power module is composed of five major subsystems, as shown in ***Figure 1-3***.

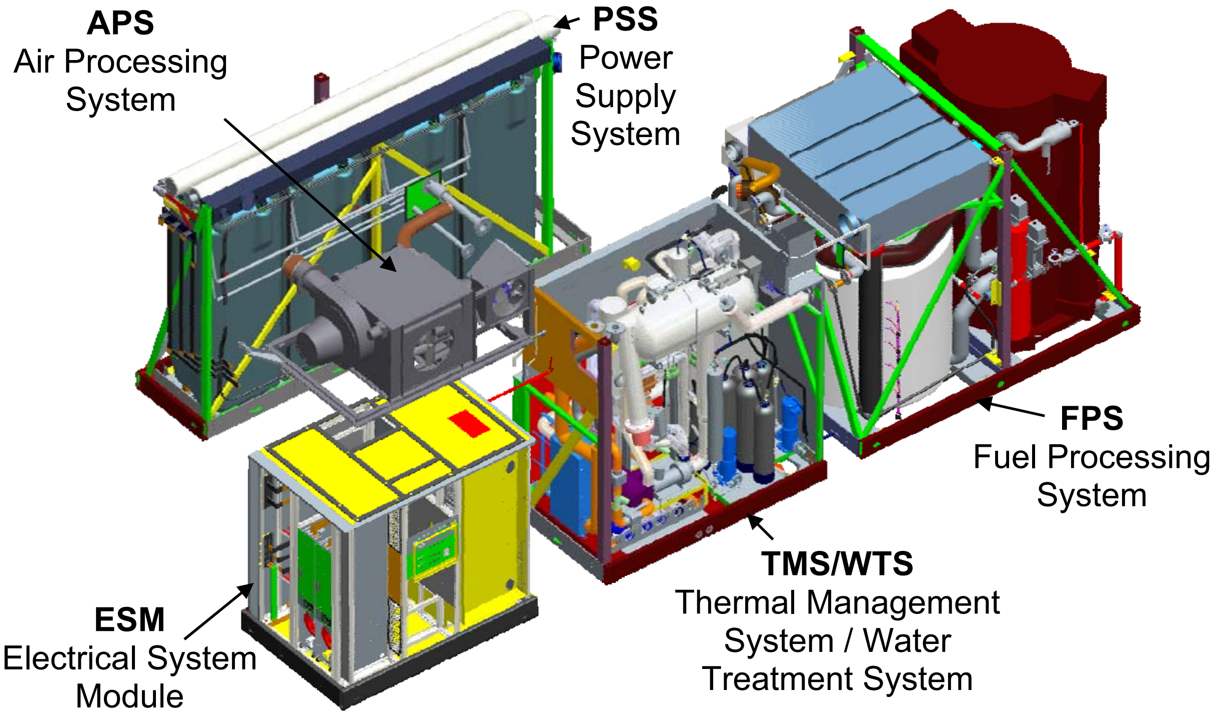

Figure 1-3. Five Subsystems of the PureCell® System Model 400

1.3.1.1 Fuel Processing System

The FPS converts pipeline-quality natural gas into hydrogen reformate; a hydrogen-rich gas that is delivered to the anode side of the fuel cell stacks. This module includes a condenser to recover water generated in the fuel cell reaction by condensing water vapor from the process exhaust. This eliminates the need for makeup water under most operating conditions. The recovered water is used in the steam reformation process.

The main components of the FPS include the following:

Hydro-Desulfurizer

The desulfurizer system removes sulfur used as an odorant in natural gas. The sulfur is a poison to the catalysts used in the fuel cell systems. This system will also remove small amounts of oxygen in the gas.

Steam Reformer

Steam (H_2O) generated in the cell stack cooling loop of the TMS is combined in the reformer with methane (CH_4) in the natural gas to generate a gas composed of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2). Natural gas containing nitrogen will also result in the creation of a small quantity of ammonia.

$$2CH_4 + 3H_2O = 7H_2 + CO + CO_2 \qquad \textit{Equation 1}$$

Integrated Low-Temperature Shift Converter

The integrated low-temperature shift converter (ILS) generates additional hydrogen through a water-gas reaction in which CO and water is converted to hydrogen and CO_2. The reduced CO content minimizes its adverse effect on fuel cell stack performance.

$$CO + H_2O = H_2 + CO_2 \qquad \text{Equation 2}$$

Ammonia Scrubber

An important feature of this FPS, new to PureCell® products, is the ammonia reduction device or scrubber, designed to minimize the ammonia entering the anode side of the fuel cell. Ammonia is formed in the fuel processor from the nitrogen present in natural gas. The ammonia scrubber increases the system's tolerance to nitrogen content, increasing fuel cell stack life to 10 years operating time.

Condenser

The condenser recovers water vapor entrained in the system exhaust. This water, which was produced in the fuel cell reaction, is returned to the TMS and ultimately becomes the source of the water used in the reformer. The heat recovered in the condenser is also the source of low-grade heat available to heat a customer-supplied fluid.

1.3.1.2 Power Supply System

The PAFC stack, like other fuel cell stacks, is constructed of numerous repeating elements. A diagram of one such repeat element is shown in ***Figure 1-4***. Each cell is composed of a matrix containing a phosphoric acid (H_3PO_4) electrolyte, an anodic layer and a cathodic layer.

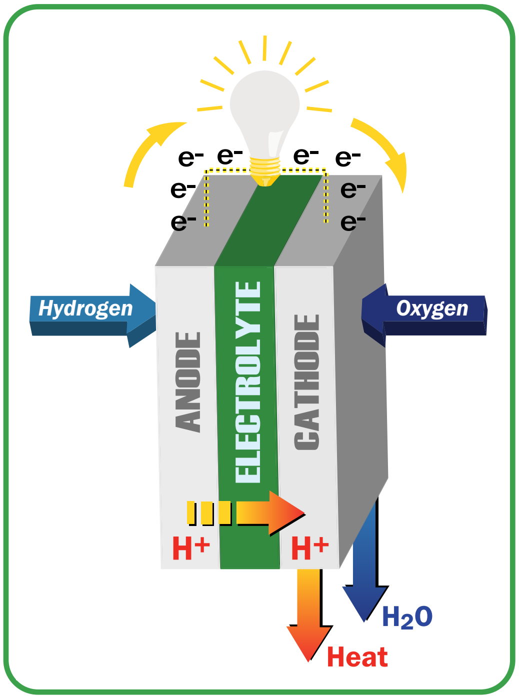

Figure 1-4. Fuel Cell Repeat Element

Hydrogen fuel flows into the cell through flow channels in a separator plate. The separator plate provides gas separation between the anode and the cathode in the repeating cells. The hydrogen interacts electrochemically with the anode catalyst to liberate an electron from the incoming hydrogen atoms, as shown in Equation 4. The phosphoric acid absorbed within the matrix material forms a proton-conducting electrolyte through which the remaining hydrogen proton migrates to the cathode catalyst layer. The electron is forced to flow around the electrolyte, creating an electric current. The oxygen consumed in the process is obtained by flowing air into the channels of the separator plate on the cathode side of the cell. Equation 5 illustrates the electrochemical reaction on the cathode side, which allows for the recombination of the proton with the electron to form the resulting water molecule.

Basic Fuel Cell Reaction:

$$2H_2 + O_2 \rightarrow 2H_2O$$ *Equation 3*

Anode Electrochemical Reaction:

$$2H_2 \rightarrow 4H^+ + 4e^-$$ *Equation 4*

Cathode Electrochemical Reaction:

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$$ *Equation 5*

The power supply system (PSS) module contains the four fuel cell stacks that comprise the heart of the Model 400. Each fuel cell stack, or cell stack assembly (CSA), contains 376 individual cells, and is capable of generating over 100 kW of electricity. The four CSAs are electrically connected in series, as shown in ***Figure 1-5***, and together generate a high-voltage DC current.

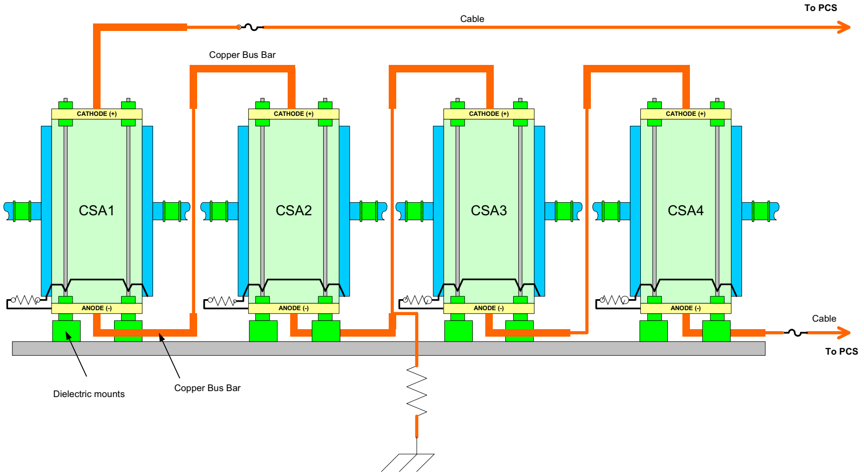

Figure 1-5. Four Fuel Cell Stack Configuration

Hydrogen reformate and air flow to each CSA in parallel such that the output power level is the same across all four CSAs. The product water from the fuel cell reaction leaves the CSAs in the process exhaust gases. The heat generated during the reaction is removed by flowing water through isolated cooling plates located throughout the cell stack assembly.

1.3.1.3 Thermal Management System/Water Treatment System

The thermal management system (TMS)/water treatment system (WTS) maintains thermal balance in the system by providing cooling water to the fuel cell stacks and to the balance-of-plant systems. Steam generated in the cell stack loop is transferred to the FPS for use in the natural gas reformation process. The TMS includes two heat-recovery heat exchangers and the controls and interface for rejecting heat to the Model 400 cooling module.

Heat recovered from the fuel cell process is provided to the customer in both low and high-grade form. High-grade heat is generated in the cell stack coolant loop and is capable of heating customer-supplied fluids to 250°F (121°C). High-grade heat constitutes approximately 40 percent of total heat available from the system. Low-grade heat is primarily generated in the condenser and is capable of heating fluids up to 140°F (60°C). Unused high-grade heat is also available in the low-grade loop at reduced temperatures. Heat recovery is explained in detail in Section 2.3.

The WTS provides process water at the proper quality for the fuel cell stacks and balance-of-plant. This is done by circulating the recovered water through a series of demineralizer bottles. Makeup water is typically not required when operating at ambient temperatures below 86°F (30°C); at temperatures above this value the makeup water is pre-treated internally prior to being polished in the same demineralizer bottles. External makeup water pre-treatment may be required in areas with poor water quality.

1.3.1.4 Electrical System Module

The electrical system module (ESM) functions as both the power conditioning system (PCS) and operating controller for the entire powerplant. DC voltage is received from the fuel cell stacks and inverted to provide a 480 VAC, 60 Hz, 3-wire output to the customer facility. The inverter-based system will automatically synchronize with the building electric system (utility grid) without the need for separate synchronizing equipment.

The ESM is also capable of providing 480 VAC power for selected customer loads during utility outages. When this grid-independent power capability is employed, the selected customer loads are normally powered by the fuel cell and utility grid. When a utility grid outage occurs, the fuel cell will transition to grid-independent operation in less than 10 seconds, and will load-follow to meet the requirements of the selected loads. The loads must be controlled to meet the load pick-up capability of the fuel cell (defined in ***Table 2-2***).

The powerplant controller is located in the ESM, providing autonomous control and remote control from the UTC Power control center through the separately supplied Remote Monitoring System (RMS) (Section 1.4). The parasitic power requirements of the balance-of-plant (motors, pumps, sensors, etc.) are also provided from the ESM. ***Figure 1-6*** is a one-line schematic representation of the electrical system.

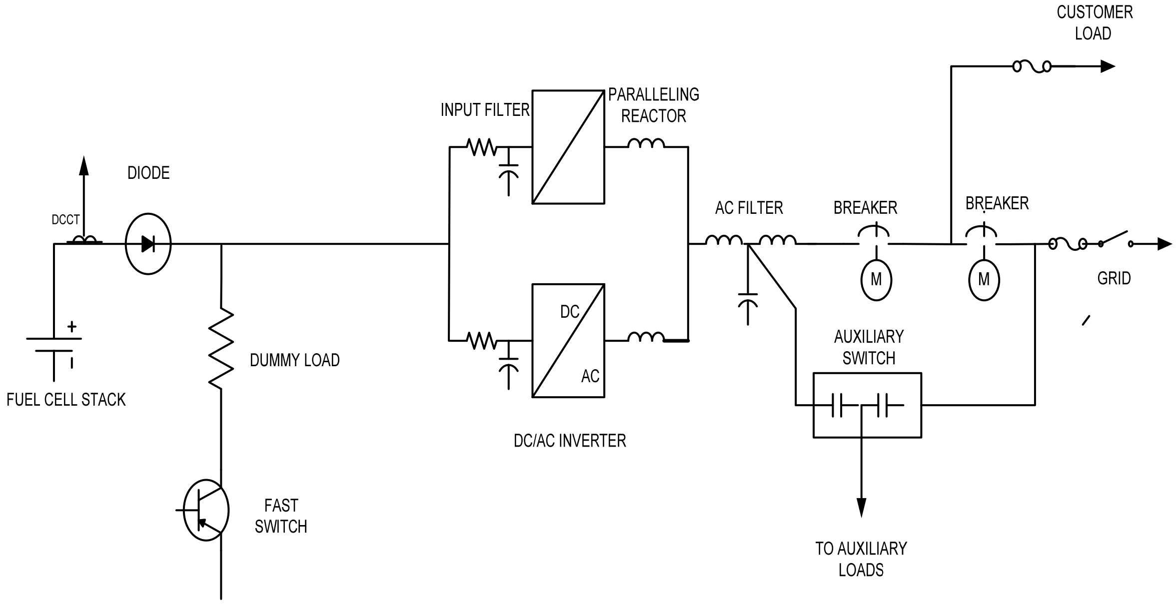

Figure 1-6. Model 400 Inverter

1.3.1.5 Air Processing System

The main function of the air processing system (APS) is to supply filtered process air to the fuel cell cathode and the FPS. A low-pressure centrifugal blower provides the needed air flow. Ventilation air is also supplied to the fuel and motor compartments located within the enclosure to properly cool and ventilate the components located within. In the event of a leak within the enclosure, the airflow provided by the blowers in the APS prevents the formation of a combustible mixture of fuel.

1.3.2 Cooling Module

The Model 400 system includes a remote dry air cooler to ensure complete heat rejection and fuel cell system cooling. As shown in ***Figure 1-7***, the cooling module has six fans that are powered directly from the powerplant as a parasitic load; cooling module operation does not reduce the net power output of the Model 400. The fans operate at variable speed and are automatically controlled to maintain internal system temperatures. Customer heat recovery reduces the total load on the cooling module.

Figure 1-7. Air Cooling Module

Although remote from the power module, the cooling module is designed as an integral component of the low-temperature coolant system of the TMS. The pump, relief valve, and controls used to drive the glycol cooling fluid are located within the powerplant. The cooling module includes an integral expansion tank and an electrical disconnect switch.

The cooling module can be remotely located from power module (refer to UTC Power sample installation drawings for requirements). It can also be mounted on top of the power module using the optional roof-mounted cooling module platform. A facility central cooling system may be used in lieu of the air cooling module, but it is imperative that the central tower system have emergency backup power, so that it continues to operate during utility grid outages. Contact UTC Power for more details.

1.4 REMOTE MONITORING SYSTEM

The powerplant includes an Internet-based communication system, called the RMS. The RMS provides the UTC Power Control Center with remote access to powerplant operating data and allows limited control, including start-up, power output kW set point and shut-down commands. The powerplant can independently “call out” to alert technicians of out-of-limit parameters, status, and need for maintenance. The RMS also supplies the system owner with website access to view the powerplant’s operating status. ***Figure 1-8*** represents the architecture of the RMS. UTC Power's preferred method of connecting to the Internet is through a secure wireless cellular modem built-in to the RMS hardware. Alternatively, a dedicated wired connection can be provided by the site owner through a separate, independent connection not connected to the site's existing or planned network or behind any firewalls.

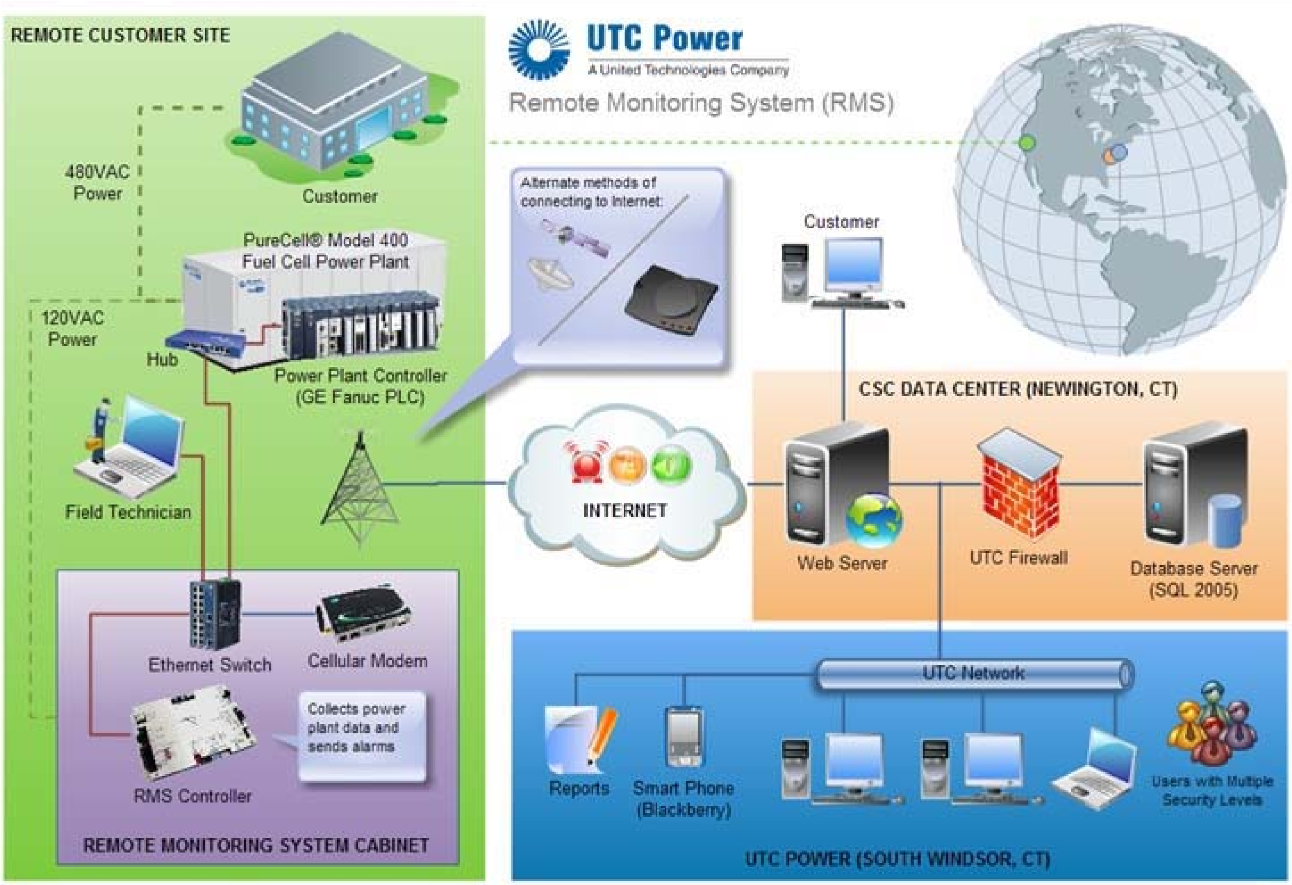

Figure 1-8. RMS Architecture

1.5 PRODUCT CERTIFICATION

The Model 400 has been designed to meet ANSI/CSA America FC 1 — 2004, American National Standard/CSA America Standard for Stationary Fuel Cell Power Systems. See Appendix A for a complete list of referenced standards.

The Model 400 inverter has been certified to UL1741 2005, conforms to IEEE1547, and is listed as an eligible technology by the California Energy Commission.

1.6 PRODUCT LIFE

The fuel cell powerplant is designed to have a 20-year product life. This requires overhaul or replacement of major components after 10 years of operation. Components requiring overhaul include the fuel cell stack assemblies and components in the FPS.

1.7 STORAGE REQUIREMENTS

The power module has been conditioned at the factory to withstand shipping and storage temperatures from -20° to 113°F (-29° to 45°C). The power module must have a weather-proof cover installed until the air ventilation hoods and lifting point cover plates are installed.

The power module is constructed without a base floor and should be stored on a flat concrete pad to prevent animals, etc., from entering the unit. When storing on dunnage steel, a temporary floor should be provided. For permanent installations on curbs or dunnage steel, an optional power module floor is available from UTC Power.

The air cooling module is shipped dry and may be stored on a flat surface or dunnage as received. Ensure that the inlet and outlet pipe connections are sealed to prevent rain water and other debris from entering the piping.

1.8 COMPONENT SIZES

Component sizes and weights are provided in ***Table 1-2***.

Table 1-2. Component Sizes[1]

Description	***Quantity***	***Length***	***Width***	***Height***	***Weight***
Powerplant	1	27'-4”	8'-4”	10'-0”	60,000 lb
Components:					
• CSA	4	3'-4”	3'-3”	9'-1”	4,500 lb
• Reformer	1	4'-4”	4'-4”	9'-7”	5,900 lb
• ILS	1	5'-1”	5'-1”	6'-7”	9,000 lb
• Condenser	1	5'-8”	2'-0”	7'-2”	2,400 lb
• ARD	1	1'-10”	1'-10”	8'-0”	2,200 lb
• PCS	1	4'-0”	4'-0”	4'-6”	5,000 lb
• N2 Bottle	10	0'-11”	0'-11”	4'-2”	100 lb
• DMN Bottle	6	0'-10”	0'-10”	4'-2”	250 lb (wet)
• Max Component		**5'-8”**	**5'-1”**	**9'-7”**	**9.000 lb**

[1] Powerplant components may be temporarily tipped up to 45 degrees during handling to reduce height.

1.9 TRANSPORTATION AND RIGGING INFORMATION

Refer to the Installation Manual (FCMAN70865) for transportation and rigging information.

1.10 HAZARDOUS MATERIALS

The Model 400 is a PAFC powerplant, capable of delivering 400 kW of electric power. As with other fuel cell technologies, hydrogen and oxygen combine in the presence of a catalyst, which causes an electrochemical reaction to produce an electric current. A PAFC uses an inorganic, concentrated phosphoric acid as the electrolyte, allowing the electrochemical reaction to take place. The Model 400 also employs on-board natural gas reforming as part of the balance of plant to provide hydrogen to the fuel cell. Within this powerplant, there are only two components that contain hazardous material: the CSA and the ILS. Neither of these components present risk when servicing the powerplant. The material in both the CSA and the ILS is classified as hazardous material for the purposes of shipping and therefore requires special attention.

The CSA is a layered bulk bin, made from the repeating elements of the fuel cell stack. Some of these repeating elements are porous carbon graphite plates. The phosphoric acid used as the electrolyte is contained by capillary action within the pores of these plates.

The ILS is a tank containing a self-heating solid catalyst composed of copper, zinc oxide, and alumina.

Material Safety Data Sheets (MSDS) are available upon request.

1.10.1 Shipping of Hazardous Material

The Model 400 is classified as "hazardous in transportation" under the U.S. Department of Transportation (DOT) 49CFR regulations, and likewise as dangerous goods under the International Maritime Dangerous Goods (IMDG) regulations. The description of hazardous materials contained within each powerplant are listed in the following subsections.

1.10.1.1 Integrated Low Shift Converter

Tank (non-spec) SELF HEATING SOLID INORGANIC N.O.S. (contains metallic copper on zinc oxide and alumina), CLASS 4.2, UN3190, PGII, 900 lb. net wt of hazardous material.

1.10.1.2 Cell Stack Assembly

Bulk bin (non-spec) SOLIDS CONTAINING CORROSIVE LIQUID N.O.S. (contains phosphoric acid), Class 8, UN3244, PGII, 1200 lb. net of hazardous material.

1.10.1.3 Integration into Fuel Cell Powerplant

The above two items are individual components that are assembled side by side in a full assembly, with other non-hazardous components, to form one complete Model 400. The containers holding the hazardous material are non DOT specification containers. U.S. DOT regulations allow for the transportation of the hazardous material noted above in non DOT specification portable tanks and closed bulk bins, as shipped in the Model 400. IMDG regulations require United Nations (UN) specified containers or an exemption for international ocean transport.

1.10.2 Servicing of Product with Hazardous Material Present

The hazardous material contained within the CSA and the ILS presents no danger to installation and service personnel since direct exposure to the material is not possible. Under normal operating conditions, each container, as defined above, will contain its hazardous material for the life of the component. When end of life requires replacement of either component, no special precautions need to be employed with respect to handling hazardous material.

1.10.3 Hazardous Waste

The fuel cell does not produce any hazardous waste. Standard MSDS are available in the product service manual.

1.11 SAFETY HAZARD ANALYSIS

The PureCell® Model 400 fuel cell system has been designed to meet strict ANSI/CSA safety standards to protect against risks from electrical, mechanical, chemical, and combustion safety hazards. The following items are a few of the safety measures incorporated into the design.

1.11.1 Fire Detection and Protection

The powerplant design incorporates a combustible gas sensor and thermal fuses located throughout the power module cabinet to detect fire. The detection of a potential combustible gas mixture, a fire, or the failure of this detection circuit will result in a powerplant shutdown and a subsequent inert gas (nitrogen) purge of the fuel cell stack and fuel processing system. This event will also result in an alarm callout notification to UTC Power service personnel.

The powerplant is designed with an integral emergency-stop button on the outside of the enclosure to enable immediate shutdown in the event of an emergency. There is also a gas shut-off valve and electrical disconnect switch easily accessible to emergency personnel.

1.11.2 Gas Leak

The powerplant is designed to have a physical barrier that separates the equipment handling combustible gases (fuel compartment) from electrical or potential spark-creating equipment (motor compartment). The fuel compartment is kept at a negative pressure relative to both ambient and the motor compartment in order to contain and remove any potential gas leaks.

1.11.3 Hydrogen

Hydrogen is lighter than air and thus does not pool like other fuels and will readily dissipate with proper ventilation making it less likely to ignite. Although hydrogen has low self-ignition characteristics, the fuel in the powerplant is not pure hydrogen. Also, the powerplant is not storing hydrogen; it produces hydrogen-rich gas equal to what it requires to produce power.

The fuel cell stack is wrapped in a fire-retardant blanket. There are no materials inside the unit that would sustain a flame. There is no large volume of gas or any ignition that occurs within the cell stack. UTC Power's worldwide fuel cell fleet of more than 290 powerplants has accumulated over 9 million operating hours without any incident of fire or explosion.

1.11.4 Phosphoric Acid

Phosphoric acid is integral part of the fuel cell system, acting as the electrolyte within the fuel cell stack. Phosphoric acid is a surprisingly common substance that is contained in common cola drinks. A leak of phosphoric acid is not possible because phosphoric acid is not in liquid form once applied in the equipment. There is no reservoir of liquid. Phosphoric acid is contained in the porous structure of the fuel cell stack material by capillary action, similar to how ink is absorbed into a blotter.

1.11.5 Fluid Leak

The only fluid source is water. All pressurized water vessels are designed to ASME boiler codes and inspected annually. All piping, welds, etc. meet pressurized piping standards. Water produced through the electrochemical process is “pure” water and is reclaimed and reused by the process. The other source of water is water used in the external cooling module, which is mixed with propylene glycol and a rust inhibitor to prevent rust and freezing in colder climates.

2. PERFORMANCE DATA

2.1 ELECTRICAL

2.1.1 Net Power Rating

The Model 400 is designed to provide the customer with a net output of 400 kW over the 10-year design life of the cell stacks. The power consumed by the air cooling module to reject waste heat not recovered by the customer is an internal load and does not reduce power output. After the cell stacks exceed design life, the powerplant may still be operable at reduced power output. In grid-independent mode, the power rating is reduced to 350 kW.

2.1.2 Start-Up and Parasitic Power

The Model 400 is started using the customer's electric distribution system. The start-up process takes approximately 3 to 5 hours, and the peak electrical demand is approximately 150 kW. The start-up power is primarily used to heat the fuel processor and cell stacks to operating temperature using electrical heating elements. After start-up the powerplant will directly power its air cooling module and communication system as internal loads, maintaining a net design output power to the customer of 400 kW. In the event of a building electrical outage, the powerplant will isolate itself from the building distribution system and either operate at idle (no net output power), or in grid-independent operation powering an isolated electric load.

2.1.3 Grid-Connect Electrical Characteristics

Table 2-1. Grid-Connected Electrical Characteristics[1]

Grid-Connected Electrical Output Characteristics	
Powerplant Rating	
Rated Capacity - net	400 kW/471 kVA
Voltage and Frequency-Standard Configuration	480 Volts, 3-Phase, 3-Wire, 60-Hz
Electrical Characteristics	
Operating Range	0 kW to 400 kW
Maximum Continuous Output Current	625A RMS
Fault Current Contribution	3620A for 5ms
Voltage Accuracy	Within ±3.5 VAC RMS
Zero Power Export	The powerplant can "load follow" (perform real power export control) to a customer settable utility import/export power level
Power Output Response	Accommodate change from minimum load to maximum load in less than 40 seconds at kW/second max
Power Factor Range (at nominal line voltage)	0.85 lag/lead to 1.0 (adjustable); 0.85 leading to ±5% line, 0.9% lag at +5% line.
Power Accuracy and Stability	Real Power regulated at ± 1% of rated. Reactive Power regulated at ± 2% of rated. These values will be achieved within 100 milliseconds following a Utility Grid transient
Fault Current Interrupting Capacity	65,000 amps
Line Voltage Unbalance	2% line-to-line at rated kVA. 5% with kVA derated to 85%. Derating is linear from rated. Interrupt if unbalance > 5%.

Table 2-1. Grid-Connected Electrical Characteristics[1]

Grid-Connected Electrical Output Characteristics	
Powerplant Rating	
Harmonics	Current harmonics shall be in accordance with UL1741 at rated power (when operating at standard impedance, 4% inductive shunted by a 56% resistive load). Voltage harmonics shall meet the voltage harmonic requirements of IEEE 519 for a generator source connected to the grid.
Protection	Utility interactive protection functions consistent with UL1741.
Reconnection	Powerplant reconnects automatically after a disconnect if grid is normal for a continuous 0 to 10 minute period (adjustable). No automatic reconnection occurs if disconnect is due to frequent interrupts.

[1] Standard impedance is defined as a 4% inductive shunted by a 56% resistive load.

2.1.4 Grid-Independent Electrical Characteristics

The Model 400 can provide grid-independent power (GI mode) to an isolated electrical load should the utility grid service be unavailable. In order to maintain a minimum grid-independent step-load capability of 50 kW, the maximum power output in GI mode is limited to 350 kW and 529 amps. When the utility grid fails, there is a loss of power to the isolated load of about 10 seconds while the fuel cell inverter reconfigures to operate in grid-independent mode. The fuel cell system can support an initial load of 50 kW, followed by a ramp rate of 10kW/sec, with step loads not exceeding 50 kW. The GI loads must be controlled by the customer to be within this capability (see Section 3.5 for GI load control design guidelines).

Table 2-2. Grid-Independent Electrical Characteristics

Grid-Independent Electrical Output Characteristics	
Powerplant Rating	
Rated Power Output	350 kW/440 kVA
Voltage and Frequency	480 Volts, 3-Phase, 3-Wire, 60-Hz
Electrical Characteristics	
Operating Range	0 kW to 350 kW
Maximum Continuous Output Current	625A RMS
Fault Current Contribution	3620A for 5ms
Steady State Voltage Regulation	±1% of nominal
Transient Overload Rating	679 Amps for up to 5 seconds
Step Load Capability	Maximum 50 kW initial load 10 kW/second maximum power ramp rate, increasing and decreasing 50 kW maximum step load increase
Transient Voltage Regulation	Maximum 3% voltage change, return to within 1% of normal within 100 milliseconds
Frequency Accuracy	Within ±0.1 Hz
Voltage Harmonics	Voltage THD < 3% with balanced linear load, and no single harmonic > 1% with balanced linear load.
Phase Separation	120 ± 3 Electrical Degrees.
Load Imbalance Capability	30% of rated output power

Table 2-2. Grid-Independent Electrical Characteristics (Continued)

Grid-Independent Electrical Output Characteristics	
Powerplant Rating	
Grid Synchronization	Powerplant synchronizes with the utility grid if it is present.
Transition Time	Transition from Grid Connect to Grid Independent mode occurs in less than 10 seconds

2.1.5 Efficiency, Fuel Consumption

The PureCell® Model 400 fuel cell system has a rated electrical efficiency at initial operation of 40 +/- 2%, based on lower heating value of the natural gas. System electrical efficiency is rated at ISO conditions - 15C ambient temperature, sea level, 60% relative humidity. The nominal rating does not include the electrical load of the air cooling module. Operating without full heat recovery will result in a slight decrease in electrical efficiency within the rated efficiency range.

Electrical efficiency decreases slightly over time, as the fuel cell stacks age, as shown in ***Figure 2-1***. As efficiency decreases, fuel input is automatically increased in order to maintain a net power output of 400 kW. The reduction of electrical efficiency also increases the available heat output. The average efficiency over the ten year life of the fuel cell stack is 38% (LHV).

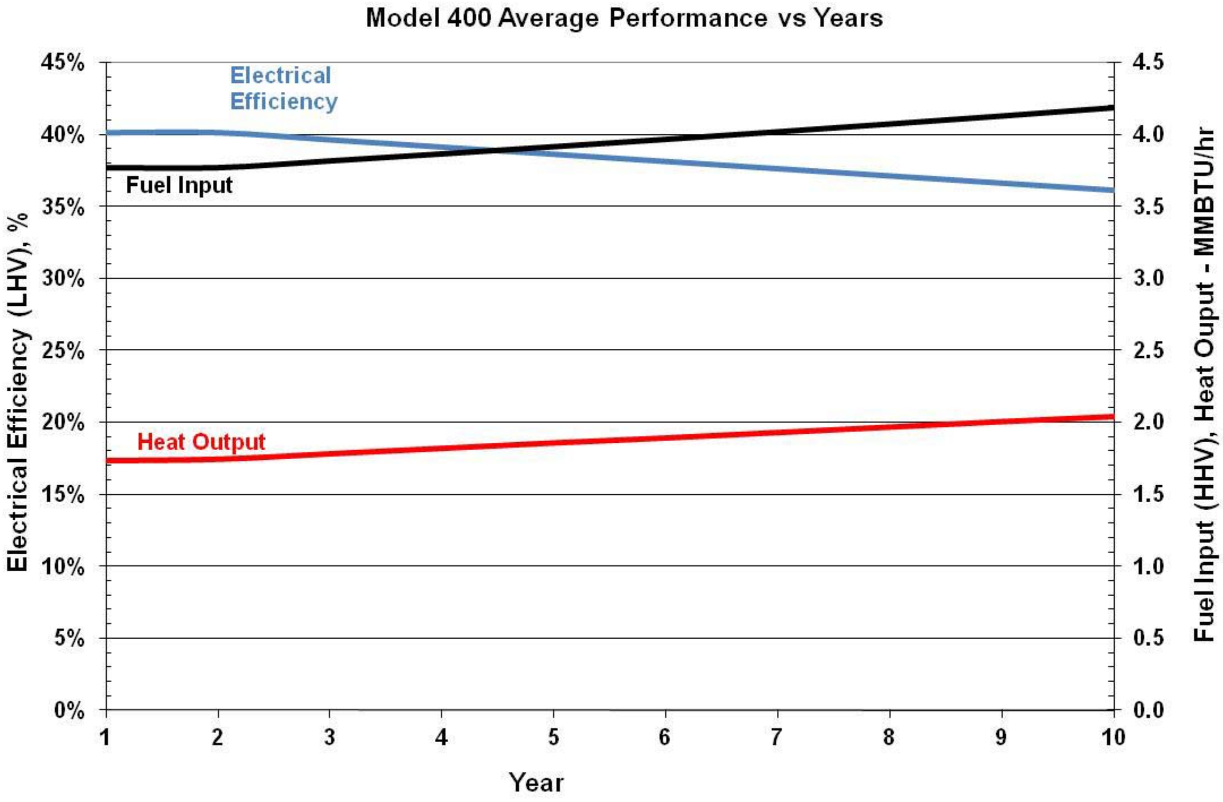

Figure 2-1. Model 400 Performance Vs. Operating Hours

2.2 PART POWER OPERATION

Figure 2-2 is based on the powerplant's beginning of life (BOL) performance.

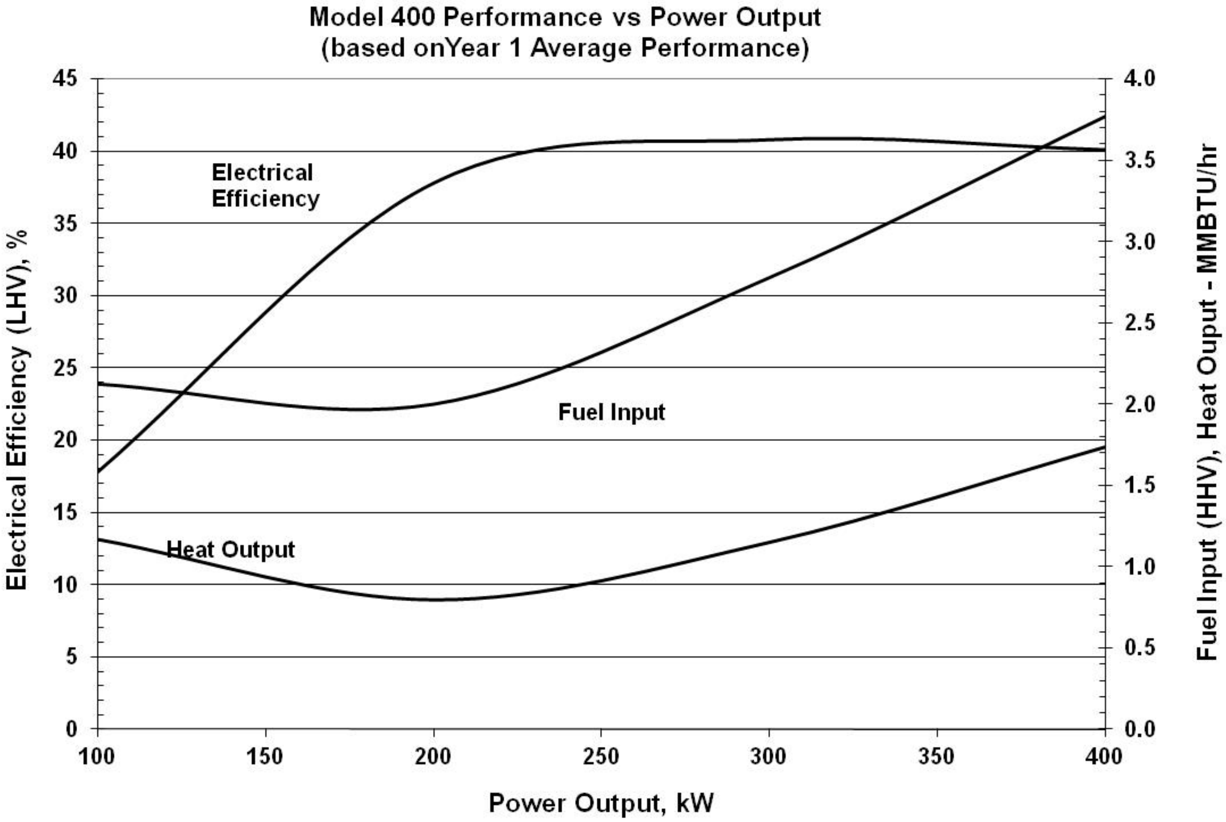

Figure 2-2. Model 400 Performance Vs. Power Output

2.3 HEAT RECOVERY

2.3.1 Use of Powerplant Heat

Since the Model 400 has been designed as a CHP solution, it is most efficient when all of the useable heat is utilized at the owner's site. When this is the case, the overall system efficiency is 90% (LHV). This is best illustrated in the following example using BOL values where appropriate:

Natural Gas (NG) Lower Heating Value (LHV) = 930 BTU/ft^3

Natural Gas (NG) Higher Heating Value (HHV) = 1030 BTU/ft^3

Natural Gas Use, HHV (BOL) = 3.8 MMBTU/hr

Fuel In (LHV)= (NG LHV/NG HHV) x Natural Gas Use (HHV)

Natural Gas Fuel In (LHV):

$$\text{Fuel In} = \left(930\frac{\text{BTU}_{\text{LHV}}}{\text{ft}^3}/1030\frac{\text{BTU}_{\text{HHV}}}{\text{ft}^3}\right) \times 3800000\frac{\text{ft}^3}{\text{hr}} = 3240000\frac{\text{BTU}_{\text{LHV}}}{\text{hr}} \approx 1000\text{ kW} \qquad \textit{Equation 6}$$

Useable Heat Output (BOL) = 1,700,000 BTU/hour (500 kWt)

Electrical Output = 400 kWe

System Efficiency = (Useable Heat Output + Electrical Output)/Fuel In

Overall System Efficiency:

$$\text{Overall System Efficiency (LHV)} = \frac{(400\text{kWe} + 500\text{kWt})}{1000\text{kW}} \approx 90\% \qquad \textit{Equation 7}$$

2.3.2 Heat Recovery Characteristics & Heat Exchanger Pressure Drop

The fuel cell powerplant has two heat recovery interfaces to directly heat customer water. These include low-grade (LG) heating delivered at up to 190ºF through a “low-grade” heat exchanger (LG HEX), and high-grade (HG) heating delivered at up to 250ºF through a “high-grade” heat exchanger (HG HEX). Actual delivery temperature to the customer from each heat exchanger will be a function of:

1. Customer inlet water temperature and flow rate
2. Powerplant power output in kilowatts
3. Powerplant age (fuel cell stack operating hours).

Maximum heat recovery is achieved when all LG heat is used. This is because the LG HEX makes available HG heat not used plus additional heat from the powerplant condenser. Powerplant LG waste heat not used by the customer is automatically rejected in the dry air cooling module provided with the powerplant. Powerplant heat may be simultaneously rejected in all three interfaces as shown in ***Figure 2-3***. Use of powerplant LG and HG heat is not required for powerplant operation.

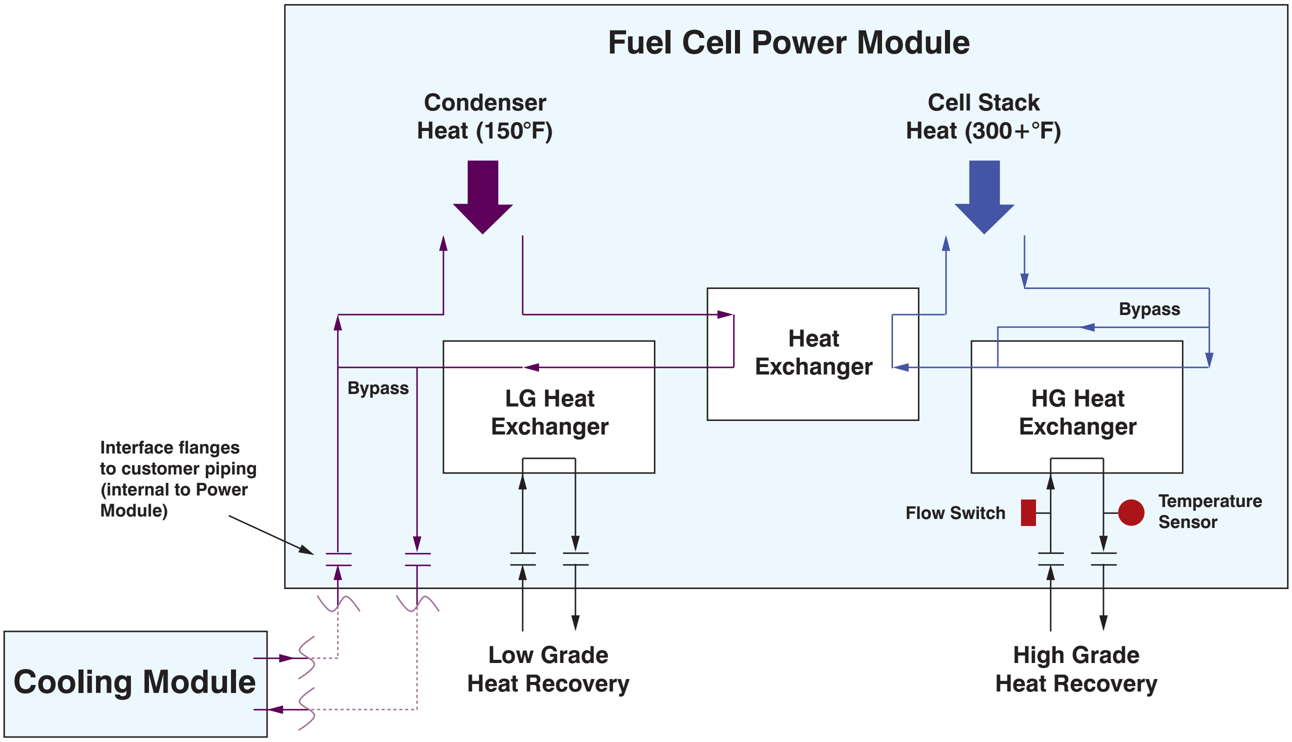

Figure 2-3. Powerplant Heat Recovery Interfaces

2.3.2.1 Low Grade Heat Available

The LG heat exchanger nominally heats a customer’s inlet water from 80º to 140ºF assuming a flow rate of about 50 gpm. When using LG heat alone (no HG heat use), approximately 1,700,000 Btu/hour of heat is available at full power operation at initial start-up. The amount of heat delivered is reduced at higher inlet (entering) temperatures, and also increases with powerplant operating hours. ***Figure 2-4*** shows the total heat available based on fuel cell stack BOL and end of life (EOL) conditions. EOL for heat recovery estimations refers to cell stack life and is defined as 10 years of operating hours (approximately 85,000 hours).

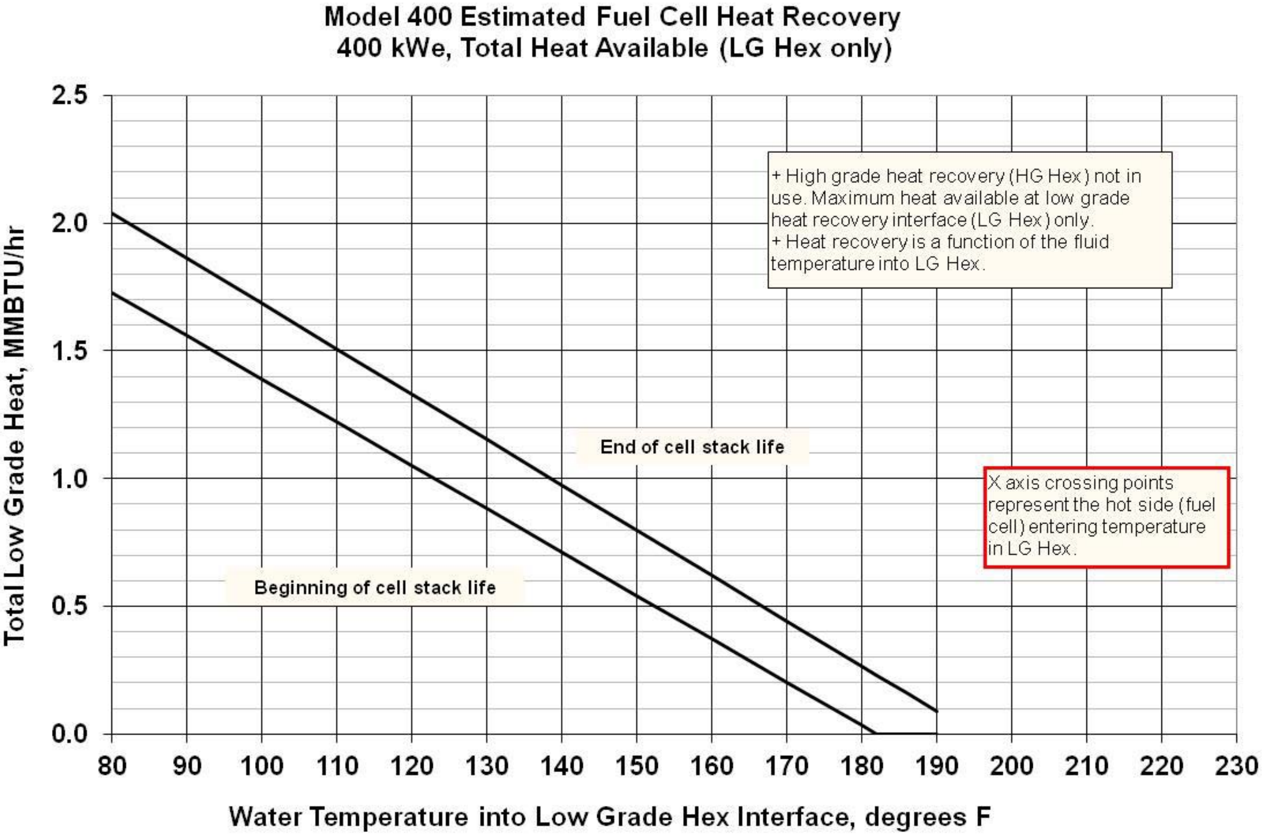

Figure 2-4. Total Average Heat Available at 400 kWe Output Vs. Inlet (Cold Side) Temperature

Heat delivery from the LG HEX is not controlled by the powerplant. The powerplant side (hot side) of this heat exchanger is always hot. Hence, heat is transferred to the customer side (cold side) of the heat exchanger whenever the powerplant is operating. The customer should control their own LG heat recovery loop to prevent overheating of any system connected to the LG HEX. Any waste heat not used by the customer will be automatically rejected in the dry air cooling module provided with the powerplant.

At a given value of LG heat availability (Btu/hour), the customer side exit water temperature is determined by the inlet water temperature and flow rate. For example, for a fixed inlet temperature, higher flow rates will reduce the exit or delivery temperature. Increases in inlet water temperature will reduce the amount of heat delivered. ***Table 2-3*** shows outlet temperatures from the LG HEX as a function of inlet flow rate and temperature at BOL and EOL conditions. Full electric power output (400 kWe) and no use of the HG HEX is assumed. The LG heat interface is designed to nominally heat 80ºF water to 150ºF with approximately 50 gpm water flow rate and delivering 1,700,000 Btu/hour at BOL. With the same flow rate at EOL conditions, the delivered water temperature will increase to about 162ºF at BOL, but the amount of available heat will decrease to roughly 1,030,000 Btu/hour.

The customer side of the LG HEX requires the installation of a customer supplied 135 psig (or lower) relief valve before any isolation valves to protect the LG HEX from over-pressurization.

The mechanical design should consider the range of fuel cell heat available from BOL to EOL conditions. A LG pressure drop curve as a function of flow rate is shown in ***Figure 2-6*** following the heat recovery tables.

2.3.2.2 High Grade Heat Available

The fuel cell powerplant also has a HG heat interface which makes available higher temperature heat from the fuel cell stack cooling loop. The HG HEX is designed to heat a customer's pressurized water supply to up to 250ºF. Heat delivery from the HG exchanger is controlled by the powerplant using a hot side bypass valve. Any amount of HG heat not used at this interface will be internally transferred to the LG heat interface, increasing the temperature of LG heat delivered. Note that the HG heat exchanger is not designed to produce steam.

The nominal amount of HG heat available is primarily a function of the electrical efficiency of the fuel cell stacks. When the powerplant is new (BOL) or after cell stack overhaul (replacement), the powerplant is more electrically efficient and therefore has less available HG heat. At BOL, approximately 700,000 Btu/hour of heat is available when operating at 400 kWe. When HG heat is being recovered, the available LG heat recovery is reduced by the amount delivered at the HG interface. The remaining LG heat is referred to as secondary LG heat.

Figure 2-5 shows available HG heat and secondary LG heat at BOL and EOL. The powerplant will adjust the hot side heat exchanger conditions to transfer only the amount of heat necessary to maintain cell stack temperature. At inlet (customer return) temperatures above 200ºF, the heat exchanger begins to get temperature pinched, which will reduce heat delivery. This "lost" heat will still be available at the LG heat interface.

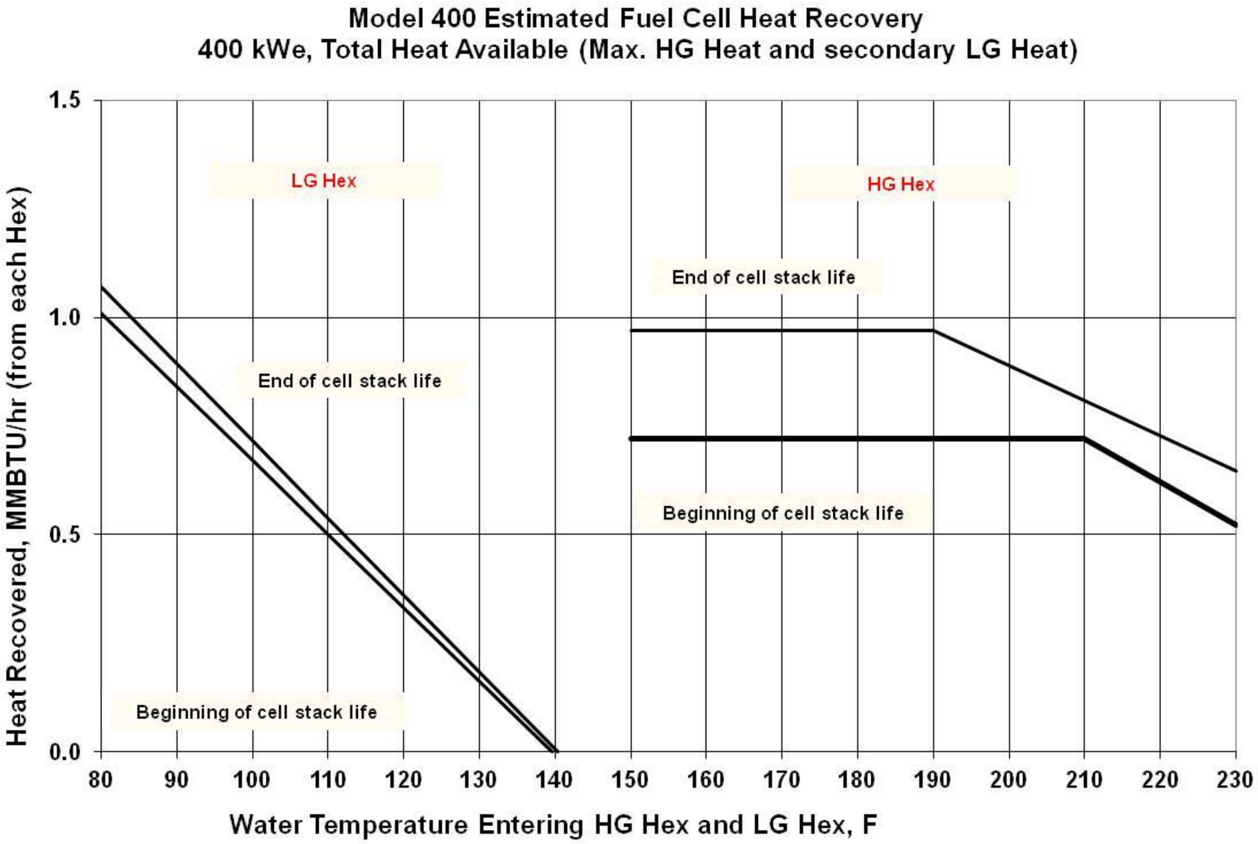

Figure 2-5. Total Heat Available at 400 kWe Output Vs. Inlet (Cold Side) Temperature Assumes maximum HG heat is utilized with resulting secondary LG heat shown.

The horizontal line in the HG HEX portion of ***Figure 2-5*** shows that the amount of HG heat available is primarily constant. The HG HEX is designed to heat water nominally from 160ºF to 180ºF at an inlet flow rate of 70 gpm. At design inlet temperature and flow rate and at EOL conditions, the delivered water temperature would increase by 8ºF to approx. 188ºF. The lines are parallel because the amount of heat available is constant. Off design flows or inlet temperatures will change the exit temperature. For example, at 50 gpm with 200ºF entering water temperature, the exit temperature would be about 230ºF at BOL. Detailed BOL and EOL temperature tables (***Tables 2-3*** through ***2-5***) are provided at the end of this section.

The customer side of the HG HEX requires a customer supplied 170 psig (or lower) relief valve before any isolation valves to protect the HG HEX.

As the fuel cell stack ages, the powerplant will consume more natural gas. This will result in additional HG heat over time. The customer should consider designing his/her system to use the additional heat available at EOL.

A HG pressure drop curve as a function of flow rate is illustrated in ***Figure 2-7***.

Use of the HG heat recovery interface is not required. The powerplant HG heat recovery system must be enabled by UTC Power using the powerplant controller software. As noted, the HG HEX has a hot side bypass for heat delivery control. The hot side bypass valve is controlled by the following:

1. The available HG heat is a function of the heat rejection required from the fuel cell stack. The powerplant will modulate HG heat rejection to control the cell stack temperature. Heat is rejected first to the HG heat recovery heat exchanger. Any available HG heat not used at the HG HEX is then rejected to another internal heat exchanger which makes the heat available via the LG HEX.
2. The customer HG heat recovery interface piping inside the power module also has an exit flow temperature sensor, TE490. The powerplant controller will monitor the temperature of this sensor and compare it to a software settable temperatures input by the customer. Two control schemes are possible:
    a. The customer can input a maximum high limit temperature. When the sensor reading exceeds this high limit set-point, HG heat will be bypassed and sent to the LG heat exchanger.
    b. The customer can input a desired exit temperature. The internal bypass valve will modulate to provide heat delivery up to this temperature. There may be conditions of customer side flow rate and inlet temperature which prohibit the exit temperature from reaching the set-point.

Alternatively, the customer may use a remote temperature signal (4 to 20 ma) to control HG heat delivery. This should be useful where the stream to be heated has higher flow than is practical to pass through the powerplant. In this case, a portion of the main flow would be heated in the powerplant. The temperature of the stream after mixing with powerplant-heated water would be used to control HG heat.

By reviewing the LG and HG heat tables, it should be noted that it is not productive to heat water using the LG heat interface if the water temperature is 140ºF (60°C) or higher. More heat will be delivered to this stream using the HG interface. In fact, with HG heat in use the customer flow might actually be cooled by the LG HEX, putting additional load on the dry air cooling module.

2.3.2.3 Secondary Low Grade Heat Available

The recovery of HG heat will reduce the quality and quantity of heat available at the LG interface. At BOL conditions using the full 700,000 Btu/hour of HG heat will reduce the available LG heat to approximately 1,000,000 Btu/hour. Combined, the LG and HG heat interfaces supply the total amount of BOL heat of 1,700,000 Btu/hour.

Table 2-5 shows that with the design 80ºF entering water temperature to the LG HEX and 50 gpm the exiting temperature is reduced to about 120ºF. At the same flow rate at EOL conditions the delivered water temperature would have increased to about 123ºF. Reducing flow will increase outlet temperature.

Use of less than the full amount of available HG heat will increase secondary LG heat. The user may interpolate to estimate these conditions.

2.3.2.4 External Mixing of Low-Grade and High-Grade Heat

It has been suggested that HG heat be added to the customer side LG flow to increase the LG supply temperature above a nominal 140°F (60°C) by connecting the LG exit to the HG inlet. This is counter-productive since these systems are connected internally. The powerplant HG HEX will heat the customers LG exit flow. Simultaneously, the system will also reduce the hot side temperature entering the LG heat exchanger by reducing the heat transferred to the LG system by an internal heat exchanger. Thus, at equilibrium the LG exit temperature will be reduced and the final supply temperature from the HG interface will be about the same temperature as it would have been using only the LG interface.

2.3.2.5 Heat Recovery Tables

The following tables (***Tables 2-3*** through ***2-5***) show exit temperatures and heat recovery given input temperature and flow rate to each HEX, assuming water to be the fluid being heated. The tables assume full power operation (400 kWe net output). Operation at reduced power levels will lower the available heat recovery.

Table 2-3. Exit Temperatures from LG HEX as a Function of Inlet Temperature and Flowrate
Full 400 kWe power output and utilization of only the LG HEX (no use of HG HEX) is assumed.

		BOL T_{out} as a function of T_{in} and gpm			
		Inlet water flow to LG Hex (gpm)			
T_{in} (deg.F)	BOL Heat (MMBtu/h)	50	60	80	100
80	1.73	149	138	123	115
90	1.56	152	142	129	121
100	1.39	156	146	135	128
110	1.22	159	151	141	134
120	1.05	162	155	146	141
130	0.88	165	159	152	148
140	0.71	168	164	158	154
150	0.54	172	168	164	161
160	0.37	175	172	169	167
170	0.20	178	177	175	174
180	0.03	181	181	181	181

		EOL T_{out} as a function of T_{in} and gpm			
		Inlet water flow to LG Hex (gpm)			
T_{in} (deg.F)	EOL Heat (MMBtu/h)	50	60	80	100
80	2.04	162	148	131	121
90	1.86	165	152	137	127
100	1.69	167	156	142	134
110	1.51	170	160	148	140
120	1.33	173	164	153	147
130	1.15	176	168	159	153
140	0.98	179	173	164	160
150	0.80	182	177	170	166
160	0.62	185	181	176	172
170	0.44	188	185	181	179
180	0.27	191	189	187	185
190	0.09	194	193	192	192

Table 2-4. Exit Temperatures from HG HEX as a Function of Inlet Temperature and Flowrate
Full 400 kWe power output and full utilization of HG HEX is assumed.

		BOL T_{out} as a function of T_{in} and gpm				
		Inlet water flow to HG Hex (gpm)				
T_{in} (deg.F)	BOL Heat (MMBtu/h)	40	50	70	80	100
150	0.72	186	179	171	168	164
160	0.72	196	189	181	178	174
170	0.72	206	199	191	188	184
180	0.72	216	209	201	198	194
190	0.72	226	219	211	208	204
200	0.72	236	229	221	218	214
210	0.72	246	239	231	228	224
230	0.52	256	251	245	243	240

		EOL T_{out} as a function of T_{in} and gpm				
		Inlet water flow to LG Hex (gpm)				
T_{in} (deg.F)	EOL Heat (MMBtu/h)	40	50	70	80	100
150	0.97	199	189	178	174	169
160	0.97	209	199	188	184	179
170	0.97	219	209	198	194	189
180	0.97	229	219	208	204	199
190	0.97	239	229	218	214	209
230	0.65	262	256	249	246	243

Table 2-5. Exit Temperatures from LG HEX as a Function of Inlet Temperature and Flowrate
Full 400 kWe power output and full utilization of HG HEX is assumed.

		BOL T_{out} as a function of T_{in} and gpm				
		Inlet water flow to HG Hex (gpm)				
T_{in} (deg.F)	BOL Heat (MMBtu/h)	40	50	60	80	100
80	1.01	131	120	114	105	100
90	0.84	132	124	118	111	107
100	0.67	134	127	122	117	113
110	0.50	135	130	127	123	120
120	0.33	137	133	131	128	127
130	0.16	138	136	135	134	133

		EOL T_{out} as a function of T_{in} and gpm				
		Inlet water flow to LG Hex (gpm)				
T_{in} (deg.F)	EOL Heat (MMBtu/h)	40	50	60	80	100
80	1.07	134	123	116	107	101
90	0.89	135	126	120	112	108
100	0.72	136	129	124	118	114
110	0.54	137	132	128	123	121
120	0.36	138	134	132	129	127
140	0.00	140	140	140	140	140

2.3.2.6 Pressure Drop Curves

The following curves (***Figures 2-6*** and **2-7**) provide pressure drop data for the customer side of the LG and HG interface heat exchangers. Maximum recommended flow for both is approximately 125 gpm.

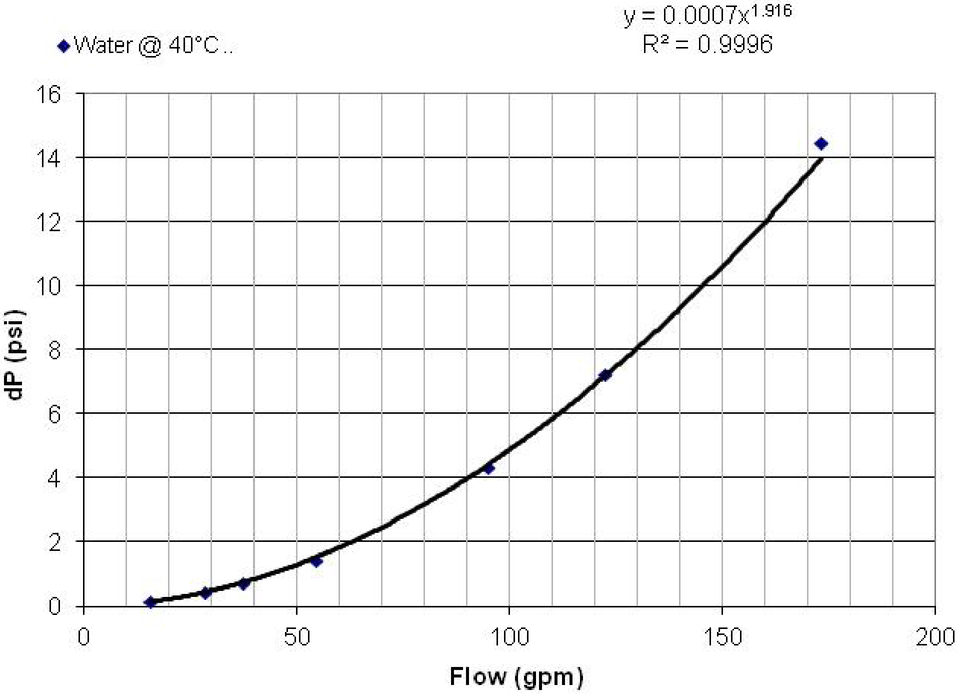

Figure 2-6. LG HEX Pressure Drop Vs. Flow, Customer (Cold) Side

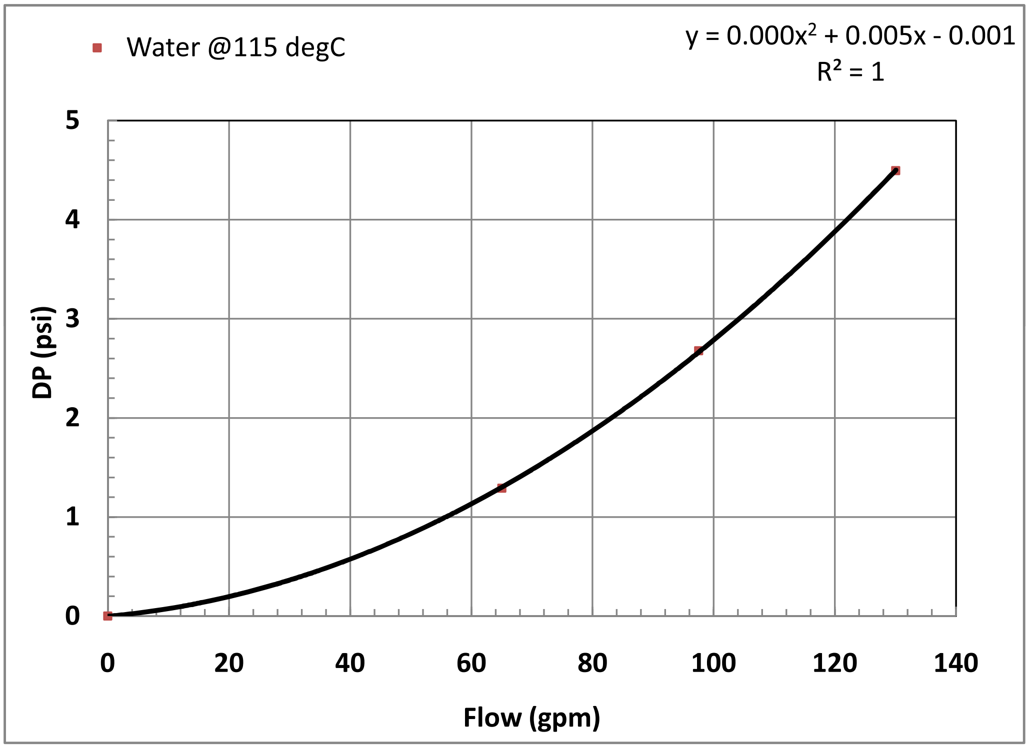

Figure 2-7. High Grade Heat Exchanger Pressure Drop Vs. Flow, Customer (Cold) Side

2.3.3 Absorption Chiller

The high-grade heat of the Model 400 can be used to drive a single-effect absorption chiller to produce an average of about 50 tons of chilled water. The heat from multiple fuel cells can be combined to drive larger absorbers. While high-grade heat is being used to create chilled water, low-grade heat can simultaneously be used to provide useful heat, allowing for combined cooling, heating and power applications for buildings. Typical applications for chilled water include space cooling and refrigeration sub-cooling.

UTC Power offers complete absorption chiller solutions matched to the Model 400 system, including chiller, controls, and evaporative cooling towers. Contact UTC Power for more information.

2.4 EMISSIONS

The Model 400 is certified by the California Air Resources Board (CARB) to meet the Distributed Generation Regulation 2007 Fossil Fuel Emission Standard.

Table 2-6. PureCell® Model 400 Emissions Data

	lb./MWh	***PPMvd @ 15.4% O_2***
NO_x	0.02	0.32
CO	0.02	0.67
VOC	0.02	1.36
CO_2	1100	

2.5 NOISE

The noise characteristics of the fuel cell powerplant are less than 65 dBA at 33 ft. (10 meters) in a free field. During full heat recovery, the air cooling module will operate at reduced capacity, and the noise level will drop to 60 dBA at 33 ft.

3. SITE DESIGN GUIDELINES

3.1 ENVIRONMENT CONDITIONS

The Model 400 is designed to provide full rated power at ambient temperatures ranging from - 20 ºF to 113 ºF and up to an altitude of 500 feet. Performance is de-rated at higher elevations - contact UTC Power for more information.

The Model 400 seismic capability is suitable without modification for location anywhere in the United States (including all of California) when located on grade.

The powerplant should be located in a clean, flat, dry, pollution free area with up to ten feet of clearance allowable for maintenance. An optional marine-grade cooling module is available when located near salt water.

3.2 NATURAL GAS

The fuel cell powerplant operates on low pressure pipeline natural gas. Allowable composition is provided in ***Table 3-1***. The powerplant will not run on peak shave gas (due to its high oxygen content) or propane. Required natural gas pressure is 10 to 14 IWC (in. water column), and required flow capacity is 4,500 SCFH to allow transient operation at EOL conditions. The Sample Installation Drawings provide mechanical design requirements. Powerplant operation at natural gas pressures below 10 IWC may be possible depending upon natural gas supply piping detailed design. Consult UTC Power for more information.

UTC Power requires the customer to provide a natural gas sample analysis for evaluation and documentation. This is can usually be obtained from your local gas company. Consult UTC Power for a standard questionnaire to supply to the gas company.

The powerplant is designed to handle natural gas with an average nitrogen content of 4%. Ammonia formed by the FPS is removed using an internal ammonia scrubber. The scrubber resin bottles are nominally changed annually. The system will accommodate natural gas with up to 15% nitrogen with more frequent changes of the resin bottles and a moderate increase in service cost.

Table 3-1. Allowable Gas Composition

Natural Gas Component	***Maximum Allowable***
Methane	100.0% volume
Ethane	10.0% volume
Propane	5.0% volume
Butanes	1.25% volume
Pentanes, Hexanes, C_8+	0.5% volume
CO_2	3.0% volume
O_2	0.2% volume
N_2	4.0% volume average, 15% peak
Total Sulfur	6 ppmv average, 30 ppmv maximum
NH_3	0.5 ppm
Halides	0.05 ppmw
Olefins	0.5%
Lower Heating Value	890-1090 Btu/ft^3

3.3 MAKE-UP WATER

The fuel cell process of electrochemically combining hydrogen and oxygen produces water. This water is condensed from the fuel cell exhaust to provide feed water for reforming methane into hydrogen and carbon dioxide. The powerplant condenser temperature is controlled to condense only enough water to maintain water balance. The condensed water is stored and cleaned to less than 1 micromho per centimeter (μmho/cm) conductivity by an internal WTS.

At ambient air temperatures above 86°F, the powerplant may require a small amount of make-up water to supplement the water being condensed. The amount of water required increases linearly from 0 gpm at 86°F to 1 gpm (average) at 110°F. A minimum water pressure of 40 psig is required. Although under normal conditions there should be no drain water discharged from the powerplant to supply the powerplant.

UTC Power requires the customer to provide a make-up water composition analysis for evaluation and documentation. Additionally, an analysis of the amount of make-up water per year must be conducted. This is based on the local environmental factors. Contact UTC Power for additional information on this analysis. The allowable make-up water composition per yearly amount is shown in ***Table 3-2***.

Table 3-2. Allowable Make-Up Water Composition

Condition	***1,000 gallons/year Level***	***2,000 gallons/year Level***	***4,000 gallons/year Level***
Total Dissolved Solids (TDS)	< 500 mg/L	< 250 mg/L	< 125 mg/L
Turbidity (NTU)	< 1.0	< 1.0	< 1.0
Silica (Si, all forms)	< 25 ppmw	< 12.5 ppmw	< 6 ppmw

Reverse osmosis (RO) systems are recommended for water pretreatment at sites with contaminants exceeding those listed in ***Table 3-2*** and for all sites above 4,000 gallons of make-up water per year. ***Table 3-3*** lists some general specifications for a required RO system. RO systems must be sized for the highest expected temperature to avoid fuel cell shutdowns or fold backs due to insufficient water. Contact UTC Power for additional information.

Table 3-3. General RO Specification

Requirement	***100°F Max Temperature***	***105°F Max Temperature***	***110°F Max Temperature***
Flow Rate	600 gallons/day	1,000 gallons/day	1,200 gallons/day
Buffer Tank	50 gallons		
Min Containment Rejection Rate	85% (92% recommended for sites above 10,000 gallons/year)		
Options	Remote bypass, anti-scalant pre-filter		

Under normal conditions there should be no drain water discharged from the powerplant. Any drain water produced will be the result of overflow from the WTS clean water storage tank. The water will be deionized, have a pH between 6 and 9 and a temperature of less than 140°F. UTC Power recommends installing a permanent drain line to an appropriate location per local code requirements.

3.4 NITROGEN PURGE SYSTEM

A purge gas supply is required for purging the powerplant fuel and air systems during start-up and shutdown cycles. No purge gas is used during powerplant steady-state operation. The purge gas specification is shown in ***Table 3-4***. Although supply of the purge gas is a customer-responsibility, UTC Power procures and manages the gas supply under its service contracts.

UTC Power supplies a purge gas manifold assembly for managing and controlling the purge gas supply. Ten 300 standard cubic feet (SCF) bottles are required to support two start/stop cycles. A pressure switch is installed in the manifold to detect when the pressure available in the purge gas bottles falls below 1,100 psig. The switch output is wired to the powerplant and is remotely monitored by the UTC Power Control Center. The purge gas is regulated down to 55 psig before being piped into the powerplant.

Table 3-4. Purge Gas Specification

95% nitrogen
5% hydrogen
Less than 20 ppm oxygen

3.5 ELECTRICAL INTERFACES

The Model 400 can operate grid-connected in parallel with the electric utility grid (grid-interactive) and also provide back-up GI power when the utility grid is lost. The output configuration is 480 VAC, 60 HZ, 3-wire. The powerplant may also be used in customer 4-wire systems. The various application options are also covered in the following sections.

3.5.1 Grid-Connected (3-Wire)

In a standard GC application, the Model 400 will be connected to the customer's internal power distribution system as would a large motor load, as shown in ***Figure 3-1***. Note that in this configuration, the 3-wire fuel cell output delivers power to all of the 3-phase loads and the utility grid provides the neutral for the single phase (277 volt, i.e., 4 wire) loads. The system's internal inverter will automatically synchronize to the utility grid as seen at its output terminals.

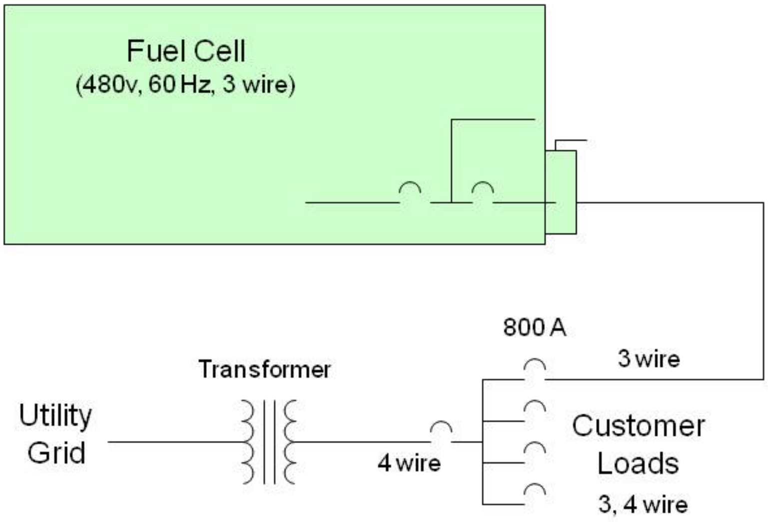

Figure 3-1. Grid-Connect Only Configuration

3.5.2 Grid-Independent (3-Wire)

The powerplant can be configured to operate in GC or GI mode and can switch between modes automatically or upon command. The powerplant normally operates in GC mode when the utility grid is available. When operating in GC mode, the powerplant will simultaneously power both the grid-connect and grid-independent circuits, as shown in ***Figure 3-2***. When there is an outage of the utility grid, the selected loads for grid-independent operation can be powered by the fuel cell through a transfer switch.

The selected loads will experience an interruption in power and must be powered up in sequence with load management.

When a utility grid outage occurs the powerplant will automatically disconnect from the facility electrical system using an internal breaker. The powerplant will then automatically transition into grid-independent mode, reconfigure internal circuit breakers, and begin grid-independent load-following operation as described below. The grid-independent reconfiguration process takes about 10 seconds, during which time the customer load panel will lose power until the powerplant enters grid-independent operation mode. When the fuel cell restores GI power to the transfer switch, the selected loads can be powered up in sequence. This transfer can occur manually with operator intervention or automatically with an automatic transfer switch (ATS) and automated load management control.

Upon return of the utility supply, the powerplant will automatically return to grid-connected mode in 5 minutes (reconnect delay time). The return to grid-connected mode will result in a momentary power interruption while either the ATS or the fuel cell switches the loads back to the grid. Normally the ATS will transfer before the fuel cell does and it's “open transition” will cause a brief power interruption. Loads on the grid-independent circuit will transfer automatically, for ATS applications. Operator intervention is required for manual transfer switch (MTS) operations.

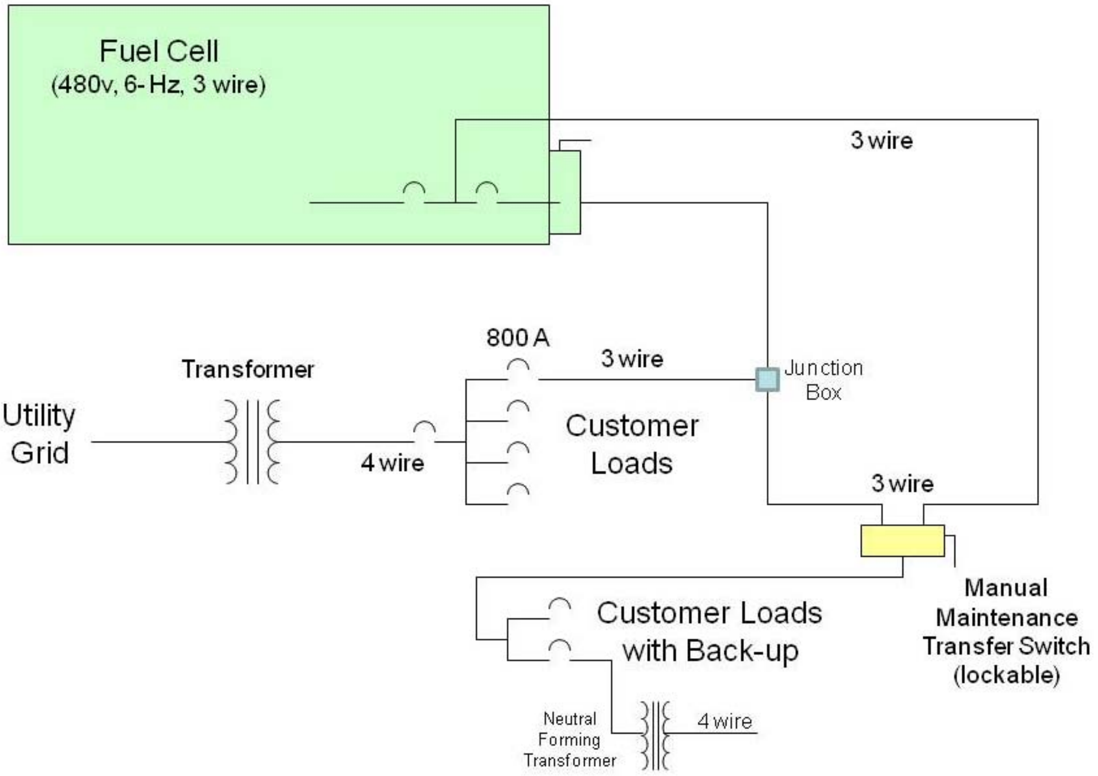

Figure 3-2. Grid-Connect With Grid-Independent Back-up Power Configuration (3-Wire)

3.5.3 Grid-Independent (4-Wire)

If a 4-wire electrical configuration is required, a neutral forming transformer must be used to supply the customer load panel with 4-wire power. In the above 3-wire configuration, those grid-independent (back-up powered) loads that require a neutral (4-wire system) would have their own neutral forming (delta-wye) transformer. In the case where all of the grid-independent loads are 4-wire, a full size 500 kVA neutral forming (delta-wye) transformer must be provided. This configuration is shown in ***Figure 3-3***.

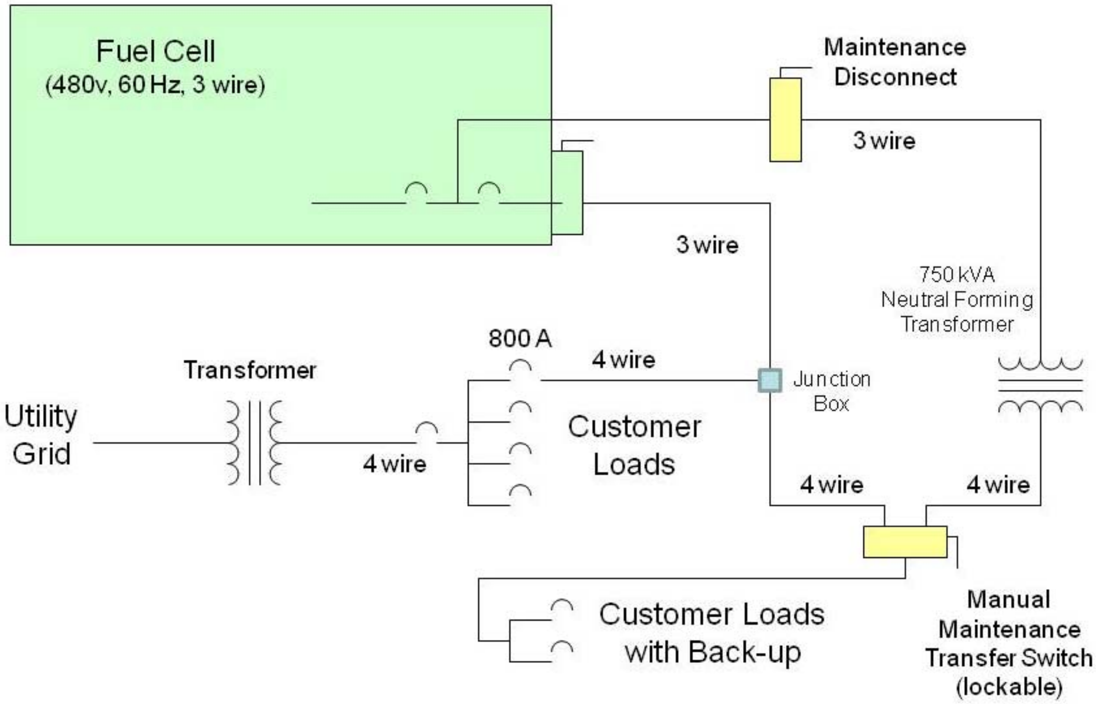

Figure 3-3. Grid-Connect With Grid Independent Back-up Power Configuration (4-Wire)

3.5.4 Grid-Independent Load Control and Sequence of Operations

In GI operation, the fuel cell has limited step load capability. Load management for selected GI loads is required to keep the step load increase within the ratings of the fuel cell. In addition, total loads on the GI circuit must also be kept within the steady state limits of the fuel cell for power and current in GI mode.

3.5.4.1 Grid-Independent Performance Ratings

The GI load pickup must be within the following GI performance ratings of the fuel cell:

- The maximum kW load step is 50 kW.
- The maximum rate of kW load increase is 10 kW/second.
  - This means a 50 kW load step can occur no sooner than every 5 seconds.
- The maximum startup transient current is 679 amps.
  - This means the running current plus transient motor starting current cannot exceed 679 amps.
- The maximum steady state running current cannot exceed 529 amps.
- The maximum steady state load cannot exceed 350 kW.
  - The GI power output capability is de-rated from 400 kW to allow for full transient capability at end of life conditions.

- The initial load cannot exceed 50 kW.

3.5.4.2 Guidelines for GI Sequence of Operations

The following guidelines are intended to aid the design of the sequence of operations for the transition to grid-independent operation.

- The step load controls must be coordinated with the fuel cell operating state in order to make sure that:
    - In normal grid-connected operation all of the loads are ON
    - The step load sequence begins only at the moment that the fuel cell restores power to the GI circuit, which occurs up to 10 seconds after loss of grid power. Considerations for such a control sequence are discussed below
    - The initial “non-controlled” load does not exceed 50 kW
    - Each individual load step does not exceed 50kW
    - The time between 50kW load steps is no less than 5 seconds
    - Once all load steps are completed, the total kW power draw does not exceed 350kW and the total running current does not exceed 529 amps
    - When grid power is restored, the load controls allows all GI loads to remain on through the transition to grid connected operation
- The load controls must not start the step load sequence until the fuel cell has completed its transition to GI mode.
    - With “normally open” contactors this means that the step load sequence must wait until power is restored to the loads by the fuel cell.
    - With “mechanically held” (latched) contactors this means that the latched contactors must be tripped open BEFORE the fuel cell restores power to the loads and then the contactors must wait to begin their step load sequence until the fuel cell has restored power to the loads.
        - A “Loss of Grid” status signal is required to tell the controller to unlatch the contactors before the fuel cell transfers to GI mode.
            - If a site protection relay with functions 27, 59, 81 is available, this would be the best method to provide the “Loss of Grid” signal.
        - If an ATS is employed to supply the source power to the GI loads, the ATS transfer to fuel cell power should be inhibited until the latched contactors have been tripped open. The ATS inhibit signal can then be removed.
        - The step load controller power and contactor coil power must be provided by a source that is ON with no grid power or fuel cell power yet available. In other words, an “uninterruptable” or “emergency” source that is immediately available to the contactors and controls when grid power is first lost.
        - The step load sequence must wait until the fuel cell restores power to the loads.
            - If an ATS is employed to supply the source power to the GI loads, this can be accomplished by using an ATS status signal to tell the controller that the fuel cell has restored power to the ATS source terminals and switched the loads to fuel cell power.

- The maximum total transient current during the sequence must be less than 679 Amps.
  - — If there are loads that have a high inrush current, they would typically be started first to take advantage of the maximum available 679 amp starting current before other running loads reduce the total current available.

UTC Power has developed a Microsoft Excel worksheet for designing the GI step load sequence to meet the Model 400 performance rating. The Excel file is available by contacting UTC Power.

3.5.4.3 Example Sequence of Operations for Grid-Independent Load Pickup

Sequence of Operations With ATS and Normally Open Load Contactors (RECOMMENDED BY UTC POWER)

Loss of Grid

- When the grid is lost, the load contactors and the step load controller all lose power.
- The fuel cell initially stops and then transfers to grid independent operation in about 10 seconds.
- The ATS will transfer its source to fuel cell power.
- Once the ATS transfers and fuel cell power is available to the loads, the step load control reboots and begins its step load sequence.
- There is no "handshaking" required between fuel cell and step load controller - load power restoration acts as the initiating event for the step load controller.

Grid Return

- Depending upon the type of ATS employed, there may be a short interruption of load power when the grid returns and load power is transferred back to the grid from the ATS. If this is not desired, a "closed transition" ATS can be employed whose operation has a short switching "overlap" where the 2 sources are both connected to the load.
- The loads reset upon the short power loss, then repeat their initial load steps and go back to normal operation once the sequence is completed.

The fuel cell will continue to operate in grid-independent mode for at least 5 more minutes until its "5 minute reconnect delay" function 79 has completed its timing, at which point the fuel cell will automatically return to grid-connected mode. Note that if the grid does not return within a preset time (typically one hour, adjustable), the fuel cell will cease trying to return to the grid automatically and must be manually returned to grid-connected operation once the grid has finally returned.

Sequence of Operations With MTS and Normally Open Load Contactors

Loss of Grid

- When the grid is lost, the load contactors and the step load controller all lose power.
- The fuel cell initially stops and then transfers to grid independent operation in about 10 seconds.
- The MTS source is fuel cell power.
- Once the fuel cell power is available to the loads, the step load control reboots and begins its step load sequence.
- There is no "handshaking" required between fuel cell and step load controller - load power restoration acts as the initiating event for the step load controller.

Grid Return

- After the grid has returned for at least 5 minutes and the 5 minute reconnect delay timer has completed its timing, the fuel cell may be manually transferred back to grid-connect mode.
- There will be a short interruption of load power during the fuel cell's transition back to grid-connect mode. The fuel cell initially opens its generator breaker MCB001, removing power from the GI loads. About 1 second later, MCB002 grid tie breaker will reclose, restoring power to the GI loads.
- The loads reset upon the short power loss, then repeat their initial load steps and go back to normal operation once the sequence is completed.

Sequence of Operations With ATS and Mechanically Held (Latched) Load Contactors

Loss of Grid

- A grid voltage sensing relay detects the loss of grid power and its output relay contact signals the load controller that the grid power has been lost.
- Once having read the grid status relay, the load controller inhibits the transfer of the ATS to fuel cell power.
- The load controller then trips the load contactors OPEN.
  - — Note that this requires the controller and the contactor coils to have control power.
- Once the contactors are opened, the ATS inhibit signal is removed and it can transfer to fuel cell power when it is available.
- The fuel cell takes about 10 seconds to reconfigure and transfer to grid-independent mode.
- When the fuel cell transfers to GI mode and provides power to the ATS “emergency” terminals, the ATS transfers to the fuel cell source, and an ATS status signal is sent to the step load controller to tell it that the fuel cell power transfer has taken place.
- Once the controller sees the ATS signal that it has transferred to fuel cell power source, it begins the step load sequence.

Grid Return

- The ATS will immediately transfer back to grid power once grid power is restored to its “normal” terminals and the GI load panel will return to grid power.
- The grid sensing relay will reset when the grid has been restored for at least 5 minutes.
- The step load controller will immediately reset to “normal” operating state (all contactors closed) once it sees that:
  - — The ATS status signal returns to grid position.
  - — The grid sensing relay signals that the grid is OK.

The fuel cell will continue to operate in grid-independent mode for at least 5 more minutes until its “5 minute reconnect delay” function 79 has completed its timing, at which point the fuel cell will automatically return to grid-connected mode. Note that if the grid does not return within a preset time (typically one hour, adjustable), the fuel cell will cease trying to return to the grid automatically and must be manually returned to grid-connected operation once the grid has finally returned.

3.5.5 Multi-Unit Load Share

For applications that require multiple Model 400 systems to operate together as a single-generation entity in grid-independent mode, an optional control system called Multi-Unit Load Share (MULS) is required. MULS is not currently available for the Model 400 system. Contact UTC Power for more information.

MULS is not required for multiple units operating solely in grid-connected mode.

3.6 CONTROLS INTERFACES

The Model 400 fuel cell powerplant has several external control and monitoring wiring options. The external control devices and wiring are customer-supplied. The Model 400 Installation Manual (FCMAN70865) describes the specific wiring requirements and terminations in detail.

3.6.1 Normal Shutdown

A customer-supplied control system or simple switch (dry contact, open circuit to cause a shutdown) can be utilized to command the powerplant to shutdown. The powerplant will immediately open its internal circuit breaker ceasing to deliver power to the building. The powerplant will draw power from the building to cool itself down. If a grid-independent load is connected, the powerplant will draw additional power to continue to power the grid-independent circuit.

3.6.2 Fast (Emergency) Shutdown

The customer may also wire the powerplant for a fast shutdown (dry contact, open circuit to cause a shutdown). A fast shutdown is a “fail safe” control in that it is not controlled by the powerplant controller. An under-voltage trip coil on the internal inverter circuit breaker will directly cause the breaker to open. This control will also close the natural gas inlet valve. The powerplant will still utilize building power to cool down and also power the grid-independent load (if connected).

3.6.3 Grid Circuit Breaker Enable

This circuit directly trips the internal powerplant circuit breaker MCB001, disconnecting the inverter output from the customer. It is typically used when an external independent utility grid protection relay is required. For example, some utilities require redundant grid protection while others require reverse power protection to prevent power export. An external relay provides a permissive to allow the powerplant to feed power to the building distribution system. When the permissive is removed (relay open contact to trip), the powerplant will still power the isolated load on the grid-independent circuit (if used).

This control capability is also useful if the powerplant is connected to a section of the building distribution system that has another back-up generator. On loss of grid this generator could trip the powerplant internal breaker to prevent the powerplant and generator from an unstable load sharing situation.

An external relay should never be used to trip an external breaker, isolating the powerplant from the building grid. If used in this way, an operating powerplant which shuts down would be prevented from cooling down. This would result in powerplant performance loss and/or damage.

3.6.4 Power Output Set Point (kW Dispatch)

This circuit takes a 4 - 20 mA signal from the customer which will set the powerplant output power. Full power is set at 20 mA, and 0 kW is set at 4 mA. Power output is proportional between these amperage levels. This circuit may be useful to the customer for several applications such as thermal load following and time-of-day dispatch operating schemes.

3.6.5 Load Following Control (Zero Power Export)

Also known as Zero Power Export Control, this circuit utilizes a bi-directional watt transducer located at the building utility meter to automatically control powerplant power output to prevent exporting power to the utility. The watt transducer operates with a 4 -12 - 20 mA signal. The 4 and 20 mA signals are powerplant controller software settable to a maximum measured power level as determined by the size of the building service. The 12 mA input would represent 0 power flow (import/export) with the utility.

The powerplant controller will also control to a minimum power import set-point. Adjusting the powerplant output to always import a fixed level of kW from the utility provides margin to allow the powerplant time to adjust its power output when the building demand suddenly drops. This is especially important when an external reverse power protection relay is employed as a "grid enable" as per Section 3.6.3. The powerplant can decrease power output at a rate of 10 kW/second. Without a minimum import margin, the relay could cause a nuisance trip of the fuel cell system.

3.6.6 High Grade Heat Remote Temperature Control

When the customer HG heat load is less than the available heat, the powerplant HG internal bypass valve can be modulated to a set-point supply temperature. This prevents overheating the customer piping. When the customer has a heating loop flow rate higher than practical to pass through the HG HEX, a portion of the flow would be heated. A remote 4 - 20 mA temperature sensor in the customer piping can be read by the powerplant to modulate heat output to match a software settable temperature. Using the mixed temperature, as opposed to controlling on HG supply temperature, permits the use of more powerplant heat. This topic is also covered in the "Heat Recovery Characteristics" section of this guide.

3.6.7 External Ventilation Fan Control and Sensing

A powerplant sited indoors will normally require a powered exhaust ventilation system. The powerplant provides two circuit connections. One connection can be used to start/stop the exhaust ventilation fan. The second circuit is from a fan flow switch which confirms the fan is operating (vent fan status). The powerplant will not operate without flow confirmation.

Note that the exhaust fan should be powered by the powerplant grid-independent circuit which permits continued operation when the utility grid is out of service. Since the powerplant takes approximately 10 seconds transition time to repower the grid-independent circuit on loss of grid, the external flow sensor must incorporate a built in 30 second time delay when acting on the flow confirmation signal.

Also note that the powerplant output signal for fan control is an active 24 VDC signal which is intended to power a site installed 24 VDC relay whose output contact would be used in the fan motor starter circuit.

3.6.7.1 External Heat Recovery Pump Start/Start Signal or BMS Fuel Cell Operation Status Signal

The powerplant output signal for the ventilation fan start/stop, described in Section 3.6.7, can optionally be used for either a heat recovery pump start/stop signal or a building management system (BMS) fuel cell operating status signal. This is because the state of the ventilation fan on/off control corresponds closely to the desired operation of a heat recovery pump and also is an indication of the fuel cell's operating state.

3.6.8 Purge Gas Supply Pressure Switch

A pressure switch is installed in the UTC Power-supplied purge gas system high pressure side piping. This dry contact closure switch is wired to the powerplant on an isolated 24 VDC, 2A limited circuit. The powerplant will not start without sufficient purge gas pressure. During operation, a loss in pressure will result in a powerplant alert notification that service is required.

3.7 REMOTE MONITORING SYSTEM

The RMS is contained in a small indoor-rated cabinet and is powered by a field-installed 120 VAC, 15A circuit from the power module. RMS communication is connected to the power module using a field-installed Cat 5 Ethernet cable. The maximum length of this cable is 300 ft. without amplification. The standard Internet connection to the RMS is through a secure wireless cellular connection. If wireless service is not available, a high-speed dedicated static IP connection is required. The standard RMS cabinet dimensions for a single powerplant RMS system are 24 in. high, 24 in. wide, and 10 in. deep.

3.7.1 Heat Recovery Monitoring

An optional heat recovery monitoring (HRM) solution is available for monitoring heat recovery and calculating overall efficiency. An HRM solution includes a data logger as well as the necessary flow meters and temperature sensors for monitoring heat recovery. The data logger is contained in a separate water and dust tight enclosure with standard dimensions of 19.6 in. high, 17.6 in. wide, and 8.8 in. deep for a single powerplant system. It is connected to the site's RMS, through which it receives necessary powerplant controller (PPC) data such as electrical output and natural gas consumption. HRM data is communicated to UTC Power and the customer through the RMS communications interface. ***Figure 3-4*** represents an HRM solution and its interfaces with other systems. The HRM equipment is provided 120 VAC power from the same fuel cell line as the RMS.

An HRM solution must be custom designed to meet the needs of each site.

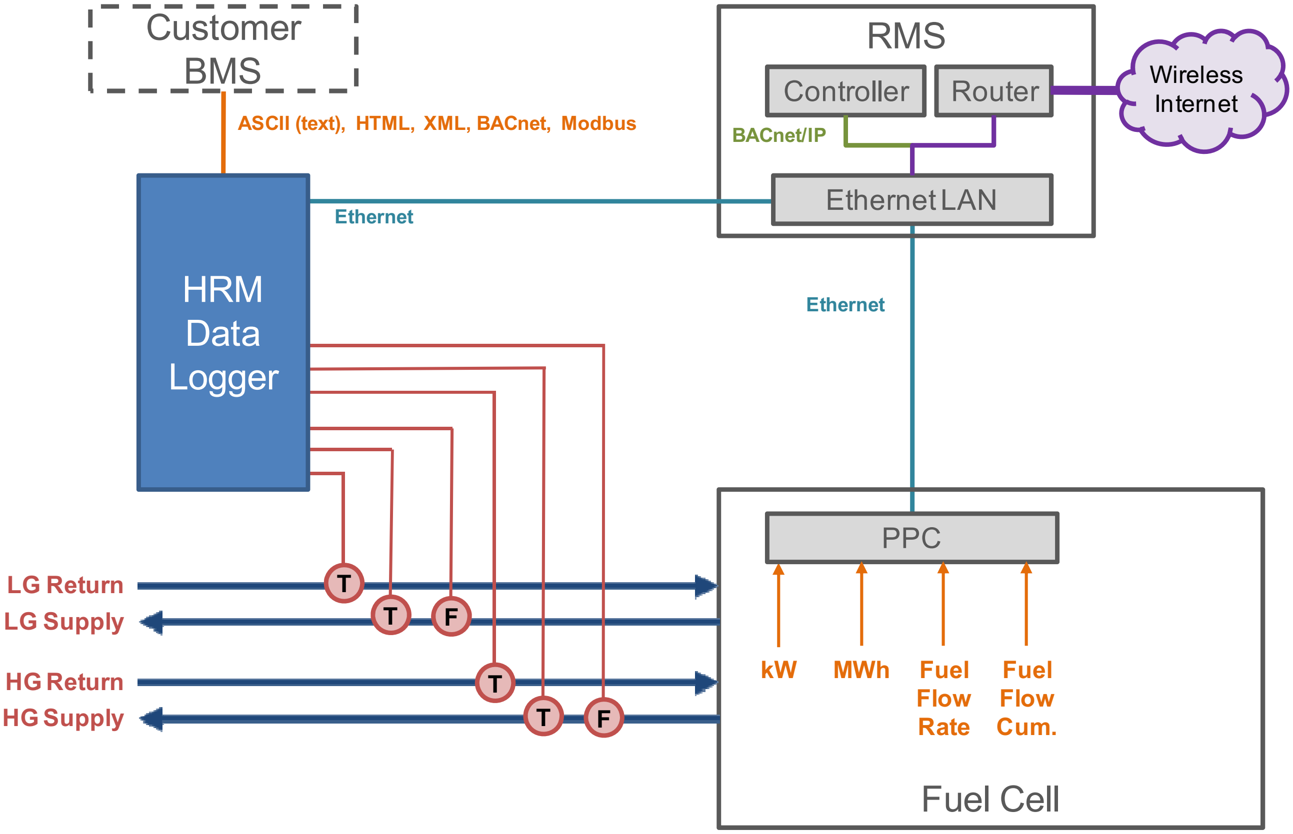

Figure 3-4. Optional HRM Architecture

3.7.2 Building Management Interface

An optional communications interface is available for sending data to a customer's building (or energy) management system. Several building management interface (BMI) protocols can be accommodated including: BACNet, Modbus, ASCII (text) and others.

Available data points include:

- Power output
- Operating mode
- Operating hours
- Cumulative electricity generated
- Natural gas flow rate
- Cumulative natural gas consumed
- Instantaneous electrical efficiency
- With optional HRM:
  - Heat recovery flow rate
  - Return and supply temperatures
  - Instantaneous heat recovery
  - Cumulative heat recovery.

3.8 UTILITY INTERCONNECTION COMPONENTS DATA

3.8.1 Powerplant Interconnection Circuit Breaker MCB001

- MANUFACTURER: ABB
- TYPE: ISOMAX SERIES S6 BREAKER, MOLDED CASE WITH MOTOR OPERATOR AND UNDERVOLTAGE RELEASE
- P/N: S6H800BW***
- MOTOR OPERATOR: K6M8
- UV TRIP: K7U8
- TRIP: SACE PR211 MICROPROCESSOR CONTROL
- UL FILE #E93565 category code DIVQ
- *** (65 KAIC RATING, OPTIONAL S6L800BW HAS 100 KAIC RATING)

3.8.2 Main Disconnect Switch MDS001 (Part of Powerplant)

- Square D H367R
  - 800 AMP, 600 VOLT, heavy duty safety switch, fusible in a NEMA 3R enclosure with Class L fuse included Bussman KRPC-800
- For indoor siting, top entry into the switch box is possible.

3.8.3 Optional Site-Installed Protection Equipment

At some sites where additional protection such as reverse power (non-export protection) is required at the utility PCC, a protection relay and its associated PTs and CTs are required to be installed at the

PCC, typically in a metering cabinet at the customer main switchboard. The relay output trips the powerplant circuit breaker via the optional "grid enable" input terminals. Load following control is also employed in conjunction with reverse power protection by means of a separate watt transducer also measuring power at the PCC. The watt transducer output is connected to the optional powerplant zero power export input terminals. A part number and wire diagram of that watt transducer are provided. Below are the recommended component specifications. A typical 3-line schematic diagram is shown in the sample installation drawings.

- Protection relay: Beckwith model M3520 multi-function
- Potential transformers (3)
  - — Voltage rating consistent with system (typically 600 volt rated for a 480 volt system, 0.3% accuracy at burdens W, M, X, y, ratio XXX/120 where XXX is the operating voltage line to neutral, typically 277 volts on a 480 volt system but could also be a medium voltage system with a different line to neutral voltage
- Current transformers (3)
  - — Voltage rating consistent with system (typically 600 volts rated for a 480 volt system), 0.3% accurate at B-1.8 burden, Relay class, ratio xxx:5 where xxx equals the current rating of the circuit to which it is installed
- Test block (CT shorting block and PT opening for test or servicing):
  - — ABB type FT-1, part number 129A514G01
- Load-following watt transducer (optional input to powerplant external zero power export)
  - — Ohio Semitronics part number GH-008EM-G-R
  - — CTs with 1% accuracy or better
  - — 277 VAC voltage taps fused at PCC
  - — Test block (same as above).

3.9 SITING OPTIONS

3.9.1 Building Roof Siting

Design recommendations for installing the Model 400 on a building roof are as follows:

1. Provide nearby ground area (i.e., parking lot) for a crane to lift large replacement components directly up to the powerplant. All traffic will be restricted in this area whenever work is being performed; therefore, if this is a roadway, alternative access for regular traffic is recommended.
   - Components may include a cooling module, coils, pumps, motors, water treatment bottles, cell stacks, reformer, and ILS converter.
   - The heaviest items include the ILS (9,400 lb.), cell stack (3,700 lb.), and reformer (6,900 lb.).
   - The powerplant should be located close enough to the crane area so components can be lifted from the ground without having to move components across the roof.
   - The powerplant should be located no closer than 15 ft. to an unprotected roof edge, unless an OSHA-approved fall protection system is in place.
   - Reinforced area on roof must be clearly marked as such.
2. Routine maintenance tasks will require replacing water treatment and nitrogen bottles.

- An outdoor ground-level location is highly recommended for the nitrogen bottles (both on-line and spares).
- Nitrogen should be piped up to the powerplant on the exterior of the building. If interior nitrogen gas piping has to be used, the piping must be designed to meet all codes. A nitrogen leak rate assessment should be conducted to determine if indoor oxygen sensors are required.
- If located indoors, preferably at ground-level, the nitrogen bottle room (online and spares) shall have an oxygen sensor.
- A service path, preferably a paved ramp, to the outdoors will be necessary for movement of nitrogen bottles.
- Spare water treatment bottles must be stored indoors in a heated space.
- Service elevator access is recommended to the roof for water treatment bottles and routine maintenance equipment. If an elevator is not provided a UTC Power-approved alternative must be in place to provide powerplant level access.
- If the service elevator stops at the top floor, but does not go to the roof level, then a ramp, hoist or equipment lift is required to move equipment from the elevator to the roof level.
- If a hoist or lift system is utilized, it must be regularly maintained by the customer to all codes and regulation, including inspections.

3. The powerplant can be supported on the roof using various methods, including but not limited to:

- Roof curbs
  - — Low roof curbs of 12 to 14 in. maximum height can be used to support the powerplant.
  - — No elevated maintenance platform is required around the system.
  - — Standard maintenance clearances around the system are required (same as ground-mounted system). The outermost edge of maintenance clearances shall be no closer than 10 ft. to an unprotected edge.
  - — The standard maintenance clearance area around the system shall be considered a landing area for equipment, and must be designed to support the maximum component weight of 10,000 lb. This area shall be clearly marked as a reinforced landing area.
  - — The roof surface in the access path to and including the clearance area shall be suitable for movement of routine maintenance equipment, and shall be clearly marked as such.
  - — Provide one 20 A duplex service receptacle at the powerplant.
  - — Installation must meet NFPA 853 “Standard for the Installation of Stationary Fuel Cell Power Systems”. In particular, Section 5.42 states, “The roofing material under and within 12 in. horizontally of a fuel cell power system shall be noncombustible or shall have a Class A rating.”
  - — The optional power module floor must be ordered and installed for this type of installation.
- Dunnage steel mounting
  - — The powerplant can be supported on dunnage steel.

- — If the bottom of the powerplant is higher than 14 in. off the roof, a maintenance platform is required around all sides of the powerplant.
- — Maintenance platform must meet OSHA requirements (railings, slip resistance, etc.).
- — A ramp is required for platform access.
- — Standard maintenance clearances around the powerplant are required (Same as ground mounted powerplant). Removable hand rails may be necessary.
- — Provide one 20 A duplex service receptacle at the powerplant.
- — The optional power module floor must be ordered and installed for this type of installation.

Alternate roof mounted supporting methods shall be submitted to UTC Power for review.

All support methods shall conform to UTC Power's minimum requirements. Consult UTC Power Drawing FC75589 for the location of support points on the power module base frame.

3.9.2 Indoor Siting

The Model 400 powerplant is designed for all-weather outdoor installation. With special consideration to ventilation and clearances for maintenance, the powerplant may also be installed indoors. The ANSI/CSA FC 1 code requires that the fuel cell manufacturer have a User Information Manual providing instructions for indoor installation.

3.9.2.1 Key Requirements

The indoor installation design must meet national and local code requirements and address several powerplant requirements:

1. Requirements as specified in the On-Site Fuel Cell Powerplant Installation Manual (FCMAN70865).
2. National Fire Protection Association Code NFPA 853, “Standard for the Installation of Stationary Fuel Cell Power Systems”, Chapter 5.3 addresses indoor installations.
3. The exhaust from the powerplant must be ducted to a safe location. The exhaust ventilation duct work should be hard-plumbed to the powerplant (reference NFPA 211 Standard for Chimneys).
4. The exhaust ductwork must not back-pressure the powerplant exhaust; therefore, the ductwork must have a powered exhaust fan. Negative pressure at the fuel cell exhaust shall not exceed -0.10 inches wc.
5. A duct condensate trap must be provided to collect and dispose of potential duct condensate.
6. The ventilation system will require the addition of makeup air to the room and exhaust duct.
7. During start-up and shut-down an external inert gas system will purge the powerplant of potentially combustible gases.
8. The ventilation system must not be connected to a chimney used for combustion equipment.
9. The powerplant will not be allowed to operate unless room sensors confirm good air quality and duct flow is verified. The air quality and flow control signals will be wired directly to the powerplant. The signal must have a 30 second time delay to prevent shutdown during loss of utility power and transition to backup power.
10. All ventilation system devices shall return to normal operation within 30 seconds, including the exhaust fan, flow switch, motorized dampers, and gas sensors.

11. The exhaust fan and room sensors must have backup power.
12. The powerplant grid-independent power may be used to power the sensors, and the exhaust fan.
13. The exhaust fan must operate whenever the fuel cell is operating. The fuel cell provides a fan control start/stop signal for this purpose.
14. The powerplant must have adequate clearance for maintenance.
15. An oxygen sensor must be installed if purge gas bottles are installed indoors.

3.9.2.2 Accessibility

For routine service, the powerplant requires approximately 5 ft. clearance on all sides. At the 10-year overhaul, 10 ft. clearance will be required on the long, non-hooded side of the powerplant. Refer to UTC Power drawing FC75589 for details.

In addition, at least 6 ft. clearance is required above the powerplant to facilitate installation and maintenance of the indoor ventilation duct work.

3.9.2.3 Powerplant Ventilation Requirements

Ventilation ductwork must be provided to the powerplant and room to:

- Remove inert and potentially combustible gas mixtures from the powerplant and room
- Provide makeup air to the powerplant exhaust
- Provide fresh air to the room for process use by the powerplant
- Remove heat build-up from the room.

The ventilation system must remove powerplant exhaust and safely direct it outdoors. Exhaust gases consists of warm, dry fuel compartment ventilation exit air mixed with warm, saturated process condenser air. The external exhaust ductwork requires makeup air for back pressure control and to ensure the exhaust gas mixture is non-combustible under all conditions. The suggested ventilation design is shown in ***Figure 3-5***. An exhaust fan is required to draw in the dilution air while not exceeding -0.1 inches wc negative back pressure on the powerplant exhaust. The exhaust fan must be powered by the powerplant or facility backup power to prevent powerplant shutdown on loss of grid power. The room hazardous gas sensors must also have back-up power. Verification signals from a duct flow sensor and room gas sensors must be wired in series to the powerplant emergency shutdown signal interface as a permissive to operate. This series circuit must include a 30 second time delay to allow the backup power systems to come on line after utility grid loss.

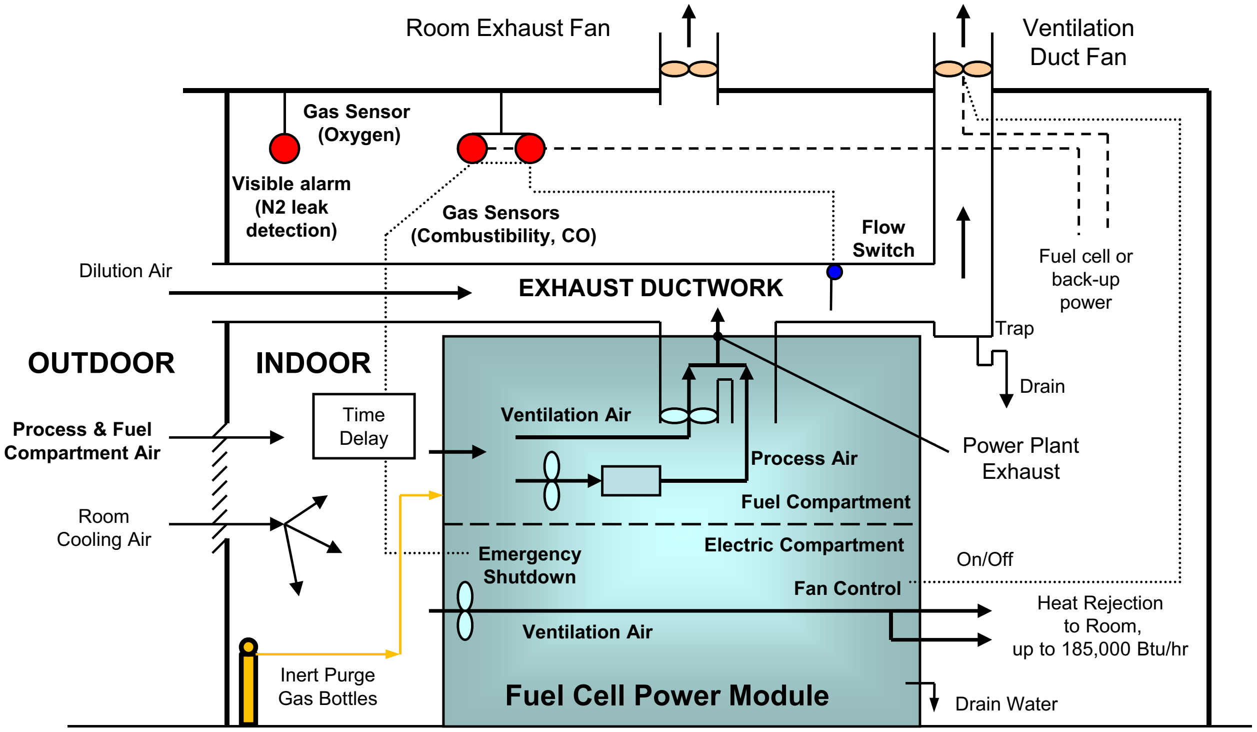

Figure 3-5. Indoor Ventilation Schematic

The ductwork should be non-corrosive. The ductwork and accessories shall be constructed, fabricated, and installed in accordance with NFPA 54, Chapter 12 and with the latest Sheet Metal and Air Conditioning Contractors National Association (SMACNA) standards. The powerplant exhaust interface exits the side of the enclosure just below the roof as shown in drawing FC75589. The exhaust ducting must be directly connected to powerplant exhaust. This will ensure gases exhausted during shutdown purge do not enter the room in the event that the ventilation exhaust fan and/or the powerplant fuel compartment fan fails. If the makeup air is drawn directly from the room, an inlet gravity back-draft damper must be provided.

The powerplant exhaust consists of fuel compartment ventilation air mixed with process exhaust. During normal operation the process exhaust normally consists of CO_2, N_2, H_2O, O_2, and argon. The saturated process exhaust flow varies depending on power level and powerplant life. The fuel compartment air adds additional dry air to the powerplant exhaust. The temperature of this combined exhaust stream is nominally 114°F (46°C) based on room ambient conditions of 86°F (30°C). Nominal exhaust composition is shown in ***Table 3-5***.

Table 3-5. Nominal Power Module Exhaust Conditions

Ambient (Room) Temperature	86°F (30°C)
Exhaust Temperature	114°F (46°C)
Nominal Exhaust Flow Rate	2,720 cfm
Composition	
H_2	0%
H_2O	6%

Table 3-5. Nominal Power Module Exhaust Conditions

CO_2	3%
CO	0%
O_2	14%
N_2	76%
CH_4 + (including higher hydrocarbons)	0%
Argon	1%

During shutdowns, un-reacted hydrogen, methane, and CO are purged (nominal 3-minute duration) from the system using an external inert gas bottle system. Dilution air aids in diluting any potential CO leaks in the fuel processing system. The dilution or makeup air flow requirement should be specified to meet applicable codes.

The duct exhaust ventilation fan is responsible for drawing out the powerplant exhaust to vent them outdoors. The maximum flow rate through the exhaust duct ventilation fan is the sum of process exhaust, fuel compartment air, and makeup air. ***Table 3-6*** summarizes the estimated flow requirements. A minimum ventilation duct fan design flow of 5,000 cfm will provide a 25 percent margin above estimated maximum EOL flow of 4,000 cfm. Maximum fuel cell exhaust accounts for fuel cell blower transient flows, and an increased fuel compartment exhaust flow while servicing with an open enclosure door.

The exhaust duct flow switch, ventilation fan, motor, and wiring should be NFPA 70, NEC, Class I Division II suitable. It is recommended that this equipment be powered by the powerplant or an emergency power source. This will prevent the powerplant from shutting down immediately if power is lost to the facility. The emergency power generator must re-power the fan and sensors within the 30 second time delay allowed by the Model 400 system.

Table 3-6. Ventilation Flows

Flow	***Design Flow***
Powerplant Exhaust (Maximum)	5,000 cfm
Excess Makeup Air (if required)	excess cfm
Total Ventilation Duct Fan Capacity	5,000 + excess cfm

The duct ventilation fan can either be vertically or horizontally mounted. However, UTC Power recommends the vertically mounted option. If the horizontal approach is taken, a wind test needs to be performed on the ventilation design to ensure adequate flow with wind back-pressure on the exit exhaust. This is a decision that needs to be considered on a site-by-site basis.

Drains should be installed at the low point of the main duct work to prevent water that could condense against the vertical duct walls from building up or flowing back into the powerplant.

While a ventilation system that is not hard-mounted to the powerplant is not recommended in most installations, other ventilation systems proposed by the customer can be evaluated by UTC Power.

Gas sensors will need to be installed in the fuel cell room to monitor combustibility (natural gas and hydrogen) and carbon monoxide (CO). If the purge gas bottles are installed indoors, an oxygen sensor must be installed that will alarm at less than 19.5% O_2 in the event of a leak at the supply bottles.

A flow switch is required to be installed in the ventilation ductwork to provide assurance that the ventilation system is fully functional. The flow switch should be installed close to the power module exhaust to shutdown the power module if the downstream ducting becomes dislodged. The flow switch set point should provide sufficient margin to avoid powerplant shutdowns while assuring adequate flow (flow switch trigger at >4,000 cfm, reset at 4,250 cfm). The flow switch and gas sensor signals are daisy-chained and connected to a powerplant input that is used as a permissive to allow powerplant operation. Any loss of flow or hazardous gas reading will automatically shut down the powerplant.

3.9.2.4 Testing Requirements

Before the fuel cell is started up the following tests of the ventilation systems must be conducted:

1. Ventilation Fan On/Off control: Verify the external exhaust fan on/off control
2. Exhaust Fan Status: Verify powerplant operation based on input from exhaust duct flow switch
3. Room Gas Sensor Status: Verify room gas sensor signal will enable powerplant startup
4. GC to GI Transition: Verify continuity of fuel cell operation with 10 second loss of exhaust fan
5. Exhaust Back Pressure: Verify stable fuel cell operation during exhaust flow transients (power level changes, enclosure door openings, etc.)
6. Room Ambient Pressure: Verify stable fuel cell operation during room exhaust fan flow changes (change in room exhaust CFM in response to room temperature and room door opening).

Consult with UTC Power for more details on the test procedures.

3.10 CENTRAL COOLING OPTION

The Model 400 can be cooled by a facility's central cooling system. A conceptual design is shown in ***Figure 3-6***. The central cooling supply and interfacing system needs to be on emergency power to prevent overheating and damage to the fuel cells if utility grid power is lost. The fuel cell piping should be separated from the central system using heat exchangers if the central system is not a closed loop (contaminated water) or is high pressure. A bypass valve on the fuel cell side is shown to control the return temperature to the fuel cells to maintain fuel cell condensed water balance. Contact UTC Power for more information.

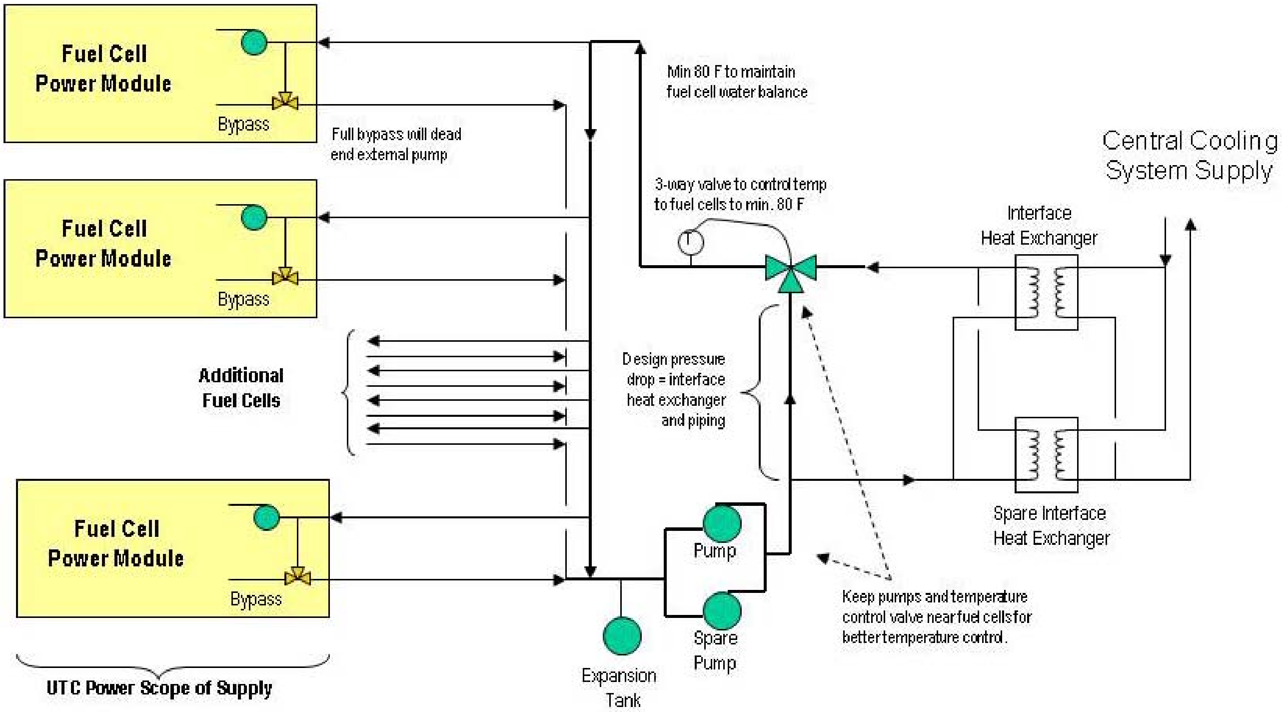

Figure 3-6. Fuel Cell Conceptual Central Heat Rejection Design

3.11 GUIDE SPECIFICATION

The Guide Specification (FCMAN65829) may be provided upon request as a separate document. This document is intended for insertion into bid documents where appropriate.

APPENDIX A — FC 1 REFERENCED STANDARDS

1. **AMERICAN GAS ASSOCIATION**

   1515 Wilson Boulevard, Arlington, Virginia, U.S.A 22209

   1.1. ANSI Z223.1-2002/NFPA 54-2002, National Fuel Gas Code

2. **AMERICAN NATIONAL STANDARDS INSTITUTE**

   11 West 42nd Street, New York, New York, U.S.A. 10036

3. **AMERICAN SOCIETY OF CIVIL ENGINEERS**

   347 E. 47th St., New York, New York, U.S.A., 10017

   3.1. ANSI/ASCE 7-1995, Minimum Design Loads for Buildings and Other Structures

4. **AMERICAN SOCIETY OF MECHANICAL ENGINEERS,**

   United Engineering Center, 345 East 47th Street, New York, New York, U.S.A. 10017

   4.1. ASME B31.9-1996, Building Service Piping

   4.2. ASME PTC 19.3-1974 (R1998), Performance Test Code - Temperature Measurement

5. **AMERICAN SOCIETY FOR TESTING & MATERIALS,**

   100 Barr Harbor Dr., West Conshohocken PA, U.S.A. 19428-2959

   5.1. ASTM A653/A653M-02a, Standard Specifications for Sheet Steel, Zinc-Coated (Galvanized) or Zinc-Iron Alloy Coated (Galvanealed) by the Hot-Dip Process

   5.2. ASTM E84-01, Standard Test Method for Surface Burning Characteristics of Building Materials

6. **AMERICAN WATER WORKS ASSOCIATION**

   6666 W. Quincy Ave., Denver, Colorado, U.S.A. 80235

7. **CANADIAN STANDARDS ASSOCIATION**

   5060 Spectrum Way, Suite 100, Mississauga, Ontario, CANADA L4W 5N6

   7.1. CSA B149.1-00, Natural Gas and Propane Installation Code

8. **CSA AMERICA, INC.**

   8501 East Pleasant Valley Road, Cleveland, Ohio, U.S.A. 44131

   8.1. ANSI Z21.15-1997ioiCGA 9.1-M97, Manually Operated Gas Valves for Appliances, Appliance Connector Valves and Hose-End Valves

   8.2. ANSI Z21.18-2000ioiCSA 6.3-2000, Gas Appliance Pressure Regulators

   8.3. ANSI Z21.21-2000oiCSA 6.5-2000, Automatic Valves for Gas Appliances

   8.4. ANSI Z21.24-2001ioiCSA-6.10-2001, Metal Connectors for Gas Appliances

8.5. ANSI Z21.35-1995ioiCGA 6.8-M95, and Addenda, Z21.35a-1997ioiCGA 6.8a-M97, Pilot Gas Filters

9. FACTORY MUTUAL RESEARCH CORPORATION

1151 Boston-Providence Turnpike, Norwood, Massachusetts, U.S.A. 02062

9.1. FM7400-1996, Liquid and Gas Safety Shutoff Valves

10. INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS

445 Hose Lane, Piscataway, New Jersey, U.S.A. 08855-1331

11. INTERNATIONAL ELECTROTECHNICAL COMMISSION

3 rue de Varembré, P.O. Box 131, CH-1211, Geneva 20, Switzerland

12. INSTRUMENTATION, SYSTEMS, AND AUTOMATION SOCIETY

67 Alexander Drive, Research Triangle Park, NC, U.S.A. 27709

13. NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

1300 N. 17th Street, Suite 1847, Rosslyn, Virginia, U.S.A. 22209

14. NATIONAL FIRE PROTECTION ASSOCIATION

1 Batterymarch Park, P.O. Box 9101, Quincy, Massachusetts, U.S.A. 02269

14.1. NFPA 54-2002/ANSI Z223.1-2002, National Fuel Gas Code

14.2. ANSI/NFPA 70-2002, National Electrical Code

14.3. ANSI/NFPA 72-2002, Protective Signaling Systems

14.4. ANSI/NFPA 80-1998, Fire Doors and Fire Windows

14.5. ANSI/NFPA 497-1997, Manual for Classification of Gases, Vapors and Dusts for Electrical Equipment in Hazardous (Classified) Locations

14.6. ANSI/NFPA 853-2000, Standard for the Installation of Stationary Fuel Cell Power Plants

15. SOCIETY OF AUTOMOTIVE ENGINEERS

400 Commonwealth Drive, Warrendale, PA USA 15096

16. UNDERWRITERS LABORATORIES INC.

333 Pfingsten Road, Northbrook, Illinois, U.S.A. 60062

16.1. ANSI/UL 33-2001, Heat-Responsive Links for Fire Protection Service

16.2. ANSI/UL 50-1995, Enclosures for Electrical Equipment

16.3. ANSI/UL 67-2003, Panelboards

16.4. ANSI/UL 94-2001, Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

16.5. ANSI/UL 98-1995, Enclosed and Dead-Front Switches

16.6. ANSI/UL 674-1994, Electric Motors and Generators for Use in Division 1 Hazardous (Classified) Locations

16.7. ANSI/UL 698-1996, Industrial Control Equipment for Use in Hazardous (Classified) Locations

16.8. ANSI/UL 705-1994, Power Ventilators

16.9. UL 723-1996, Surface Burning Characteristics of Building Materials

16.10. ANSI/UL 778-2002, Motor-Operated Water Pumps

16.11. UL 795-1999, Commercial-Industrial Gas-Heating Equipment

16.12. ANSI/UL 796-2002, Printed-Wiring Boards

16.13. ANSI/UL 823-1996, Electric Heaters for Use in Hazardous (Classified) Locations

16.14. ANSI/UL 834-1998, Electric Heating, Water Supply, and Power Boilers

16.15. ANSI/UL 842-1999, Valves for Flammable Fluids

16.16. ANSI/UL 844-1996, Electrical Lighting Fixtures for Use in Hazardous (Classified) Locations

16.17. ANSI/UL 877-1993, Circuit Breakers and Circuit-Breaker Enclosures for Use in Hazardous (Classified) Locations

16.18. ANSI/UL 886-1994, Outlet Boxes and Fittings for Use in Hazardous (Classified) Locations

16.19. ANSI/UL 891-1998, Dead-Front Switchboards

16.20. ANSI/UL 894-1998, Switches for Use in Hazardous (Classified) Locations

16.21. ANSI/UL 900-1995, Air Filter Units

16.22. UL 913-2002, Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II and III, Division 1, Hazardous (Classified) Locations

16.23. ANSI/UL 1002-1996, Electrically Operated Valves for Use in Hazardous (Classified) Locations

16.24. UL 1004-1994, Electric Motors

16.25. ANSI/UL 1008-1998, Automatic Transfer Switches

16.26. ANSI/UL 1010-1996, Receptacle-Plug Combinations for Use in Hazardous (Classified) Locations

16.27. ANSI/UL 1012-1996, Power Supplies

16.28. ANSI/UL 1020-1996, Thermal Cutoffs for Use in Electrical Appliances and Components

16.29. ANSI/UL 1025-1991, Electric Air Heaters

16.30. ANSI/UL 1054-1997, Special Use Switches

16.31. UL 1067-1997, Electrically Conductive Equipment and Materials for use in Flammable Anesthetizing Locations

16.32. UL 1203-2000, Explosion-Proof and Dust-Ignition-Proof Electrical Equipment for Use in Hazardous (Classified) Locations

16.33. UL 1562-1999, Transformers, Distribution, Dry Type - Over 600 Volts

16.34. ANSI/UL 1581-1998, Electric Wires, Cables and Flexible Cords

16.35. UL 1604-1994, Electrical Equipment for Use in Class I and II, Division 2, and Class III Hazardous (Classified) Locations

16.36. UL 1738-1993, Venting Systems for Gas Burning Appliances, Categories II, II and IV

16.37. UL 1741-1999 revised 2005, Inverters, Converters and Controllers for use in Independent Power Systems

16.38. UL 1773-1993, Termination Boxes

16.39. UL 1836-2000, Subject for Investigation for Electrical Motors and Generators for Use in Class I, Division 2 and Class II, Division 2 Hazardous (Classified) Locations

16.40. ANSI/UL 1998-2000, Software in Programmable Controls

16.41. UL 2021-1997, Fixed and Location-Dedicated Electric Room Heaters

16.42. UL 2075-2000, Subject for Gas and Vapor Detectors and Sensors

16.43. ANSI/UL 2111-2002, Overheating Protection for Motors

16.44. UL 61010C-1-2003, Process Control Equipment

17. UNDERWRITERS LABORATORIES CANADA

7 Course Road, Scarborough, Ontario, Canada M1R 3A9

17.1. ULC S636-1995, Type BH Gas Venting Systems

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195 Governor’s Highway
South Windsor, CT 06074

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