

**Hydrogen Education Foundation
2011-2012 Theme:
Design a CHHP System
for your University Campus**

Specifications for CHHP System Design

November 2011

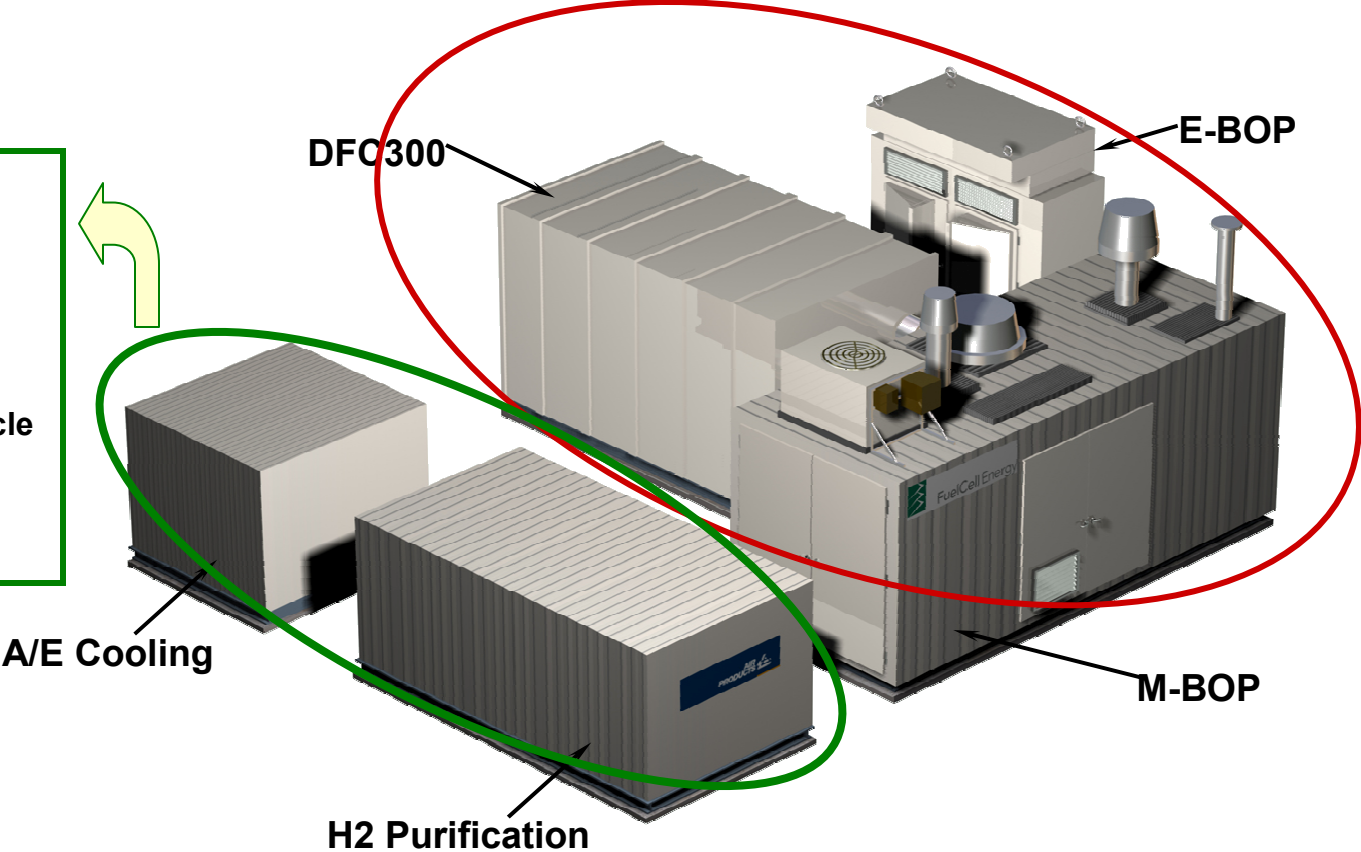
Design a CHHP System for your University Campus

- CHHP means Co-production of Hydrogen Heat and Power.
- Power source is high efficiency internal reforming fuel cell.
 - e.g., FuelCell Energy's Direct Fuel Cell (DFC)
 - The internal reforming creates hydrogen for the fuel cell reaction and excess hydrogen for export.
- DFC power plant size options (300 kW, 1400 kW, 2800 kW)
- Fuel Options: Natural Gas, Biogas, Propane, etc.

CHHP System Design Basis

- Specifications for Simple Cycle DFC Power Plant
 - Fuel in
 - Water in
 - Electrical efficiency (e.g. 47%)
 - Facility Exhaust waste heat

- Specifications for Hydrogen Production
 - Anode exhaust composition
 - DFC Fuel Utilization
 - Impact on simple-cycle waste heat
 - Supplemental Fuel Option



Direct Fuel Cell[®] (DFC[®]) Power Plant

- Simple Cycle Products:
 - DFC300[™], DFC1500[™], DFC3000[™]
- Simple cycle product specifications available at:
<http://www.fuelcellenergy.com/products.php>
 - Specifications also included in appendix.
- For cost sensitivity analysis DFC simple cycle capital cost may be taken as \$5,000 to \$1,000 per kW net AC capacity.
 - Cost does not include additional equipment for CHHP system

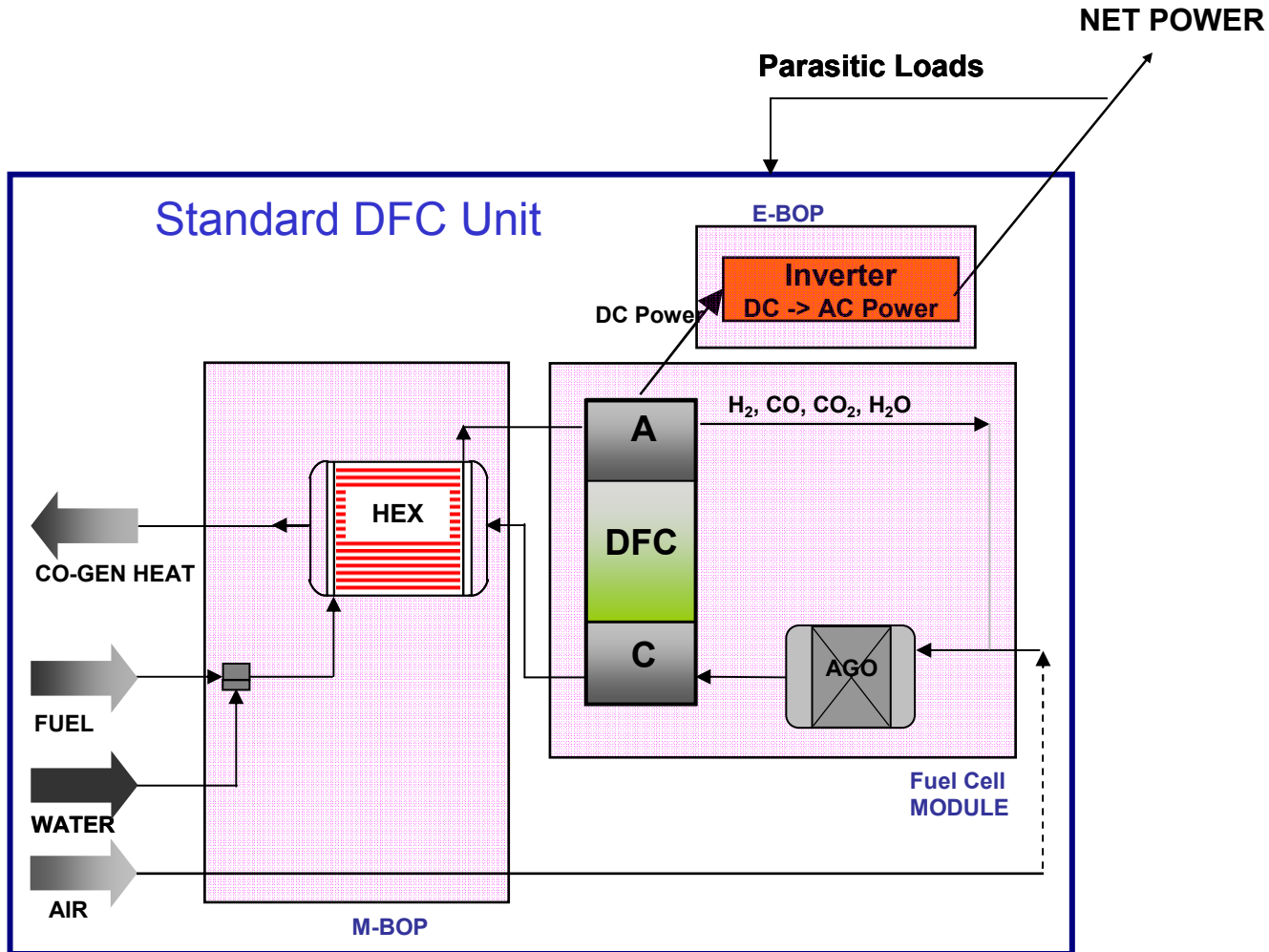
Fuel Specification for CHHP System

- Baseline Fuel: Natural gas
- Examples of Renewable Fuels:
 - Biogas derived from anaerobic digester, landfill
 - Minimum methane content 60%
 - Syngas derived from thermal gasification.
 - Must be methane rich, at least 50% methane
- Fuel pretreatment
 - Non required for pipeline natural gas
 - Clean up required for renewable/other fuels
 - Sulfur, siloxane, and halogens down to sub-PPMV level.
- Renewable fuels may be blended with natural gas.

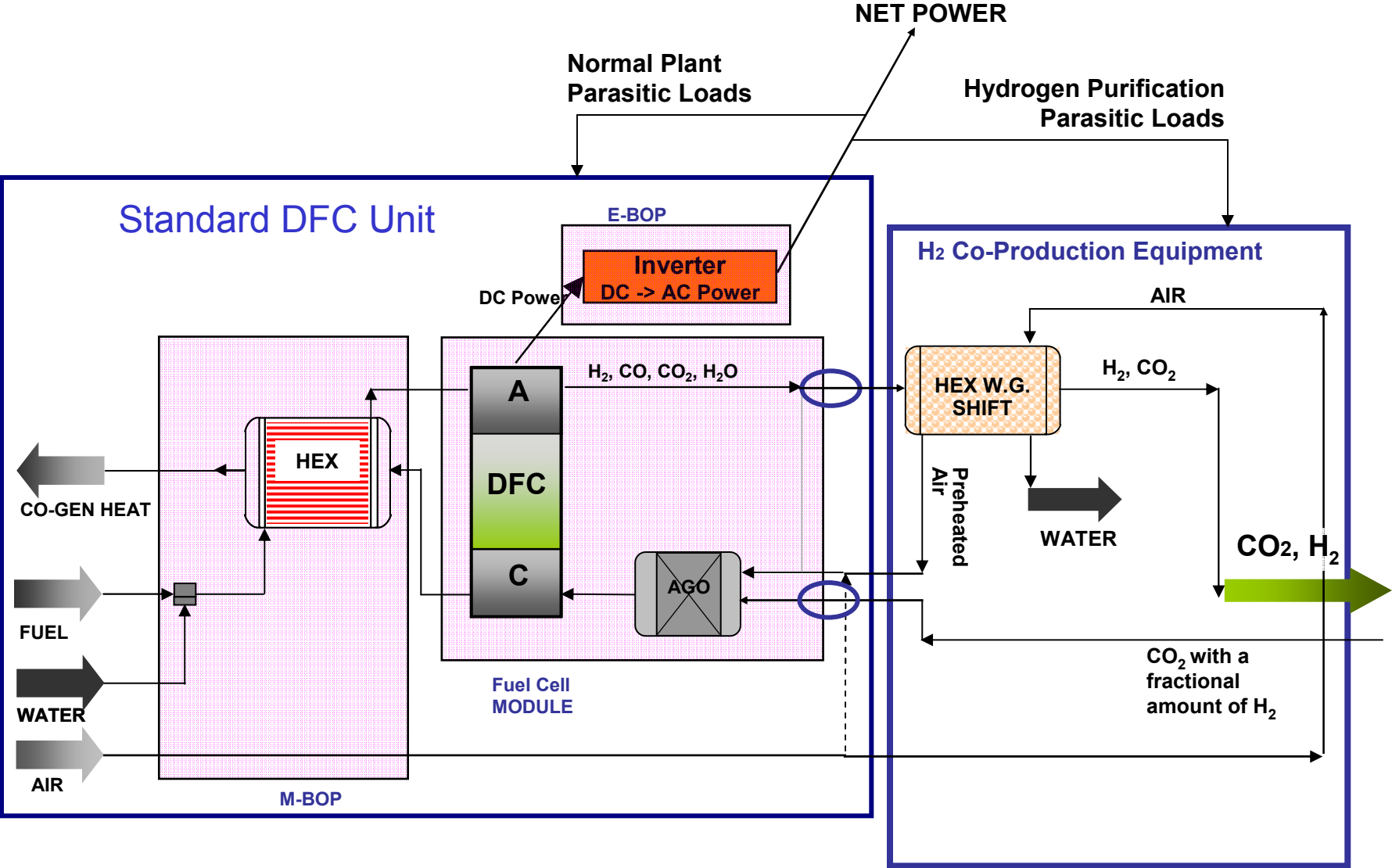
Basis for Hydrogen Co-Production

- Anode Exhaust Composition (at fuel utilization of 65%)
 - H₂ 10%
 - H₂O 40%
 - CO 5%
 - CO₂ 45%
 - N₂ 0.3 – 0.8% (fuel dependent)
 - CH₄ <1%
- Impact of Hydrogen Co-Production on Heat Energy available for recovery:
 - Available heat energy is reduced from simple-cycle specification on a one-for-one basis of the heat value of hydrogen product exported.
- Supplemental Fuel Option:
 - Supplemental fuel may be added to facilitate greater hydrogen production.
- Fuel Utilization may be decreased to increase hydrogen production:
 - Normal simple-cycle fuel utilization 70% - 80%.
 - For increased hydrogen production the fuel utilization may be decreased down to 60%.
 - Anode exhaust will be richer in hydrogen and carbon monoxide with decreased fuel utilization according to carbonate fuel cell reaction equations.

Simple Cycle DFC[®] Configuration



Example CHHP Configuration



APPENDIX

DFC Product Specifications

DFC300

Key Features

- High Efficiency
- Low Environmental Impact
- Fuel Flexibility
- High Reliability
- Quiet Operation

Advantages

The DFC300™ stationary fuel cell power plant from FuelCell Energy provides high-quality, Ultra-Clean electrical power with 47% efficiency in a small footprint. Designed for commercial and industrial applications, the system offers operation around-the-clock, easy transport, quiet and reliable operation, and easy site planning and regulatory approval.

Performance

Power Output

| | |
|-----------------------------|---------------------------|
| Power @ Plant Rating | 300 kW |
| Standard Output AC Voltage | 480 V |
| Standard Frequency | 60 Hz |
| Optional Output AC Voltages | 460, 440, 420, 400, 380 V |
| Optional Output Frequency | 50 Hz |

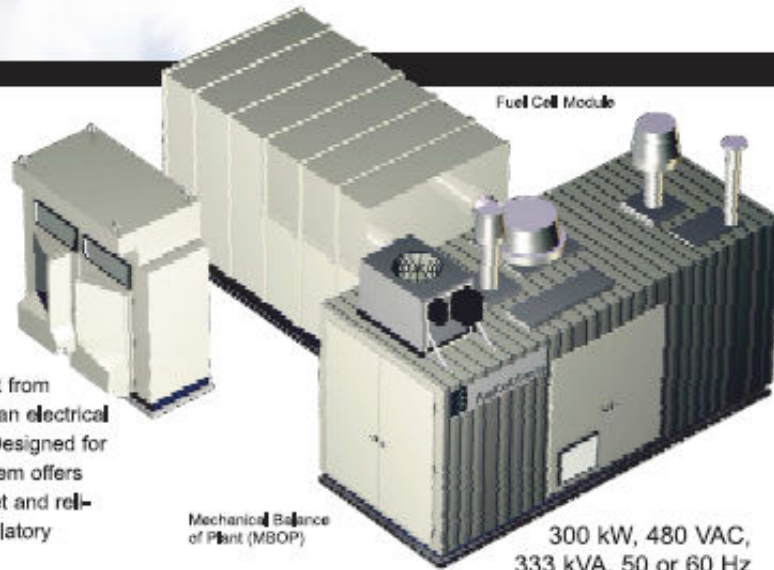
Efficiency

| | |
|-----|------------|
| LHV | 47 +/- 2 % |
|-----|------------|

Available Heat

| | |
|-----------------------------------------------|---------------|
| Exhaust Temperature | 700 +/- 50 °F |
| Exhaust Flow | 3,950 lb/h |
| Allowable Backpressure | 5 iwc |
| Heat Energy Available for Recovery (to 250°F) | 480,000 Btu/h |
| (to 120°F) | 808,000 Btu/h |

Electrical Balance of Plant (EBOP)



Mechanical Balance of Plant (MBOP)

300 kW, 480 VAC,
333 kVA, 50 or 60 Hz

Fuel Consumption

| | |
|-------------------------------------------|---------------|
| Natural gas (at 930 Btu/ft ³) | 39 scfm |
| Heat rate, LHV | 7,260 Btu/kWh |

Water Consumption

| | |
|---------------------------|---------|
| Average | 0.9 gpm |
| Peak during WTS backflush | 10 gpm |

Water Discharge

| | |
|---------------------------|----------|
| Average | 0.45 gpm |
| Peak during WTS backflush | 10 gpm |

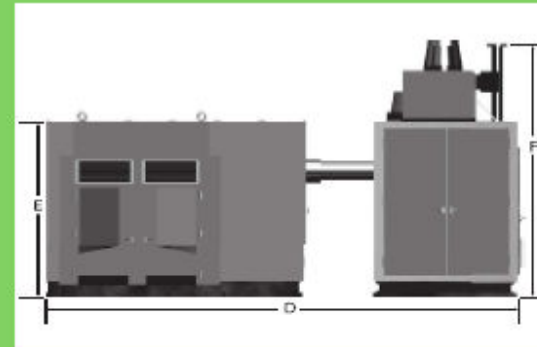
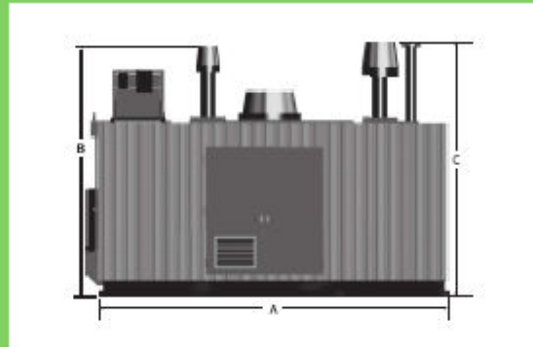
Pollutant Emissions

| | |
|-----------------|----------------|
| NO _x | 0.01 lb/MWh |
| SO _x | 0.0001 lb/MWh |
| PM10 | 0.00002 lb/MWh |

Greenhouse Gas Emissions

| | |
|--------------------------------------------|----------------|
| CO ₂ | 980 lb/MWh |
| CO ₂ (with waste heat recovery) | 520-680 lb/MWh |

Specifications



Dimensions

Front View

| | |
|------------------------------------------------------------------------|---------|
| A Overall Width | 20.0 ft |
| B Height of Air Intake Filter | 15.1 ft |
| C Height of Exhaust Stack (Required on units with no heat recovery) | 14.5 ft |

Side View

| | |
|----------------------------|---------|
| D Overall Length | 28.0 ft |
| E Height of EBOP | 11.8 ft |
| F Height of Discharge Vent | 14.5 ft |

Weights

| | |
|-----------------------------|-----------|
| Mechanical Balance of Plant | 27,000 lb |
| Electrical Balance of Plant | 15,000 lb |
| Fuel Cell Module | 35,000 lb |

Sound Level

| | |
|----------|---------------------|
| Standard | 72 dB(A) at 10 feet |
| Optional | 65 dB(A) at 10 feet |

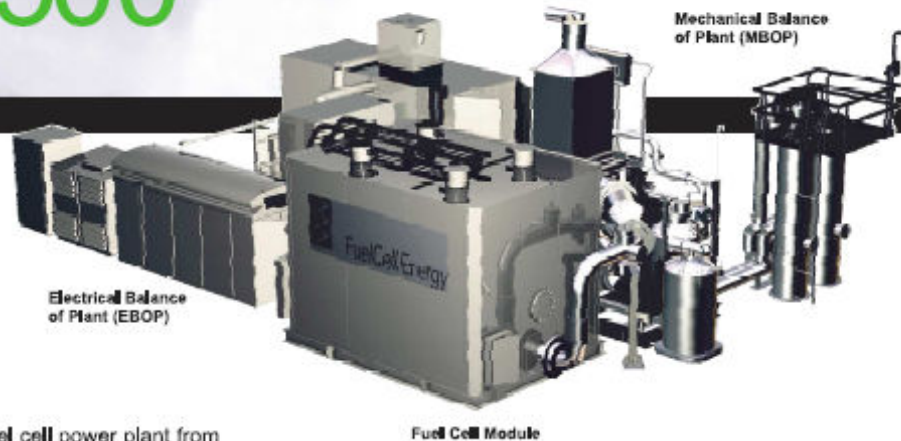
Experience & Capabilities

DFC® fuel cells are generating power at over 50 locations worldwide. The Company's power plants have generated over 650 million kWh of power using a variety of fuels including renewable wastewater gas, biogas from beer and food processing, as well as natural gas and other hydrocarbon fuels. FuelCell Energy has partnerships with major power plant developers and power companies around the world. The Company also receives funding from the U.S. Department of Energy and other government agencies for the development of leading edge technologies such as fuel cells. For more information please visit our website at www.fuelcellenergy.com

This brochure provides a general overview of FuelCell Energy products and services. This brochure is provided for informational purposes only. Warranties for FuelCell Energy products and services are provided only by individual sales and service contracts, and not by this brochure. This brochure is not an offer to sell any FuelCell Energy products and services. Contact FuelCell Energy for detailed product information suitable for your specific application. FuelCell Energy reserves the right to modify our products, services, and related information at any time without prior notice.

FuelCell Energy's fleet of Direct FuelCell power plants are certified to or comply with a variety of commercial and industrial standards: ANSI/CSA America FC-1, UL 1741, CARB 2007, OSHA 29 CFR Part 1910, IEEE 1547, NFPA 70, NFPA 853, and California Rule 21.

DFC1500



Key Features

- High Efficiency
- Low Environmental Impact
- Fuel Flexibility
- High Reliability
- Quiet Operation

Advantages

The DFC1500™ stationary fuel cell power plant from FuelCell Energy provides high-quality, Ultra-Clean electrical power with 47% efficiency around-the-clock. Designed for commercial and industrial applications, the system offers easy transport, quiet and reliable operation, and easy site planning and regulatory approval. The DFC1500 is ideal for wastewater treatment plants, manufacturing, food and beverage processing, large hotels, hospitals, and universities.

**1,4 MW, 480 VAC,
1,550 kVA, 50 or 60 Hz**

Performance

Power Output

| | |
|-----------------------------|---------------------------|
| Power @ Plant Rating | 1,400 kW |
| Standard Output AC Voltage | 480 V |
| Standard Frequency | 60 Hz |
| Optional Output AC Voltages | 460, 440, 420, 400, 380 V |
| Optional Output Frequency | 50 Hz |

Efficiency

| | |
|-----|------------|
| LHV | 47 +/- 2 % |
|-----|------------|

Available Heat

| | |
|---------------------|---------------|
| Exhaust Temperature | 700 +/- 50 °F |
| Exhaust Flow | 18,300 lb/h |

Allowable Backpressure 5 iwc

| | |
|--------------------------------------------------|-----------------|
| Heat Energy Available for Recovery (to 250°F) | 2,216,000 Btu/h |
| (to 120°F) | 3,730,000 Btu/h |

Fuel Consumption

| | |
|-------------------------------------------|---------------|
| Natural gas (at 930 Btu/ft ³) | 181 scfm |
| Heat rate, LHV | 7,260 Btu/kWh |

Water Consumption

| | |
|---------------------------|---------|
| Average | 4.5 gpm |
| Peak during WTS backflush | 15 gpm |

Water Discharge

| | |
|---------------------------|----------|
| Average | 2.25 gpm |
| Peak during WTS backflush | 15 gpm |

Pollutant Emissions

| | |
|------|----------------|
| NOx | 0.01 lb/MWh |
| SOx | 0.0001 lb/MWh |
| PM10 | 0.00002 lb/MWh |

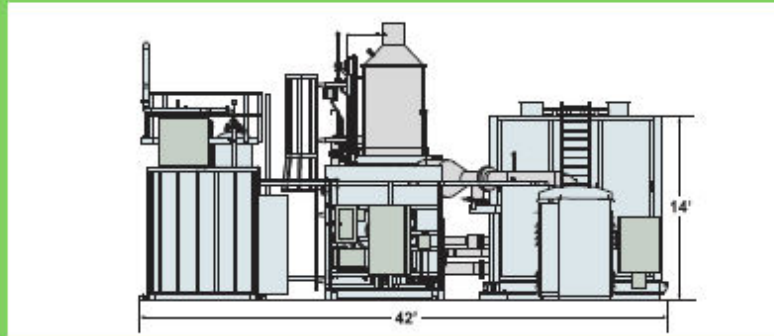
Greenhouse Gas Emissions

| | |
|--------------------------------------------|----------------|
| CO ₂ | 980 lb/MWh |
| CO ₂ (with waste heat recovery) | 520-680 lb/MWh |

Sound Level

| | |
|----------|---------------------|
| Standard | 72 dB(A) at 10 feet |
| Optional | 65 dB(A) at 10 feet |

Specifications



Weights

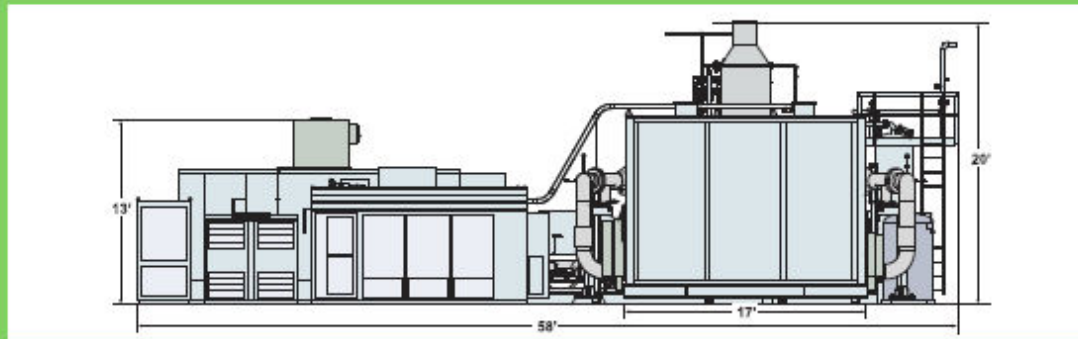
Water Treatment Skid
20,000 lb

Main Process Skid
50,000 lb

Desulfurization
15,000 lb

Electrical Balance of Plant
50,000 lb

Fuel Cell Module
107,000 lb



Experience & Capabilities

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DFC3000

Key Features

- High Efficiency
- Low Environmental Impact
- Fuel Flexibility
- High Reliability
- Quiet Operation

Advantages

FuelCell Energy's DFC3000™ system is the largest of the Direct FuelCell® (DFC®) power plant fleet, capable of providing high-quality baseload power with 47% electric power generation efficiency around-the-clock. Scalable up to 50 MW, the system is especially suitable for applications with larger load requirements such as universities, manufacturing facilities, wastewater treatment plants, and utility/grid support.

Performance

Power Output

| | |
|-----------------------------|-----------------|
| Power @ Plant Rating | 2,800 kW |
| Standard Output AC Voltage | 13,800 V |
| Standard Frequency | 60 Hz |
| Optional Output AC Voltages | 12,700, 4,160 V |
| Optional Output Frequency | 50 Hz |

Efficiency

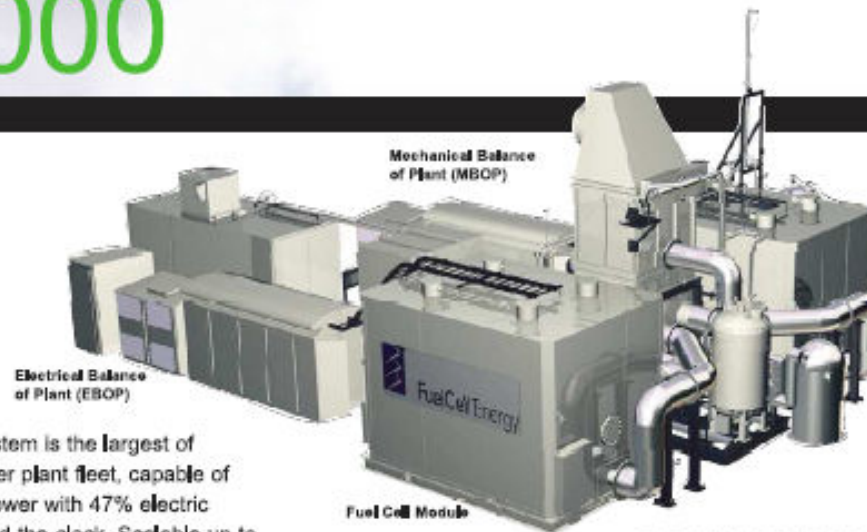
| | |
|-----|------------|
| LHV | 47 +/- 2 % |
|-----|------------|

Available Heat

| | |
|-----------------------------------------------|-----------------|
| Exhaust Temperature | 700 +/- 50 °F |
| Exhaust Flow | 36,600 lb/h |
| Allowable Backpressure | 5 iwc |
| Heat Energy Available for Recovery (to 250°F) | 4,433,000 Btu/h |
| (to 120°F) | 7,460,000 Btu/h |

Fuel Consumption

| | |
|------------------------------|---------------|
| Natural gas (at 930 Btu/ft³) | 362 scfm |
| Heat Rate, LHV | 7,260 BTU/kWh |



2.8 MW, 13.8 kVAC
3,110 kVA, 50 or 60 Hz

Water Consumption

| | |
|---------------------------|--------|
| Average | 9 gpm |
| Peak during WTS backflush | 30 gpm |

Water Discharge

| | |
|---------------------------|---------|
| Average | 4.5 gpm |
| Peak during WTS backflush | 30 gpm |

Pollutant Emissions

| | |
|------|----------------|
| NOx | 0.01 lb/MWh |
| SOx | 0.0001 lb/MWh |
| PM10 | 0.00002 lb/MWh |

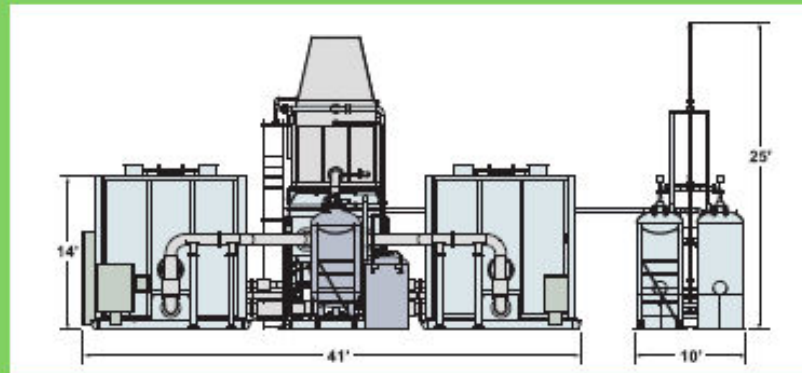
Greenhouse Gas Emissions

| | |
|--------------------------------------------|----------------|
| CO ₂ | 980 lb/MWh |
| CO ₂ (with waste heat recovery) | 520-680 lb/MWh |

Sound Level

| |
|---------------------|
| 72 dB(A) at 10 feet |
|---------------------|

Specifications



Weights

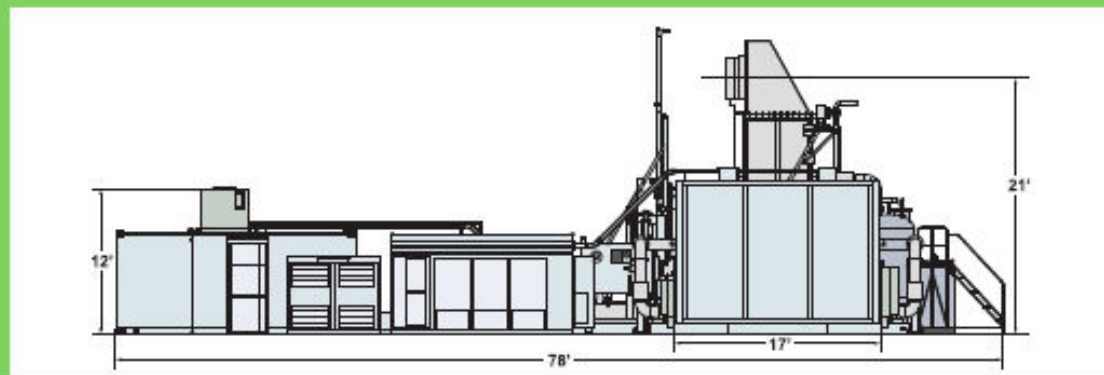
Water Treatment Skid
20,000 lb

Main Process Skid
50,000 lb

Desulfurization
15,000 lb

Electrical Balance of Plant
60,000 lb

Fuel Cell Module
107,000 lb (each module)



Experience & Capabilities

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