DIRECT FUELCELL® DFC1500 POWERPLANT SPECIFICATION SUMMARY

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FuelCell Energy, Inc.
Attn: Ross M. Levine, Esq.
3 Great Pasture Rd.
Danbury, CT 06813
rlevine@fce.com

1.0 INTRODUCTION

This document summarizes the Direct FuelCell® (DFC®) powerplant design specifications. The DFC1500 powerplant consists of power generation and balance of plant skids arranged to provide sufficient access for maintenance activities. The major elements of the powerplant include:

- DC Power Section: One 4-stack DFC® module
- Electrical Balance of Plant: : DC to AC conversion and voltage transformer, control system and operator interface
- Heat Recovery Unit (HRU),Anode Gas Oxidizer (AGO) and Instrument Air Skid: Fuel preheat, humidification, and air preheat
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- Fuel and Water Treatment Skid:

An illustration of the system is shown in Figure 1:

Figure 1**DFC1500 Powerplant**

As shown in Figure 1, the powerplant is configured into skids that contain logically grouped subsystems. The layout shown in Figure 1 represents the standard arrangement that involves the least amount of project specific engineering.

The DC Power section comprises one fuel cell module containing four DFC® stacks and associated piping and instrumentation. The module is a cylindrical, truck-transportable unit internally insulated to maintain the outer skin of the container near ambient temperature. The module is fed with a hot fuel/steam mixture from the HRU skid and heated air from the oxidant supply skid.

The Electrical Balance of Plant (EBOP) contains the inverter, control system, operator interface and transformers. This skid also contains all of the necessary hardware needed for interconnection into the grid. The electrical system in the plant converts DC power from the Fuel Cell Stack Module to AC power output supplying all of the plant auxiliaries and exporting the remaining power to the grid. The reactive component (up to 1700 kVA) is regulated by a specified VAR input. A battery-supported uninterruptible power supply (UPS) is provided to maintain power for the Distributed Control System (DCS) and other critical components during electric grid voltage dips or outages. This skid contains the plant control hardware and the local user interface panel.

The Heat Recovery Unit / Anode Gas Oxidizer (HRU/AGO) Skid takes treated cold water and fuel and produces a fuel/steam mixture at the appropriate temperature for delivery to the fuel cell stacks. The Skid also consists of a packaged catalytic reactor and cold air supply blower (and associated local controls, etc). The residual fuel in the anode exhaust is used in the catalytic reactor to preheat incoming air. An instrument air compressor is also packaged in the HRU/AGO skid.

The Fuel and Water Treatment Skid contains the fuel cleanup systems and other required fuel treatment reactors (e.g. de-oxidation reactors for peak shaving natural gas). The skid also treats municipal water using typical treatment equipment , eg. softeners and reverse osmosis to provide a quality suitable for use in the steam generator. The skid includes a storage tank for treated water. . This skid is equipped with several cylinders of nitrogen that are used during plant startup, shutdown, and maintenance activities.

The operating characteristics and performance presented in this document reflect both current and advanced fuel cell technology that FCE has achieved and expects to further advance on in the near future . The balance of plant (BOP) equipment is based on proven and commercially available technology.

The DFC1500 has been designed and built in accordance with nationally accepted codes and standards in addition to codes presently under development. FCE expects these additional codes and standards to be ratified in the near future.

- CSA FC 1 (formerly ANSI Z21.83) American National Standards for Stationary Fuel Cell Systems
- NFPA 853, Installation Standard for Stationary Fuel Cell Powerplants
- IEEE SCC21 P1547, Interconnect Standard
- UL 1741, Inverter Standard

2.0 PLANT PERFORMANCE AND OPERABILITY CHARACTERISTICS

2.1 Overall Design Specifications:

The following target specifications have been established for the DFC1500 powerplant:

Table 1, Plant Specifications

	Current Product	
Dimensions		
Height	25	Feet
Width	44.5	Feet
Length	39	Feet
Power Output		
Power at Plant Rating	1000	kW
	Up to 1700	kVA
Voltage	480	VAC
Frequency	50 or 60	Hz
Power Quality	Per IEEE 519	
Efficiency At Rated Output	49%	LHV
Heat Rate	6,965	Btu/kWh LHV
Fuel Consumption at rated output (natural gas)	125 scfm	@933 Btu/ft^3 LHV
Water Use		
Water Uptake	153	gph
Water Discharge	65	gph
Available Heat (at rated power)	Approx 1.4	MMBtu/h
Exhaust Temperature	About 650 F	°F
Exhaust Flow	13,800	lb/hr
Exhaust Absolute Humidity	20%	by volume
Exhaust Back Pressure	< 5”	water column
Noise	70	dB(A) at 10 feet
Emissions		
NO_X	0.3	ppmv
SO_X	0.01	ppmv
CO	10	ppmv
NMOC	10	ppmv

2.2 General Operability Characteristics

2.2.1 Plant Control:

The plant is designed for unattended operation with local and remote dispatching/control. The powerplant has a local control console that is limited to displaying operating mode (see below) and providing inputs for selecting desired power output level or mode transition. Additional data and controls are provided through local computer hookup or remote computer monitor stations (with security restrictions in each case).

2.2.2 Operating Modes:

Out of Service:	Plant is at ambient temperature.
Heatup:	Plant is heating up to operating temperature
Hot Standby:	Plant is at operating temperature, but not on load
Cool Down:	Plant is slowly being cooled to ambient temperature
Power Output Dispatch Mode:	Plant is delivering power to a set point kW demand
Power Output Regulation Mode:	Plant is meeting load of isolated load island
Manual Mode:	Operated with manual override of all or portions of control system
Tripped and Isolated:	Plant is tripped, with slow nitrogen purge

The baseline plant is not capable of black start from out of service.

2.3 Plant and Subsystem Life

The design life target for the overall plant is 30 years, assuming appropriate maintenance and component replacement. Each fuel cell stack requires replacement after 25,000 hours for current products and 40,000 hours for replacement modules . "Hours" here refers to hours of operation at a stack temperature above 900 ^{o}F. During operation of these stacks performance gradually decreases; this performance degradation results in a combined loss of efficiency and power output of approximately 10% over the life of the stack. Operation of the stacks beyond these lifetime windows may be possible, but at restricted power output and lower efficiency.

2.4 Operation and Maintenance Requirements

The DFC1500 powerplant will require periodic replacement of the following equipment and consumables:

- Fuel cell stacks, as discussed above (also see section 2.5.1).
- Water treatment chemicals and components (salt, activated carbon, softener resin, RO membranes and filters).
- Fuel cleanup sulfur sorbent
- Bottled nitrogen (used as a blanket and/or purging gas for the system during startup, shutdown, and emergency shutdown of the plant).
- Catalysts (for the preconverter and peak shaving de-oxidizer, if included).
- Miscellaneous materials for normal operation and maintenance (O&M) of the plant (including filters, lube oil, etc).

The estimated initial quantities and service life of major catalysts and chemicals for the DFC1500 powerplant are listed in Table 2.

Table 2
Catalysts and Chemicals Summary

ITEM	INITIAL AMOUNT	SERVICE LIFE
Fuel Preparation		
Sulfur Sorbent	2000 lbs	6 months – 2 years(2)
Preconverter Catalyst	4 ft^3	3 years
De-Oxidizer Catalyst (1)	1 ft^3	5 years
HRU Catalyst	13 ft^3	2 years
Oxidant Supply		
Anode Exhaust Catalyst	4 ft^3	5 years
Water Treatment		
Salt	80 gallon	2 to 6 months

Notes:
(1) Required for peak shave gas option only
(2) At 100% capacity, dependent on type of odorant in natural gas

Labor requirements for O&M are expected to be limited to labor to replace these consumables, routine maintenance, and periodic checks of the plant.

2.5 Installation and Site Issues

The powerplant is designed for installation at a wide variety of sites, with a range of conditions. Host sites with ambient conditions other than those below may require modifications, additional equipment and/or may result in a reduced output. The following subsections discuss the modularization, transportation, and site issues.

2.5.1 Modularization and Transportation

As discussed above, the DFC1500 is a fully modularized plant, consisting of a Fuel Cell Stack Module and mechanical and electrical equipment skids. All components are designed for outdoor installation and can be transported by truck to the plant site. .

The DFC® Module and balance of plant (BOP) equipment skids are assembled and tested prior to shipment to the site. Each DFC® Module, containing four fuel cell stacks and internal distribution piping/ducting, is assembled and conditioned in the factory. All mechanical and electrical equipment, piping, and valves will be shop installed on the equipment skids prior to delivery. Because of the Matched Modular design, minimal assembly is required at the plant site. All instrumentation and electrical components are pre-wired with all connections terminating at junction boxes.

The DFC1500 design facilitates rapid installation at the plant site. Access to critical plant components for inspection and maintenance work is provided in the standard arrangement (catalyst and absorbent replacement, valve maintenance, air filter replacement, etc.).

The Fuel Cell Stack Module is approximately 14 feet in diameter, and weighs approximately 90,000 lbs. The shipping weight of the other BOP skids is summarized in Table 3:

Table 3, BOP Skid Shipping Weights

DFC powerplant Weights	Estimated Shipping Weight lbs	Estimated Operating Weightlbs
HRU / AGO Skid	91,000	91,000
Fuel and Water Treatment Skid	53,000	70,000
Electrical Balance of Plant	48,000	48,000

Shipping of the Fuel Cell Stack Module and equipment skids will be in accordance with Department of Transportation (DOT) regulations. . Special routing with escort and special permitting may be required , particularly in metropolitan areas.

Approximately four weeks are required to complete interconnects and commissioning following delivery of the equipment to the site.

As noted above, the fuel cell stacks have to be replaced every three (current product) to five years. This will be done by delivering a new or reconditioned module to the site and swapping out the old module with a minimum of fieldwork and down time. The used module will be returned for materials recycling or reconditioning.

The plant requires a rectangular plot area of less than 1750 square feet. An access zone capable of supporting the module transporter and the crane used to lift and replace the DFC® Modules is required at the front of the site. A five-foot perimeter access zone is required for maintenance activities. .

2.5.2 Site Conditions

Site and climatic design conditions for the plant are listed in Table 4. The plant has been designed to allow installation at most sites around the world. Design conditions refer to the range of conditions that a standard plant must operate under. Conditions outside of this range may require plant modifications at extra cost. Performance point data refer to the conditions at which the plant will provide its rated output and efficiency.

TABLE 4
GENERIC SITE DESIGN CONDITIONS (1)

CATEGORY	DESIGN CONDITIONS	PERFORMANCE POINT (2)
Elevation above Sea Level	0 to 2500 ft	0 ft
Ambient Temperature	-20 to 104 °F	59 F
Relative Humidity	0 to 100 %	60 %
Wind Loading @ 33 ft	24 PSF (3)	
Snow Load	30 PSF (4)	
Precipitation	2.5 inches/hour	
Seismic	UBC Zone 4	
Ambient Dust Loading, Ave./yr	27 micro-gram/m^3	
Ambient Gaseous Halide Concentration, Ave./yr	20 ppbw	
Ambient Gaseous Sulfur Dioxide Concentration in Air	< 10 ppb	

Notes:
(1) Highway access is required. Rail siding is not required.
(2) Basis for powerplant performance calculations.
(3) This wind load of 30 PSF is based on a wind speed of less than 90 mph and Exposure C. Exposure C is defined as “Open terrain with scattered obstructions having height generally less than 30 feet” (American Society of Civil Engineers standard ASCE 7-95).
(4) This snow load is equivalent to a ground snow load of 40 PSF and a snow exposure factor of 0.7 per Uniform Building Code UBC-97.

2.5.3 Plant / Site Interfaces

The plant is designed for the following interconnections at the plant boundary limit:

- Pipeline natural gas supply
- Municipal quality potable water supply
- Firewater supply (depending on local regulations)
- Waste water discharge
- Flue gas discharge to safe location
- Safety relief valve discharge to safe location
- Discharge of ventilation gases

The plant also includes connections for telephone and/or data lines. These lines can be used for interconnection of the controller and fire alarm control panel with the buyer's control center, dispatch facility, local fire department, FCE, etc.

A connection to an electric grid is also required. Whenever the powerplant will not be generating power (such as during plant startup and shutdown), electric power for the plant auxiliaries will have to be backfed from the electric grid.

Minimum requirements for gas and water entering the plant are described in the next sections.

2.5.3.1 Fuel Quality Requirements

The plant is designed to operate with natural gas that meets the criteria listed in Table 5. A small addition to the standard plant provides the capability to generate power on peak shave gas (natural gas mixed with propane or butane and a small amount of air, with up to 4% oxygen content), as defined in Table 6. Optional equipment is also available to run on anaerobic digester gas.

Natural gas with the "performance fuel" characteristics listed in Table 5 is used as the basis for estimating the plant's rated performance. Use of natural gas with a different composition or heating value, or use of a peak shave gas , may impact plant performance.

Table 5
Pipeline Natural Gas Requirements (Delivered To Site)

PROPERTY	RANGE/LIMITS	PERFORMANCE FUEL (1)
<u>Composition</u>		
Methane, vol %	80 - 100	93.8
Ethane, vol %	0 - 10	1.9
Propane vol %	0 - 3	1.6
Butanes, vol %	0 – 1.25	0.5
Pentanes+, vol %	0 - 0.5	0.0
Unsaturated Hydrocarbons	None	None
Inert Gases	0 - 5	2.2
- Nitrogen, vol %	0 - 3	1.1
- Carbon Dioxide, vol %	0 - 3	1.1
Oxygen, vol %	0 - 0.2(2)	0.00
<u>Impurities</u>		
Total Sulfur, ppmv	0 - 12(3)	6(4)
grains/100 SCF	0 - 0.7	0.36
- H_2S, ppmv	0 - 0.8	0
- COS, ppmv	0 - 2	0
- Odorants, ppmv	0 - 12	6
Halogens (Cl, etc)	None	None
Dust/Gum/Solid Matter	None	None
Water, lb/MMscf	0 - 7	Dry
<u>Physical Properties</u>		(1)
Heating Value, Range		
- LHV, Btu/scf	870 – 1000	933
- HHV, Btu/scf	970 – 1100	1035
Pressure, psig	15	15(5)

Notes for Table 5
(1) The composition and heating value of the performance natural gas are the mean values from a survey of natural gas in 26 major metropolitan areas of the U.S. (from GRI report GRI-92/0123, March 1992). Deviations from this specification will impact plant performance.
(2) If the natural gas has a higher oxygen content, such as when propane-air peakshaving gas is present, the plant must be maintained in standby mode, unless the peak shaving option is installed, in which case the plant performance will be down-rated.
(3) Nearly all pipeline natural gases will meet this specification, based on the sulfur impurity levels reported in GRI-92/0123.
(4) Basis is the average total sulfur content in pipeline natural gas from a survey in GRI-92/0123.
(5) Basis for the DFC1500 powerplant performance estimate and the sulfur adsorption capacity of the sorbent in the natural gas desulfurization system.

Table 6
Peak Shave Gas Compositions (Delivered To Site)

PROPERTY	PROPANE/AIR (1)	BUTANE/AIR (1)
<u>Composition</u>		
Hydrogen, vol %	0.5	0.5
Methane, vol %	44.0	53.5
Ethane, vol %	2.0	2.0
Propane vol %	31.0	1.0
Butanes, vol %	0.5	21.0
Pentanes+, vol %	0.0	0.0
Oxygen, vol %	4.0	4.0
Inert Gases	18.0	18.0
- Nitrogen, vol %	17.0	17.0
- Carbon Dioxide, vol %	1.0	1.0
Unsaturated Hydrocarbons	0.0	0.0
<u>Impurities</u>	Similar to Natural Gas Data	Similar to Natural Gas Data
<u>Physical Properties</u>		
Heating Value, Range		
- LHV, Btu/scf	1163.8	1172.9
- Wobbe No.	1183.2	1187.9
Pressure, psig	15	15

Notes for Table 6
(1) Gas compositions estimated from values provided for European peak shave gas compositions. Compositions based on maximum oxygen and propane/butane concentrations, assumed to be worst-case scenario for process design; other values fall within ranges for peak shave gas compositions and chosen comparable Wobbe Nos.

Water Quality Requirements
The plant is designed to operate with municipal potable water makeup that meets the criteria listed in Table 7. These criteria were used in estimating specifications for the water treatment system. The performance water criteria listed in the table is the basis used for estimating the plant's water treatment requirement. Water quality outside this range will typically require more frequent maintenance intervals or additional treatment equipment.

Table 7
Water Requirements (Delivered to Site)

ITEM	RANGE / LIMITS	PERFORMANCE WATER [1]
Quality		
Calcium (Ca), mg/l as $CaCO_3$	0 - 120	44
Magnesium (Mg), mg/l as $CaCO_3$	0 - 30	16
Sodium (Na), mg/l	N/A	16
Bicarbonate (HCO_3), mg/l as $CaCO_3$	0 - 90	50
Chloride (Cl), mg/l	0 - 50	17
Sulfate (SO_4), mg/l	0 - 90	20
Total Dissolved Solids, mg/l	0 - 350	135
Total Hardness as $CaCO_3$, mg/l	0 - 150	60
Silica (SiO_2), mg/l	0 - 10	3
Iron (Fe), mg/l	0 - 0.1	0.03
Copper (Cu), mg/l	0 - 0.05	0.01
Silt Density Index	0 - 5	2
Specific Conductance, micromho/cm	0 - 580	205
pH	7 - 8.5	7.6
Properties		
Temperature, °F	40 - 90	59
Pressure, psig	50 - 65	60

Note:
(1) Basis used for estimating the powerplant water treatment requirements