11. Description of Attachments. Form EIA-459E, Technical Progress Report.

MONTHLY TECHNICAL PROGRESS REPORT

DOE CONTRACT: DE-FC21-95MC31184--35

TITLE: MCFC Product Design Improvement

DATE: April 2000

INTRODUCTION

This contract is supported by DOE and DOD/DARPA funds. The objective of the DOE program is to advance the direct carbonate fuel cell technology to a level suitable for commercial entry. The specific objectives of the DOD's initiative on 2 MW Fuel Cell Fixed Base Power Plant are:

A. To provide a detailed engineering design, development and cost estimate of the 2 MW fuel cell fixed base dual fuel power plant for DOD applications. Installation and operational support systems will also be developed.

B. To construct a full-size MW-class dual fuel power plant simulator.

These objectives are planned to be achieved in the program coordinated with the Department of Energy, which has been funding a multiyear natural gas fueled direct fuel cell power plant program (DE-FC21-95MC31184) for civilian applications. Because many DARPA and DOE objectives are similar, the coordinated program activities are considered the most cost-effective for accomplishment of the program objectives. The DARPA/DOE joint program was launched in 1994. The DOE part of the program is expected to continue to Year 2000. The final output of this DOE program is to construct and operate a 2 MW power plant on an East Coast site. The site will be accessible to DOD energy/ environmental systems base planners and logistics personnel as well as mission and policy planners to refine deployment configurations of this new power generation system for fixed base applications.

A dual fuel fixed base design for military fuels operation, as well as support system logistics, will be the key deliverables for the DARPA part of the program. The DARPA-sponsored program accomplishments are printed in italics in this technical progress report and identified by an encircled "A" at the right hand margin.

TASK 1 NEPA INFORMATION. This task is designed to develop environmental information for NEPA review. The NEPA review was

planned to be carried out in stages: the first stage for the existing laboratory test facilities and the landfill-gas test site and the second for the power plant demonstration site at Danbury, CT. Based on environmental impact assessment information provided to DOE/FETC, a Categorical Exclusion B Recommendation was received for testing at FCE laboratory and Anoka landfill gas sites. The NEPA clearance, a Categorical Exclusion B Recommendation, was also received for the MW-Class power plant test at the Danbury, CT site.

This task is essentially completed.

TASK 2 PRODUCT DEFINITION AND PLANNING. FCE plans to offer a standard 2.85 MW size power plant with optional configurations at additional cost. The standard power plant requirements and specifications have been defined based on preliminary design and customer surveys. Activities to develop plans for product supply, distribution, and servicing are also part of this task.

No major activity was carried out during this reporting period.

TASK 3 SYSTEM DESIGN AND ANALYSIS. The final design of a modular, multifueled market entry MW-Class product will be developed in this task. The power plant design will include a diesel fuel processing option to allow dual fuel fixed base DOD applications. At this time, design of the baseline natural gas power plant is being developed in collaboration with Fluor Daniel, Inc. The final design of the power plant has been completed. The diesel fuel processing information was developed experimentally under a parallel program. Using these inputs, the baseline design will be modified as necessary to define a dual fuel power plant design.

Following completion of the final design of the baseline natural gas power plant, the prototype product demonstration plant specific design activities are being carried out under this task. The design and construction of the MW-Class power plant simulator are focused on Task 4.

No major activity was carried out during this reporting period.

TASK 4 MANUFACTURING PROCESS DEVELOPMENT. Manufacturing process development activities are planned for cost reduction, cell area scale up, manufacturing and material recycle processes development, quality improvement, and commercial manufacturing facility design. A MW-Class power plant simulator which would also provide conditioning of stack modules will be designed and constructed under this task. The specific accomplishments are discussed next.

The equipment for in-house manufacturing of electrolyte is being received and the system is being assembled. The direct internal

reforming (DIR) catalyst dough mixing and extrusion experiments have successfully demonstrated the capability to extrude the new improved catalysts. Robotic welding of the bipolar plates using the advanced wet seals has been successful. Optimization of process parameters is being pursued. Corrosion testing of the weld bead also continues and the results are encouraging. Based on the analysis of test results from the horizontal high energy mill (for cell matrix slurry preparation) experiments, the process step dominating the mill wear has been identified. Long-term operation will dictate the replacement frequency of the attrition mill discs. A new disc material is under test which may offer longer life.

TASK 5 ASSEMBLY AND PACKAGING. Efforts have been planned to develop efficiently packaged stack and balance-of-plant (BOP) equipment module designs for use in commercial as well as DOD fixed base dual fuel power plants. The stack module in the commercial design is an internally insulated cylindrical container having four stacks, as compared to the rectangular base with four individually insulated stacks for the Santa Clara Demonstration Project. This design has increased the cell packaging density by a factor of nine, on an equal footprint basis. The preliminary design of the stack module has been completed and the final design is near completion. In parallel, efforts have been launched to design and manufacture the stack module simulator. The reporting period accomplishments are discussed next.

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No major activity was carried out during this reporting period.

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TASK 6 TEST FACILITY DEVELOPMENT. FCE has a subscale power plant for simulation of BOP equipment, full-size stack module, and power plant control and operational parameters. This plant is being modified to represent the commercial power plant design and to accept 9000 cm^2 area stacks with a capacity of up to 400kW. The modifications include the replacement of the fuel delivery system, oxidizer catalyst, flow control hardware, load bank, fuel preconverter, and piping. The control system will be enhanced to allow for automatic startup, shutdown, load change, and steady state operations. The reporting period progress is discussed next.

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Following the modifications, the power plant is now being used for evaluation of the 400 kW-Class BOP equipment and 9000 cm^2 cell area full size stacks. This plant simulates FCE's MW-class simplified system in terms of mechanical and flow configurations. To date, the plant has completed over 14,700h of operation going testing of Stack FA-100-1 for 10,200h.

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Stack FA-100-1 test was held at the 200 kW power point for a majority of this reporting period. As before, the plant remained unattended during the night and weekend operations. Testing

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events included a plant trip due to a disturbance in the power grid. As mentioned previously, the power grid disturbance causes the plant to trip to an "off" status with only an inert blanketing system remaining. When a grid disturbance occurs, the plant's unattended monitoring system, as designed, notifies two on-call operators. The operators arrive at the plant, review the situation, and then restart the system to OCV. The OCV condition is compared to a previous similar point and then the plant is ramped up in load. This was the case for each grid disturbance to date. Overall, the power plant output summary to the end of this reporting period includes a total of 1640 MWh generated, >8800h on-load, 6900h at >200 kW DC, with >95% fuel cell availability.

Activities for the next reporting period include holding at the typical ~200 kW power generating condition.

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TASK 7 TECHNOLOGY DEVELOPMENT, IMPROVEMENT AND VERIFICATION. This task consists of stack and BOP equipment design development for dual fuel operation, followed by a full-size commercial prototype power plant field verification. Specific accomplishments of the reporting period are discussed below.

Long-term single cell testing of improved DIR catalyst (designated as DIR-2) continued successfully beyond 3500h. In parallel, catalyst dough of high packing density was developed for DIR catalyst extrusion process. Cell testing has verified the enhanced (>40%) life benefit of the denser packing. The desired catalyst and manufacturing process have been selected for Stack FA-5-7 and upcoming field trial stacks.

In FCE's baseline bipolar plate design, the corrosion protection for the wet-seals is provided by HVOF (high velocity oxygen flame) processing. The HVOF process is expensive (high handling cost) and non-uniform. In order to further improve the corrosion protection and reduce manufacturing cost, a new protected stainless steel wet-seal material has been developed. These wet-seals are separately fabricated and then welded to the active blank to form a functional bipolar plate. The new material is very uniform and cost effective. Its corrosion resistance is also superior to HVOF. A bipolar plate was successfully manufactured using the new wet-seal material; with less welding distortion and uniform weld seams compared to the baseline design. This new bipolar plate will be used in the upcoming Stack FA-5-7.

Development testing and redesign of the internal reforming unit (RU) for FCE's Direct Fuel Cell (DFC^R) have been completed. Both water flow visualization and hot-wire anemometry have been successfully employed to determine the effect of the redesign on flow distribution within the RU. The new design provides approximately 20% higher fuel flow and 50% more reforming

catalyst to the hottest region of the cell area. In addition, the reformer components were redesigned slightly to improve the RU manufacturability. The new RU, designated as RU-12, will be incorporated in upcoming stacks (FA-5-7, FA-100-2) as well as subsequent demonstration units.

Stack FA-20-4R (30 cells, 9000 cm^2 nominal) has completed 1600h of stable operation and testing continues at design conditions. The stack performance has been observed to be comparable to recent Stacks FA-100-1 and FA-5-6. Methane reforming remains at 99% of the theoretical conversion and ohmic resistance remains low. Temperature profile comparison with Stack FA-20-4 at 130 mA/cm^2 showed a 30°C improvement in the maximum in-cell temperature difference. This improvement is attributed to the new anode current collector design. The new design has also improved fuel flow uniformity and has facilitated operation at high fuel utilization. Stable operation was achieved at 160 mA/cm^2, producing 0.89kW per cell. The stack is presently being used as a test vehicle for simulating operating conditions for different power plant configurations designed or under consideration. Testing of this stack at simulated system conditions corresponding to plant operation with a typical digester gas has shown no power rating and/or efficiency penalties associated with this medium Btu fuel compared to pipeline natural gas. Thermodynamic loss (Nernst) on the fuel side seems to be adequately compensated by the cathode side gain due to higher amount of carbon dioxide present. This is a unique attribute of the carbonate fuel cell that makes it suited for the bio-derived fuel applications.

The 200kW-system demonstration with the building block Stack FA-100-1 continued beyond one year of operation. The total electricity generated exceeded 1,640,000 kWh. Additional information is reported under Task 6.

The operation of the 250kW power plant at Bielefeld field trial in Germany continued. FuelCell Energy’s Torrington, Connecticut manufacturing facility produced 298 fuel cells used in the plant. MTU Friedrichshafen began operating the power plant in November 1999. The ‘Hot Module’ fuel cell power plant, developed by MTU Friedrichshafen, is located on the campus of the University of Bielefeld. The plant provides the Bielefeld municipal power utility with electricity, and byproduct high quality heat and steam. So far the plant has been operated for >2500h, generating ~270 MWh of electrical power, and ~485 MWh of combined heat, steam and electrical power. The total plant electrical efficiency is 46.5% (LHV).

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