FuelCell Energy
World Leader in Ultra-Clean Power

# Project Fact Sheet
# Direct FuelCell/Turbine® Power Plant

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**Project Partners:**

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**Montana State University, Bozeman, MT**
**CTA Architects Engineers, Billings, MT**

## Objectives

FuelCell Energy, Inc., (FCE) has been selected by the U.S. Department of Energy to support the Vision 21 initiative. Vision 21 is the U.S. Department of Energy's initiative for developing the technology necessary for ultra-clean, near-zero emission, fossil fuel-based energy plants that will be needed in the coming decades of the 21st century. The goal of Vision 21 is to effectively remove the environmental concerns associated with the use of fossil fuels for producing electricity and transportation fuels. The approach is to focus on the key technologies that will be critical in a Vision 21 energy plant, stress innovation and system integration, involve stakeholders, produce energy benefits ("spinoffs"), and exercise flexibility to meet market needs.

FCE is committed in bringing its research, engineering, and manufacturing expertise to this program through development and demonstration of an integrated fuel cell/turbine, highly efficient power plant

The overall project goal is to develop ultra-high efficiency power plants based on Direct FuelCell/Turbine® (DFC/T®) technology. The specific objectives are:

- Develop the conceptual design of multi-megawatt (MW) hybrid DFC/T systems with efficiencies approaching 75 % (natural gas fuel), and with sulfur and nitrogen oxide emissions < 0.01 lb/million BTU.
- Verify commercial viability of the DFC/T systems for near-term deployment.
- Design a packaged sub-MW DFC/T system for distributed power generation.

- Verify the potential benefits of hybrid technology and show its readiness for commercialization by the grid-connected field demonstration of a sub-MW DFC/T power plant at a customer site.
- Develop design of a 1-3MW DFC/T product based on the lessons learned from the field demonstration of the sub-MW DFC/T power plant.

## Introduction

FCE's DFC/T hybrid system concept is based on integration of the company's Direct FuelCell® with a gas turbine. A simplified process flow diagram of the DFC/T system is shown in Figure 1. The power plant design utilizes a heat recovery approach for extraction of heat from the balance-of-plant. The fuel cell plays the key role by producing the larger share of the power (>80%). The gas turbine is utilized for generation of additional power by recovering the fuel cell byproduct heat in a Brayton cycle, as well as for providing the air for the fuel cell operation.

Features of the DFC/T system include: electrical efficiencies approaching 75% on natural gas (60% on coal gas), direct reforming internal to the fuel cell, minimal emissions, reduced carbon dioxide release to the environment, simple design, and cost competitiveness with existing combined cycle power plants.

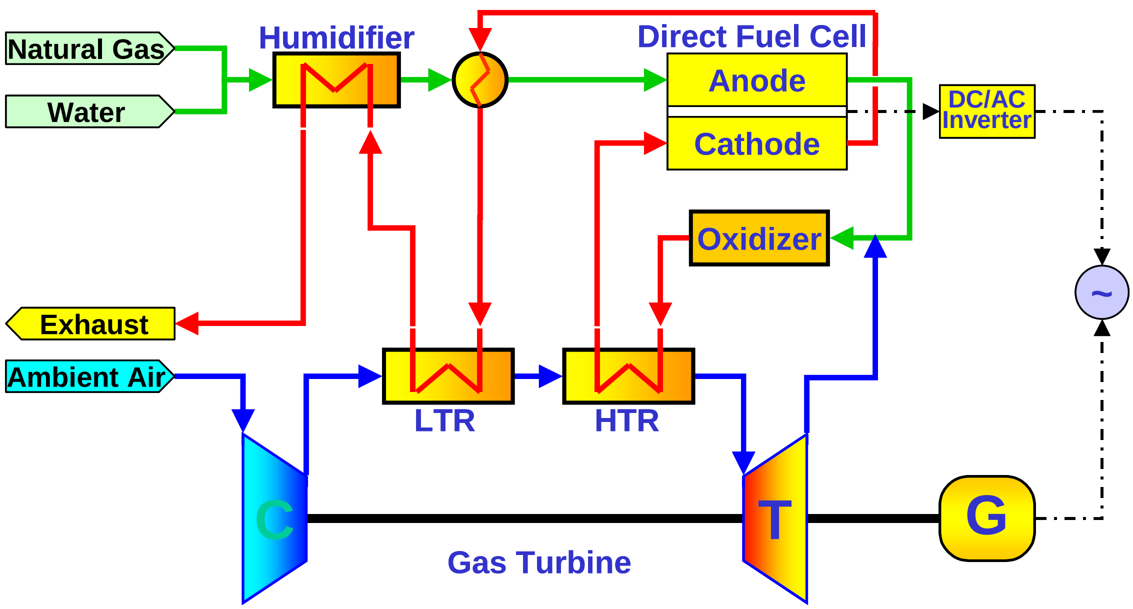


**Figure 1. DFC/T Ultra-High Efficiency System Concept**

## Approach

The hybrid technology development plan includes design, construction, and testing of an Alpha sub-MW DFC/T unit. Prior to fabrication of the sub-MW DFC/T unit, the DFC/T system concept was implemented in a power plant test facility (pre-Alpha power plant) by integration of a 250kW DFC stack and a Capstone microturbine. The focus of the pre-Alpha testing was the verification of the DFC/T concept, development of critical system components, and acquisition of design information for development of power plant products. The results from the proof-of-concept tests established the foundation for the design of the packaged sub-MW unit.

Upon successful pre-Alpha proof-of-concept tests, the design and fabrication of a packaged, "Alpha" DFC/T unit was completed. This unit was first factory tested at FCE headquarters in Danbury, CT and later shipped to a demonstration site in Montana. The test results and experience from the Alpha unit are being utilized in the design of a MW-class DFC/T power plant.

## Results

- **MULTI-MW POWER PLANT DESIGN:** The preliminary design of a 40 MW power plant hybrid system concept was completed. An overall layout/plot plan of the 40 MW plant is shown in Figure 2. The design was based on a scalable approach, using FCE's M-10 (MW-scale) fuel cell modules in a cluster arrangement. The fuel cell cluster design has five M-10 modules in a cluster with common distribution piping for the fuel and

oxidant gases. Based on the scalable overall plant design concept, the plant is arranged in three sections (power blocks) in addition to the centralized equipment. Each power block consists of two clusters of fuel cell modules together with supporting equipment. The centralized equipment, which supports all three sections, includes a gas turbine, an anode gas oxidizer, and other common site equipment such as a fuel clean-up subsystem and a water treatment subsystem.

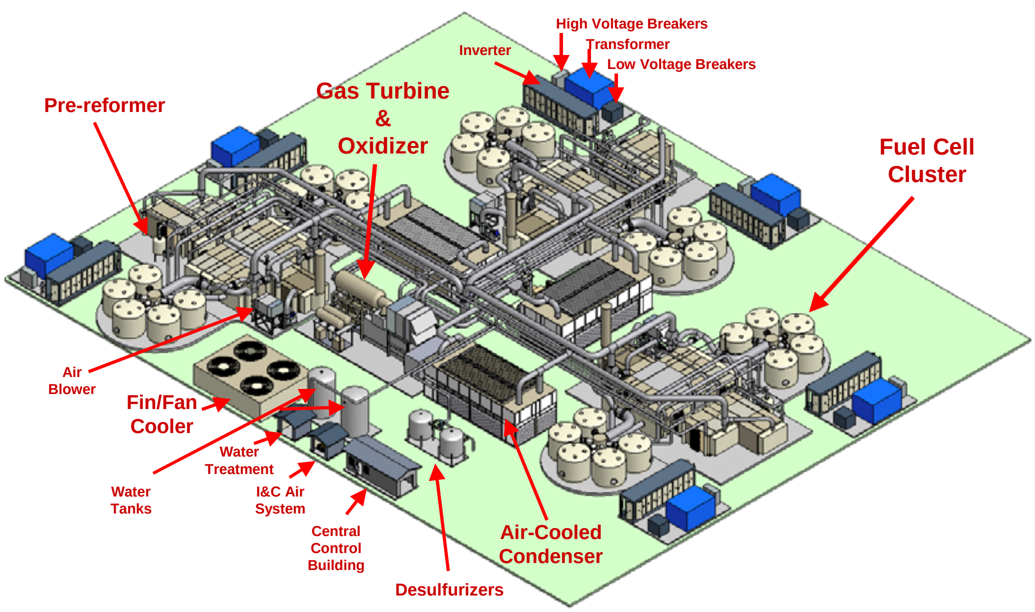


**Figure 2. 40-MW DFC/T Power Plant Layout and Site Plan for Near-term High Efficiency Power Generation**

- **SUB-MW POWER PLANT DESIGN AND DEMONSTRATIONS**: Fabrication of the Alpha sub-MW DFC/T hybrid power plant, based on the detailed design developed, was completed. The Alpha unit consists of three main sections: 1) Mechanical Balance-of-Plant (BOP), 2) DFC Stack Module, and 3) Electrical Balance-of-Plant, which are transportable as separate units. The modular design of the power plant sections allows for ease of installation and service. The power-conditioning module of the Alpha unit includes a dc-to-ac inverter and a tie-in connection for the microturbine. Fabrication of a 250kW stack module for integration in the Alpha DFC/T was completed at FCE's Torrington (CT) manufacturing plant. The conditioning and checkout tests of the fuel cell stack module were performed prior to its integration with the BOP equipment, including a 60kW Capstone microturbine.

Factory testing of the Alpha unit was conducted in FCE's Danbury (CT) facility. The factory testing included grid-connected operation, validation of plant performance, and emission tests. The Alpha DFC/T hybrid power plant achieved a power generation level of 320+ kW at 56% fuel efficiency based on LHV of natural gas. Figure 3 shows a computer screen shot taken during the power plant operation and documenting the plant performance.

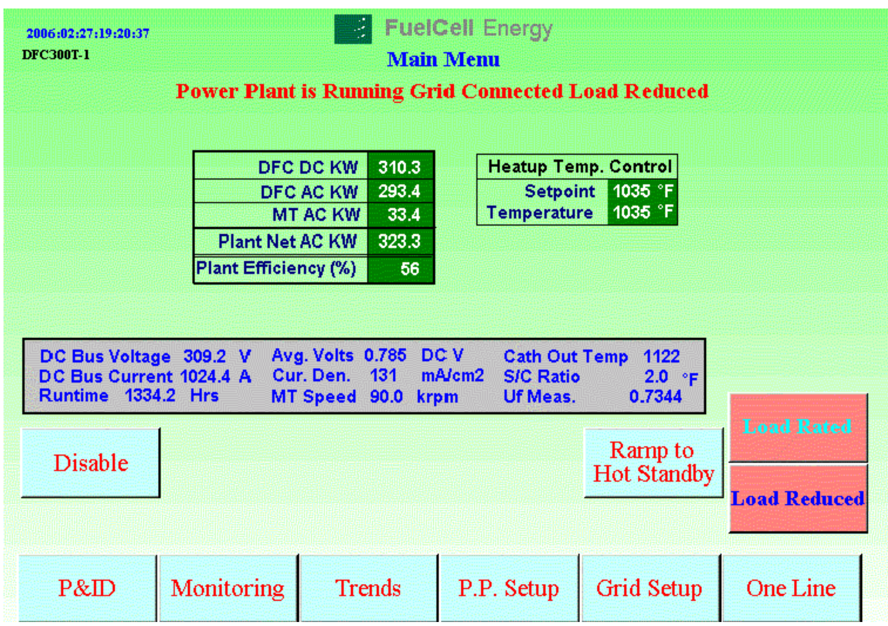


**Figure 3. Alpha Sub-MW DFC/T Power Plant Performance Achieved During Factory Tests in FCE's Danbury (CT) Facility**

Preliminary tests indicated that the Alpha unit successfully met CARB 2007 emission standards for $NO_x$, carbon monoxide, and volatile organic compounds (VOC) at rated power. Table 1 presents a summary of the emission test results. Upon successful completion of the factory testing, the Alpha power plant was shipped to the Montana demonstration site.

| | lb/MW-hr | | |
|---|---|---|---|
| | **NOx** | **VOC** | **CO** |
| **DFC/T *** | 0.004 | 0.002 | 0.075 |
| **CARB-'07 weighted emission limit** | 0.07 | 0.02 | 0.1 |

* Tests on 02/21/06, Average 307 kW

**Table 1. Alpha DFC/T Packaged Power Plant Met California Air Resources Board's 2007 Emission Standards**

The Alpha unit was installed at Billings Clinic in Montana for field demonstration tests in 2006 (Figure 4). The unit completed over 8000 hours of field testing, generated over 1145 MWh, and achieved 87% power generation availability for the Clinic. Design of the next generation DFC/T unit has been initiated.


**Figure 4. Alpha DFC/T Unit after Installation at Billings Clinic, the Montana Demonstration Site**

## Conclusions and Future Directions

The factory tests of the Alpha hybrid power plant were performed for more than six months, including the initial performance and control checkout tests. During grid-connected operation, the alpha unit achieved 323 kW net AC output at 56% electrical efficiency (based on natural gas LHV) – a record-setting performance in a sub-MW class power plant. The Alpha unit also met CARB 2007 emission standards in preliminary emission tests at the factory.

The Alpha power plant was shipped to the Montana demonstration site in 2006. It was installed at Billings Clinic, restarted, and successfully completed demonstration tests in 2007. The Alpha unit power plant concluded its demonstration phase in Billings, MT, on February 28, 2007. During the period between April 2006 and March of 2007, the power plant generated over 1145 MWh of power for the Billings Clinic. The plant overall availability, including hot standby and power production, surpassed 91%, which is a significant achievement for a first-of-a-kind Alpha unit. The tests demonstrated grid-connected operations and helped assess the efficiency potential of the sub-MW plant, while providing valuable data on integration and operation of DFC/T power plants.

Design activities were directed towards development of mega-watt (MW) Class DFC/T power plants. Process development and definition of a MW-Class (1-3 MW) DFC/T Hybrid Power Plant was initiated. Design input, based on operational data, and lessons learned during Alpha unit factory tests and operations at Montana demonstration site, is currently being incorporated into the design of a MW-class power plant.

## Recent Publications/Presentations


1. H. Ghezel-Ayagh, J. Walzak, S. T. Junker, D. Patel, and F. Michelson, "DFC/T: The Power Plant From and For Paradise", 2006 Fuel Cell Seminar, Honolulu, Hawaii, November 13-17, 2006.

2. H. Ghezel-Ayagh, S. T. Junker, D. Patel, F. Michelson, J. Walzak, and H. Maru, "Development of SubMW Hybrid Direct FuelCell/Turbine Power Plant", Presented at Fuel Cell Seminar 2005, Palm Springs, CA, November 14-18, 2005.

3. H. C. Maru and H. Ghezel-Ayagh, "Direct Carbonate Fuel Cell – Gas Turbine Combined Cycle Power Plant", Presented in European Fuel Cell Forum, Lucerne, Switzerland, July 5-8, 2005.


## Acronyms

DFC/T® (Direct FuelCell/Turbine®); FCE (FuelCell Energy, Inc.); balance-of-plant (BOP); Human Machine Interface (HMI); megawatt (MW); Lower Heating Value (LHV); Programmable Logic Controller (PLC); British Thermal Unit (BTU); California Air Resources Board (CARB).