1 of 1

**Detailed Design of the 2 MW Demonstration Plant
Task 2**

Topical Report

September 16, 1993

Work Performed Under Contract No.: DE-FC21-92MC29237

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Fuel Cell Engineering Corporation
Danbury, Connecticut

MASTER

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P.O. Box 880
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**By
Fuel Cell Engineering Corporation
3 Great Pasture Road
Danbury, Connecticut 06813**

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1.0 INTRODUCTION

This document provides a summary of the design of the 2MW carbonate fuel cell power plant which will be built and tested under DOE cooperative agreement DE-FC21-92MC29237. The report is divided into sections which describe the process and stack module design, and Appendices which provide additional design detail.

Section 2.0 provides an overview of the program, including the project objectives, site location, and schedule. A description of the overall process is presented in Section 3.0. The design of the fuel cell stack Modules is described in Section 5.0, which discusses the design of the fuel cell stacks, multi-stack enclosures, and Stack Modules.

Additional detail is provided in a report Appendix, the Final Design Criteria Summary. This is an abstract of the design criteria used in the design of the Submodules and Modules.

2.0 PROJECT OVERVIEW

The objective of the 2MW Santa Clara Demonstration Project is the demonstration of the carbonate fuel cell technology at full scale. The carbonate fuel cell is a power generation technology which has the potential for significant benefits in terms of reduced dependency on foreign fuels and reduced greenhouse and acid rain emissions. However, in order for utilities to adopt the technology into their generation mix, it is essential that it be demonstrated at the multi-megawatt level. The Santa Clara Demonstration Project will be the first such demonstration plant for the carbonate technology.

The site for the plant is located at 1205 Space Park Drive in the City of Santa Clara. The site is owned by the City's Electric Department and is immediately adjacent to the Scott Receiving Station, a 115/60kV switching station on the City electrical system. The demonstration plant will occupy a portion of the site, measuring approximately 150 by 150 feet.

The project is being funded by the Santa Clara Demonstration Project (SCDP, a group of utilities, EPRI, and the NRECA) and by the U.S. Department of Energy under the Cooperative Agreement. Fuel Cell Engineering Corporation is providing over all management of the project. The stack design is being developed by Energy Research Corporation (parent company to FCE) based on technology from separate ongoing development programs. The stacks will be fabricated by ERC's manufacturing subsidiary, Fuel Cell Manufacturing Corporation. Fluor Daniel, Inc. is serving as the power plant A&E and is providing engineering support to the design of the multi-stack fuel cell modules.

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A summary level project schedule is shown in **Figure 2.1**. The project is currently in the engineering phase, with procurement scheduled to start in November, 1993 and construction in February, 1994. Upon completion of these activities, the plant start-up phase will begin. This includes BOP testing, stack installation, and power plant initial start-up. Following this, the operational phase of the plant will consist of an acceptance test, with 1000 hours of plant operating time, followed by the demonstration test period, which will involve a total plant operating time of 9000 hours. The acceptance test and demonstration test periods (a total of 10,000 hours system operating time), are expected to last through 1996. The following sections describe the process and the mechanical layout of the power plant.

FIGURE 2.1
PROJECT SUMMARY LEVEL SCHEDULE

3.0 POWER PLANT PROCESS DESCRIPTION

The process involves treating natural gas to remove impurities, after which it is mixed with steam and sent to the fuel cell stacks. The fuel/steam mixture is reformed in the stacks, providing the hydrogen which is consumed in the fuel cell anodes. The anode reaction also produces CO_2 , which is required in the fuel cell cathodes. The cathode feed is produced by taking the anode exhaust, burning any residual fuel with air, and sending the flue gas with excess air to the cathodes. The system uses 16 fuel cell stacks, which are configured into two 1MW module units, as described in Section 5.3 below.

A simplified process flow diagram is shown in **Figure 3.1**. The system represents ERC's "Simplified Design," with provision for startup, fuel cleanup, recirculation of carbon dioxide to the cathode side and exhaust of spent gases. The following sections describe the major process subsystems in the plant.

3.1 Natural Gas Processing Subsystem

As shown in the Figure 3.1, the natural gas fuel is preheated by exchanging heat with cathode exhaust gases in E-103. The gas is then sent through the fuel processing system, in which sulfur odorants and other impurities are removed. The treated gas is mixed with steam, and fuel/steam mixture is brought up to the required fuel cell temperature in E-101, the final superheater. The 1100 to 1250°F gas is then sent to the fuel inlet headers of the 1MW modules.

3.2 Cathode Supply System

The fuel is internally reformed to hydrogen in the fuel cell stacks, and 75% of the hydrogen is consumed in the power generation reactions of the fuel cell anodes, producing water and CO_2 . The anode exit stream consists of this steam and CO_2 , carbon monoxide from the reforming and shift reactions, plus the 25% residual hydrogen. The exit stream is sent to the main burner, H-101, where the hydrogen and carbon monoxide are combusted with excess air.

This quenched flue gas stream now contains the oxygen and CO_2 required by the fuel cell cathodes, and it is sent back to the fuel cells as the cathode feed stream. The quench air used in the burner is adjusted to provide the desired temperature for use in the fuel cell cathodes. Once the burner flue gas has been quenched to this temperature (1100°F), more than enough oxygen has been mixed in to supply the cathode oxygen consumption reaction. The anode exhaust burner is a catalytic reactor (with a thermal section for start-up and off-design operating modes) which reacts the anode exhaust gas with no measurable NO_x production.

FIGURE 3.1 2MW SCDP POWER PLANT SIMPLIFIED PROCESS FLOW DIAGRAM

3.3 Heat Recovery System

Cathode exit gases are used to provide heat to the HDS reformer (R-102), the fuel/steam heater (E-101), water boiler/superheater (E-102) and the fuel preheater. These heat exchangers are configured into a packaged heat recovery unit (HRU), which also contains the start-up burner (H-102) and the system exhaust stack. The cathode exit gas is the shell side gas in all of the exchangers, with water, steam, or fuel in the tube side streams. The packaged HRU skid will also house the deaerator for the steam generator.

3.4 Ancillary Subsystems

In addition to the systems described above, other subsystems in the plant include the water treatment system, instrument air compressor, backup power generator, and an inert gas heater for use during the first power plant start-up.

4.0 POWER PLANT MECHANICAL LAYOUT

The mechanical layout of the plant is shown in **Figure 4.1**. The plot plan shows the location of the major equipment shown in the process flow diagram, plus additional storage facilities and equipment. This report focuses in detail on the design of the 1MW fuel cell Modules, designated MOD-1 and MOD-2 in the Plot Plan.

FIGURE 4.1 2MW SCDP POWER PLANT LAYOUT

5.0 FUEL CELL STACK MODULE CONFIGURATION

The DC power section of the plant will consist of two 1MW Stack Modules. Each of these Modules will contain two Submodules, which are the truck shippable units which enclose the fuel cell stacks. The following sections describe the design of the stacks, the Submodules, and the 1MW Modules.

5.1 Fuel Cell Stack Design

The carbonate fuel cell stack is the building block repeating unit of the fuel cell system. The stack consists of 246 electrochemical cells, 41 fuel reforming units, and ancillary clamping, manifolding and electrical connection hardware. The electrochemical cells are similar to batteries in that they consist of anode and cathode (negative and positive) electrodes. Consumption of fuel occurs in the fuel cell anodes and consumption of oxidant (O_2 and CO_2) occurs in the cathodes. Both electrodes have catalytic surfaces over which gas is circulated. The anode and cathode catalytic layers are separated by a porous matrix material filled with molten carbonate salts. The stack operates at 1000 to 1260 °F in order to keep the carbonate salts in the liquid state.

The anode is fed with a hydrogen rich stream from the fuel processing reforming units. Hydrogen is consumed in the anodes in the following reaction:

The CO_3^{2-} ion is supplied by the carbonate electrolyte in the cell matrix material. The electrons ($2e^-$) produced provide the negative pole of the electrical power.

The cathode electrodes consume oxygen, from the air feed, and CO_2 in the following reaction:

The cathode electrodes serve as a sink for the electrons produced at the anode, completing the electrical circuit. The electrodes also produce carbonate ion, replacing the ions consumed at the anode.

Each cell package (anode/matrix/cathode) produces 0.761 volts at 666 amps at rated operating conditions. 246 cells are configured in a "stack" in which the cells are electrically in series, providing 187 volts at 666 amps, or 125 kW DC power.

In addition to the 246 cells in the stack, 41 Reforming Units are spaced throughout the stack, between sets of six-cell groups. The RUs are electrically conductive (to provide continuity of the stack current) gas passages with catalyst surfaces for fuel processing. The RUs are fed with natural gas and steam to produce hydrogen for the fuel cell. The reforming reaction is endothermic, so the RUs provide the additional function of absorbing some of the stack waste heat. After being processed in the Reforming Units, almost all of the natural gas hydrocarbons have been converted to hydrogen, and the stream is sent to the anode inlet manifold. As hydrogen is consumed in the anodes, the reforming reaction proceeds further, consuming any hydrocarbons which were not consumed in the RUs. The anodes will consume 75% of the hydrogen produced by reforming the natural gas. As described above, the gas exiting the anodes is sent to a catalytic reactor where residual hydrogen and carbon monoxide are reacted with air to supply the cathode feed gas.

5.2 Multi-Stack Fuel Cell Submodule Design

The fuel cell stacks will be configured into multi-stack, truck shippable submodules. Each submodule will consist of four stacks and associated piping, instrumentation, and electrical components in a sealed enclosure which is capable of operating at an elevated pressure as high as 1 psig. By operating the submodules at an elevated pressures, the stack process gas flow pressures can be higher without increasing the pressure differential across the stack manifold seals. This provides sufficient pressure for the stack exhaust gases to flow through the heat recovery unit without a system exhaust blower.

The structural enclosure for the stack submodules will be shop fabricated and shipped to the FCMC facility in Torrington, CT. There the fuel cell stacks will be installed in the enclosure and all piping, electrical, and instrumentation work within the enclosure will be completed. All piping connections will terminate at the enclosure sides with weld connections which will be sealed during shipment to the site. The penetrations of the pipe connections through the enclosure have been specially designed to limit heat loss from the hot pipes to the cool enclosure structure, and to withstand the mechanical stresses caused by the thermal expansion as the process pipes heat from ambient to operating temperature.

The overall dimensions of the 4-stack Submodules will be 9'-3.75" wide by 11'-11.5" high by 37'-4" long. The transport truck for the Submodule will be about 100 feet long, including a steerable rear trailer. The trailer will be equipped with a center drop well for the submodule to provide adequate overhead space and sufficient bed strength to limit deflection.

To provide shock protection and restrain movement of the top of the stack, rods will be provided between the stack and the enclosure structural frame which hold the top of the stack. The shock connections will be connected to the enclosure structural frame in a slotted arrangement. This allows vertical movement, such as due to thermal expansion, so that the restrainers can be left in during system operation, in which case they provide earthquake shock resistance.

All electrical and instrument connections will be brought to terminal boxes on the outside of the enclosure. This design approach provides for installation of the submodules at the Santa Clara site with a minimum of field labor. The four submodules will be truck shipped to the site, where two units will be installed in each of the two 1MW modules.

The four stacks in each submodule will be electrically connected in series. The voltage between stacks 2 and 3 will be the ground point of the string, so the series string voltage (with reference to ground) will go from a negative pole of -370 V to a positive terminal of +370 volts at rated power (and as high as -550 to +550 at open circuit).

5.3 1MW Fuel Cell Module Design

The DC power section of the power plant is split into two Fuel Cell Modules, each rated at 1 MW. Each Module will consist of two of the Submodules described in Section 5.2, with associated gas distribution piping, instrumentation connections, and electrical connections. The cathode gas distribution piping will consist of two 14" diameter header lines which provide cathode feed gas to each of the two submodules in a Module. The feeder lines off the header into the stack Submodules are 8" diameter. The cathode exit lines are 8" diameter lines which collect in pairs into 12" diameter subheaders, which direct the gas into a central 18" diameter cathode exhaust header. The anode gas distribution system starts with a central 6" diameter header, which feeds four 4" diameter subheaders, which then split into eight 3" diameter fuel feed lines. The anode exit lines from the stacks are 6" diameter lines which collect in pairs to 8" diameter subheaders, which direct the gas to a central 10" diameter anode exit header.

The design of the gas distribution piping is critical to the power plant. Significant variations in flow from stack to stack can lead to reactant utilizations in excess of the design range. A specification of stack-to-stack flow uniformity of $\pm 2\%$ was set by stack operating requirements as the Module interconnect piping design target. A flow modeling effort was conducted during the Module Design work to insure that the gas distribution system could meet this specification. It was determined that the incorporation of flow trimming valves in the cathode feed lines would provide the capability to meet the flow distribution specification. These flow control valves will be set once during the BOP test

(before the stacks are installed), using spool pieces which simulate the pressure drop characteristics of the stacks.

To further ensure the attainment of uniform flow distribution, and to obtain a more compact module design, the two Submodules in each 1MW module are arranged as mirror image pairs, and stacks will be provided with fuel inlet locations such that the fuel inlet lines in one Submodule will be directly across from the fuel inlet lines of the second Submodule in the Module. The configuration of the 1MW Fuel Cell Module can be seen in **Figure 5.1**.

FIGURE 5.1
1MW FUEL CELL MODULE CONFIGURATION

APPENDIX

The following appendix provides additional design detail for the 1MW Module, Submodule and stack designs. The Final Design Criteria Summary for the fuel cell Modules is an abstract of the design criteria used to develop the stack module design.

Please note:
There is no page 3 in this
appendix. The text continues
from page 2 to page 4.

**2MW FUEL CELL DEMONSTRATION PROJECT
DESIGN CRITERIA SUMMARY
1MW STACK MODULE**

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**2MW FUEL CELL DEMONSTRATION PROJECT
FINAL DESIGN CRITERIA
1MW STACK MODULE**

1.0 OVERVIEW

The DC power source for the 2MW Carbonate Fuel Cell Demonstration System will consist of two 1MW stack module subsystems. Each 1MW module will be comprised of eight 125 kW carbonate fuel cell stacks, connected electrically in two parallel sets of four in series electrical arrangement. Process gas streams will be fed to, and exit from, the stacks in parallel.

Each 1MW stack module is a self-contained subsystem in the plant, with interfaces to the balance of plant for process streams, electrical power lines, and instrumentation and control connections. The 8 stacks within each module will be split into two submodules with 4 stacks each, with an interconnecting pipeway between the two submodules with common header piping for the stacks. Each stack will be connected to appropriate headers by header feeder and exit lines. Each stack will have four piping interfaces - anode (fuel) inlet and outlet and cathode (oxidant) inlet and outlet.

These submodules will be shop fabricated shippable units with the required structural rigidity for truck transport from the factory to the demonstration project site. The submodules will be totally sealed units capable of being pressurized up to 1 psig with air or nitrogen. The seal integrity will be maintained during shipment in order to protect the stacks from weather and humidity.

The submodules will be connected within the module subsystem by the required process stream header and feeder lines. To the extent that it presents cost or logistical advantages, these piping subsystems will be shop fabricated, cleaned, painted and shipped to the site for final assembly into the module subsystem. The design of the gas flow distribution system in the piping module will be optimized for flow uniformity using computer modeling of the process flows.

2.0 CODES, STANDARDS AND REFERENCE CRITERIA AND SPECIFICATIONS

The stack module subsystem is a structural assembly with high temperature gas flow lines and high voltage electrical lines. As such the codes and standards requirements for the following areas need to be addressed:

General

- OSHA Standards, State of California
- National Fire Codes, NFPA
- American Society for Testing and Materials
- American National Standards Institute
- Santa Clara City Codes

Structural

- American Institute of Steel Construction (AISC), Steel Construction Manual, 9th Edition
- Structural Welding Code, ANSI/AWS D1.1
- Uniform Building Code (UBC) 1991

Mechanical/Piping

- Power Piping ASME B-31-1
- Power Piping ASME B-31.1
- Chemical Plant and Petroleum Refinery Piping ASME/ANSI B-31.3
- Steelpipe Flanges and Flanged Fittings, ASME/ANSI B-16.5
- Butt Welding Ends, ASME/ANSI B-16.25
- Stainless Steel Pipe, ASME/ANSI B-36.19

- Socketwelding End Components, ASME/ANSI B-16.11
- Special Finish Flanges, ASME/ANSI B-46.1
- Spiral Wound Gaskets, API 601
- Thermal Insulation Manufacturers Association (TIMA)

Electrical and Control Systems

- National Electric Code (NEC), ANSI/NFPA-70
- National Electrical Safety Code (NESC), ANSI C2
- Institute of Electrical and Electronic Engineers (IEEE)
- National Electrical Manufacturers Association (NEMA)
- Underwriters Laboratories, Inc. (UL)
- Instrument Society of America (ISA)
- Insulated Cables Engineers Associations (ICEA)

3.0 SITE CONDITIONS

- Site elevation 30 ft above Mean Sea Level
- Dry bulb temperature range 24°F to 105°F
- Maximum wet bulb temperature 68°F
- Average annual precipitation 14.2 inches
- Mean annual relative humidity 55%
- Wind: Basic wind speed 80mph, Exposure B
- Seismic Zone: UBC Zone 4
- Enclosure inside temperature will be in the range of 140°F to 200°F
- Enclosure internal operating pressure is 1 psig maximum; design pressure is 2 psig.

4.0 DESIGN CONDITIONS

The 1MW module will be connected to two feed streams and two exit streams (fuel and oxidant) :

Fuel Feed Stream:	▶ Steam and purified natural gas, with a 2 to 1 steam-to-carbon ratio. ▶ 1200 °F maximum ▶ 25 to 65 IWC gauge pressure in stack RU header lines ▶ During start-up and hot standby this stream provides steam with enough fuel to maintain a reducing atmosphere over the anode catalyst surfaces.
Anode Exit Stream:	▶ Reformed natural gas, with some of the hydrogen and CO removed and CO₂ and steam added by the fuel cell reactions. ▶ 1300 °F maximum ▶ 10 to 20 IWC gauge pressure in stack anode exhaust manifolds

- Cathode Feed Stream:** ▶ Anode exit stream after combustibles are burned with system air feed. Stream contains sufficient excess air to provide required oxygen for fuel cell reactions and to adjust burner flue temperature to desired temperature.
- ▶ 1400 °F maximum
 - ▶ 15 to 30 IWC gauge pressure in stack cathode feed manifolds
 - ▶ During start-up, this stream provides heated air or burner flue gas to provide heat to the stacks.
 - ▶ On hot standby this stream provides burner flue gas to maintain stack temperature.
- Cathode Exit Stream:** ▶ Cathode feed stream with some of the oxygen and CO₂ removed by the fuel cell reactions.
- ▶ 1300 °F maximum.
 - ▶ 5 to 10 IWC gauge pressure in stack cathode exhaust manifolds.

In addition to these major feed and exit streams, the 4-stack submodules will also be connected to air or nitrogen lines to raise the enclosure pressure.

5.0 EQUIPMENT & PERFORMANCE REQUIREMENTS

The major equipment in the stack module consists of the two 4-stack submodules, the flow distribution piping, electrical connections, submodule enclosure pressurizing system, and instrumentation and control connections.

5.1 Fuel Cell Stacks

The fuel cell stacks are the building block repeating unit of the fuel cell system. The stack consists of 246 electrochemical cells which produce electrical power when fed with fuel and oxidant streams. In addition, each stack contains 41 fuel reforming units (RU) spaced evenly throughout the stack, along with ancillary clamping, manifolding, and electrical connection hardware.

The reforming units are electrically conductive (to provide continuity of the stack current) gas passages with catalyst surfaces for fuel processing. The RUs are fed with natural gas (or auxiliary fuel) and steam to produce hydrogen for the fuel cell. The reforming reaction is endothermic, so the RUs provide the additional function of absorbing some of the stack waste heat.

An electrochemical cell consists of an anode electrode and a cathode electrode. Both electrodes have catalytic surfaces over which gas is circulated. The anode and cathode catalytic layers are separated by a porous matrix material filled with molten carbonate salts. The stack operates above 1000°F in order to keep the carbonate salts in the liquid state.

The anode is fed with the hydrogen rich stream from the fuel processing reforming units. The anodes consume hydrogen in the following reaction:

The CO₃²⁻ carbonate ion is supplied by the carbonate electrolyte in the cell matrix material. The electrons (2e⁻) produced provide the negative pole of the electrical power.

The cathode electrodes consume oxygen (from the air feed) and CO₂ (from the anode exhaust) in the following reaction:

The cathode electrodes serve as a sink for the electrons produced at the anode, completing the electrical circuit. The electrodes also produce carbonate ion, replacing the ions consumed at the anode.

At rated power each cell package (anode/matrix/cathode) produces 0.761 volts at 666 amps. 246 cells are configured in a "stack" in which the cells are electrically in series, providing 187 volts at 666 amps, or 125 kW DC power.

5.2 Electrical Connections

Each of the 4 stack submodules will be electrically connected to form a series string with center grounded. The two series strings will be connected to D.C. Switchgear in parallel via cables. The electrical terminals from the stacks will be extended beyond the stack insulation and the stack interconnection bussing will be at the ambient temperature within the module enclosure in order to facilitate change-out of stacks.

5.3 Piping Connections

The feed and exit streams for the stacks in a 1MW module will be connected by flanges to a parallel piped header system. Each stack will be connected to this pipe header system by a mirror image piping system for each opposite pair of stacks. An example would be the cathode exhaust header receives gas from each pair of stack's cathode exit streams through a common line for collection into a common header for 8 stacks.

6.0 SYSTEM INTERFACES

The major system interfaces are as follows:

- ▶ The feed and exit streams, as described above.
- ▶ The electric power interface, as described above.
- ▶ The instrumentation and control interfaces. These include:
 - ▶ Temperature monitoring sufficient to verify that the stacks are operating (or heating up in the case of start-up) in the desired temperature range.
 - ▶ Pressure monitoring sufficient to verify that the pressures in stack manifolds do not exceed seal limits and that the pressure differential between anode and cathode streams do not exceed the matrix dP capability
 - ▶ Voltage monitoring for each stack, including monitoring of the full stack voltage and the voltage of at least one six-cell group in each stack.
 - ▶ Current monitoring for the submodule.

7.0 SPECIFIC DESIGN CRITERIA

7.1 Structural

The following are the main design considerations:

- ▶ The enclosure will be designed to withstand an internal operating pressure of 1 psig maximum.
- ▶ The enclosure will also be designed to withstand a possible upset condition wherein the vapor build up inside the enclosure can increase the internal pressure to about 2 psig.
- ▶ The transportation loads imposed on the enclosure will be 1.0g applied simultaneously in the lateral and vertical direction.
- ▶ Design loads shall include dead, live, operating, impact, vibration, thermal, test, wind, earthquake, transportation and rigging.
- ▶ Loading combinations and allowable stresses shall be as specified in the Uniform Building Code.
- ▶ The piping penetrations at the enclosure walls will be totally sealed. There will be a removable top cover at each of the fuel cell stack locations to enable stack removal when maintenance is required or during stack replacement.

7.2 Piping

a. Design Considerations

Piping layout and design shall consider the maximum design temperature of each system for thermal flexibility and supporting of the piping. Piping materials shall be established by the system's temperature, pressure, commodity and corrosion allowance as required by Code ASME/ANSI-B31.1 and B31.3.

Expansion of the piping systems must be compensated for by flexibility built into the piping routing or by the use of expansion joints.

Piping materials, design, fabrication, seismic requirements, pressure testing and insulation shall be governed by the applicable codes listed under "Codes and Standards".

b. Design Loads and Supports

Supporting components shall be capable of carrying the range of load as specified by the stress analysis. They shall be designed to provide the required supporting effort and allow pipeline movement with thermal changes without causing overstress of piping or connecting equipment nozzles.

Designs shall provide for proper support of piping while maintaining economy, simplicity, functionality, and utilizing standard component supports where possible. The design shall be optimized by combining common supports for closely spaced

pipes. Design shall consider and allow for relative movements of pipes supported from a common assembly.

Supports of piping with the longitudinal axis in approximately a horizontal position shall be spaced to prevent excessive sag, bending, and shear stress in piping, with special consideration given where components, such as flanges and valves, impose concentrated loads. Where calculations are not made, the pipe spans shall not exceed the allowable spans as required by Code. Vertical supports shall be spaced to prevent the pipe from being overstressed from the range of all loading effects.

c. Piping Requirements

Fuel cell piping headers will be sized for eight (8) stacks to service the anode and cathode connections at the stacks. The branch piping to and from the stacks will have expansion joints to minimize the loads on the fuel cell flanged connections, which are anchored to the base frame.

Thermal insulation type and thickness shall meet the requirements of maintaining the operation temperature with minimum heat loss.

Temporary piping connecting the anode inlet and outlet will have to be provided for the start-up burn-out phase (pac test), prior to installation of the stack modules. The same will have to be done for the cathode inlet and outlet.

d. Design Requirements

Layout of the fuel cell stacks submodule shall fit into a truckable shipping size. Maintenance access within the stack submodule shall be provided to reach piping, electrical and instrumentation connection points to permit stack replacement. Crane access space shall be provided on the sides of the stacks for lifting stacks out of the top of the submodule by a crane.

Piping flanged connections to the fuel cell stacks have to be disconnected for stack removal and be designed to take the operating and dead loads. The pipeway headers are not in a module. They will be shop fabricated and field erected with a minimum amount of field welds.

e. Ventilation Requirements

During transportation a relative humidity of 25 percent at 70 degrees Fahrenheit will be maintained inside the stack module.

7.3 Electrical

7.3.1 Design Consideration

Hazardous Gas Accumulation - The module enclosure has adequate ventilation or nitrogen pressurization to prevent the accumulation of explosive vapor or gas mixtures. The air flow, pressurization and hazardous gas shall all be monitored and alarmed. All electrical instrumentation equipment and wiring shall be suitable for installation in the classified area.

System Grounding - The D.C. power system will be bi-polar with the center grounded. Pole to pole voltage is approximately 1025 volts open circuit. The equipment and stack module enclosure shall be grounded to the plant ground grid. A minimum of two external ground pads one at each diagonal corner shall be provided for connecting the module enclosure grounding system to the plant grounding system.

Fuel Cell Stack Interconnections - The four fuel cell stacks in each stack module enclosure will be interconnected to form a series string. This string will be routed through underground duct bank to D.C. switchgear. The four strings (2MW) are parallel connected to the D.C. switchgear.

Temperature Effect on Cable - Electrical power cable ampacity shall be properly derated due to high ambient temperature. The insulation material of the cable shall be suitable for the ambient temperature of 200°F. Silicon rubber and high temperature PVC insulation material are likely to be selected for this application.

Tray and Conduit System - Cable trays and/or conduits will be installed inside the module enclosure. It shall be firmly supported and grounded. The power and instrumentation/thermocouple circuits shall be routed in the separated trays and/or conduits. The design of tray/conduit system shall facilitate the removal of the fuel cell stacks.

Terminal Boxes - Terminal boxes will be installed at each stack for termination of ac power, instrumentation and thermocouple wires. Terminal cabinets shall be installed on the external of the module for interface to the Balance of Plant.

7.4 Instrumentation and Controls

The following addresses all four submodules each containing four fuel stacks.

7.4.1 Temperature Measurements

Instrumentation is required for measuring temperature at each of the following locations:

- a. Anode inlet line to each stack module (Qty-16),
- b. Reformer outlet (anode turnaround) manifold (Qty-16),
- c. Stack module (Qty-16),
- d. Anode outlet line from each stack module (Qty-16),
- e. Anode outlet header from each 1 MW stack (Qty-2),
- f. Cathode inlet line to each stack (Qty-16),
- g. Cathode outlet line from each stack (Qty-16).

7.4.2 Temperature Test Points

Temperature testing points are required at the following locations:

- a. Anode outlet lines from each stack module (Qty-16),
- b. Cathode inlet lines to each stack module (Qty-16),
- c. Cathode outlet lines from each stack module (Qty-16).

7.4.3 Pressure Measurements

Within the stack module enclosure, pressure measurements are required on stack modules 1, 4, 5, 8, 9, 12, 13 and 16 as follows:

- a. Reformer outlet (anode turnaround) manifold (Qty-8),
- b. Stack anode outlet manifolds (Qty-8),
- c. Cathode inlet manifold (Qty-8),
- d. Cathode outlet manifold (Qty-8).

In addition to the above stack module measurements, pressure measurements are required to monitor and control enclosure pressure as follows:

- a. Air or nitrogen to the module enclosure (Qty-2),
- b. Module enclosure near the exit point (Qty-2).

7.4.4 Voltage Measurements

Voltage measurements are required as follows:

- a. Overall stack (Qty-16),
- b. Stack mid-point (Qty-16).

7.4.5 Gas Analyzer Sample Points

Sample points for supplying gas analyzers will be required at the following locations:

- a. Reformer outlet manifold (Qty-16),
- b. Anode outlet lines from each stack (Qty-16),
- c. Anode outlet header from each 1 MW stack module (Qty-2),
- d. Cathode outlet lines from each stack (Qty-16),
- e. Cathode outlet header from each 1 MW module (Qty-2).

7.4.6 Pressure/Vacuum Safety Valves

Pressure/vacuum safety valves will be required on the module enclosures. These valves will be sized to relieve positive pressure buildup within the enclosure due to pressurization valve failures or other abnormal events. Vacuum relief is required to protect the enclosure during cooldown. These valves will be either pilot or weight loaded type depending upon the design requirements.

In addition to the safety valves, blow out panels will be provided.

7.4.7 Control Valves

Control valves are required for controlling purge air to the stack enclosures when on air purge and for controlling N₂ vent to atmosphere when on N₂ purge. The purge air valve will be a butterfly type to produce low pressure drop at full combustion air flow. The N₂ vent valve will be a globe valve with cage trim.

7.4.8 Pressure Gauges

Locally indicating pressure gauges are required on the purge lines connecting the stack enclosures.

7.4.9 Test Instrumentation

In addition to the above permanently installed instrumentation, there is also a requirement for instrumentation for use during BOP testing. Specifically, in place of each stack a spool piece will be installed during the testing phase which will simulate the pressure drop of the stack using an orifice or other device. Pressure differential measurements are required at each stack to produce an initial flow balance to each stack. Once accomplished and BOP testing is complete, this instrumentation will be discarded.

8.0 SPECIAL REQUIREMENTS

8.1 Safety

Safety systems should be sufficient to protect personnel from the following hazards:

Electrical, with up to 550 volts pole to ground

Toxic gas leaks, principally carbon monoxide and including the off gases produced during first start-up from binder burn-out and insulation heat-up.

Flammable Explosive gases, CO, CH₄, H₂

High Temperatures, (up to 1300 °F)

8.2 Fire Protection

The fire protection system should include monitoring of ambient air for combustibles present in the module process streams. Any use of water based fire protection systems should take into consideration the sensitivity of the stacks to moisture. Fire hydrants and dry type fire extinguishers shall be provided.

8.3 Materials

The high temperatures and high purity requirements in the process dictate the use of stainless steel for all of the piping used in streams which feed the stacks. Insulation materials used on the piping need to be sufficient to prevent excessive heat losses from the gas streams.

A supply of dry air is needed to blanket the stack flow channels during cold stand-by, because humidity can damage the stack matrix components.

8.4 Maintenance & Access

The minimum removable unit in the module will be a single stack, so access needs to be provided to:

- a) Break the enclosure around 4-stack submodules
- b) Connect and disconnect electrical and process connections
- c) Remove and flange off a stack
- d) Replace the stack.

8.5 Submodule Transportability

The 4-stack submodules in each module will be shop fabricated and shipped to the plant site. The design of the units must account for the following issues:

- ▶ The size and weight limitations of truck transport
- ▶ Interstate permitting requirements
- ▶ Shock and vibration exposure in transit and during loading/unloading operations
- ▶ Weather exposure during shipping
- ▶ Ability to elevate pressure during system operation.

8.6 Testing

A process and control test will be run on the 2 MW Demonstration Project balance of plant before the stacks are installed in the system. The 1MW modules need to provide for the installation of "dummy" stack simulators to mimic the pressure and flow characteristics of the stacks.

8.7 Stack Conditioning

When the stacks are delivered to the site the ceramic cell matrices will not have been conditioned. Unique, one-time only aspects of the conditioning operation involve driving off solvents and binders used during cell fabrication, and oxidation of cathode catalyst surfaces. This will be done during the first heat up of the plant, using the 2MW system balance of plant. All emissions from the curing process will be incinerated before release to the atmosphere by the start-up burner in the heat recovery system, or by other means.

8.8 Spent Fuel Cells

At the end of the useful life of the fuel cell stacks, the stacks will be returned to the vendor for post-test analysis.

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