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M-C Power's Product Design and Improvement

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CONTRACT INFORMATION

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Period of Performance December 19, 1994 to December 18, 1999

Schedule and Milestones
Program Schedule

	94	95	96	97	98	99
Tech. Development						
250 kW Power Plants Oper.						
Prod. Design & Imp.		—	—			
1 MW Power Plants Oper.					—	—

OBJECTIVE

The sole mission of M-C Power is the development and subsequent commercialization of molten carbonate fuel cell (MCFC) stacks. These MCFC stacks are based on the Internally Manifolded Heat EXchanger plate design developed by the Institute of Gas Technology. Integration of the MCFC stack into a commercially viable power plant is the mission of the IMHEX® team. The team is composed of leaders in the packaging and design of power generation equipment, including fuel cell technology, and includes Stewart & Stevenson,

Bechtel, The Institute of Gas Technology and M-C Power.

In an effort to succeed in their respective missions, M-C Power and the IMHEX® team have developed a commercialization program. At the present time the team is making the transition from Phase I (Technology Development) to Phase II (Product Design & Improvement) of the program. Phase II's objective is a commercially viable (cost effective and technologically reliable) MCFC power plant ready for market by the turn of the century.

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BACKGROUND INFORMATION

Introduction

Product Design & Improvement (PDI).

The Product Design and Improvement activities began at the start of 1995 in parallel with the final steps of the Technology Development efforts. The major focus of the Phase II activities is to address cost reduction issues and to establish the commercial readiness of the power plant, stack technology, and marketplace infrastructure. The team's efforts will initially address these issues at the component level, followed by verification of advanced technologies in prototype power plant hardware.

The major barrier to successful fuel cell commercialization has been the higher first cost in comparison to conventional equipment. The molten carbonate fuel cell technology is no different, and therefore, the Team's goal must be to define and develop advanced stack and power plant technologies that allow the introduction of a cost-effective product even during the low production volumes of the initial few years.

M-C Power has defined a range of advanced technologies which have the potential to achieve this goal. These technologies address the two major cost reduction areas of the stack - separator plates and non-repeat hardware. Advanced separator plate designs reduce the number of components needed for the assembly from the fifteen pieces (used in Unocal) to two pieces.

Cost reduction of the non-repeat hardware will be achieved through creative engineering efforts which eliminate hardware and integrate functions. In parallel cost reduction in the repeat components are also being examined. These include faster manufacturing processes and reduced raw material through thinner components and reduced scrap.

Verification tests and power plant efforts are

directed toward the construction and operation of a prototype, 1-MW power plant. This unit is intended to reflect all of the design and operational features of the Team's market entry product. The first 1-MW power plant is scheduled for operation during the early part of 1998. Southern California Edison will host this test at their Highgrove Generating Station in Grand Terrace, CA.

Market Entry Product

Design Description. Product design and definition activities completed in 1994 have provided the team with a blueprint for a 1MW market entry unit. The unit consists of three highly packaged skids which require minimum field assembly at the customer's site. Overall power plant design and layout is illustrated in figure 1 below.

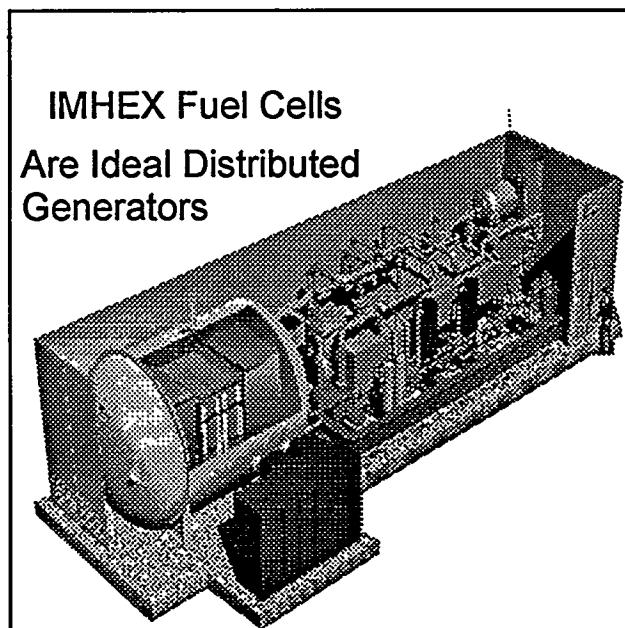


Figure 1. 1MW Market Entry Design

The fuel cell skid includes two 300-cell stacks along with two Ishikawajima-Harima Heavy Industries' plate reformers within a housing vessel.

The reformers convert natural gas into hydrogen and carbon monoxide as the stack fuel feed. Major components of the mechanical skid include; Heat Recovery Steam Generator (HRSG), a turbogenerator, two nitrogen bottles, two desulfurization bottles, six demineralizer bottles, and two boiler feed water pumps. The electrical skid contains a power conditioning unit and the system control unit. The power conditioning unit has an inverter to convert the stack DC power into AC power. The control unit is a simple industrial size PC based system geared toward an unattached operation of the fuel cell unit.

Each skid is sized within the height, length, and width limits for shipping. The unit is designed with maintenance in mind. Equipment requiring frequent servicing or replacement is placed at locations with easy access.

Operating Characteristics. Incorporated within the mechanical skid, the turbogenerator supplies compressed air as the oxidant feed to the stacks and generates additional power by expanding the hot flue gas from the cell reactions. The expanded gas from the turbogenerator flows to the HRSG where waste heat is recovered to perform the following steps: Preheat the compressed air prior to its feeding to the stacks; preheat the desulfurized natural gas; generate steam for the reforming reactions; and finally recover by-product heat for customer use. The HRSG is further equipped with an auxiliary burner, as well as the necessary burner control center to provide startup heat for the fuel cell unit.

A summary of the power plant characteristics is provided in Figure 2. The overall electrical efficiency is very high, 54.4% based upon HHV and 60% based on LHV. The current design is geared toward maximum power production. As a result, the HRSG flue gas is hot enough only for cogeneration of hot water. The overall efficiency including both power and hot water generation is

82% on HHV basis. The fuel cell unit is capable of turning down to approximately 30% load while still maintaining a reasonable electric efficiency close to 35%.

The Team estimates the capital cost of the market entry product will be in the \$1500/kW range with production volumes of only 20 to 50 units per year. Achieving a cost-competitive pricing structure in low production volumes is believed to be critical to marketplace success as the power industry in the U.S. evolves with increasing competition.

Market Entry Product	
<u>Projected Characteristics - Jan. 1995</u>	
Rated Capacity	1 MW
Heat Rate	5680 Btu/kWh
Efficiency	60% LHV
Fuel Source	Natural Gas
Thermal Output	
250°F	430 kBtu/h
160°F	1430 kBtu/h
Foot Print	
Module	52x19x14ft
Fence	65x25ft
Emissions	<1 ppm NO _x

Figure 2. Market Entry Power Plant Characteristics

PROJECT DESCRIPTION

Product Development and Improvement

Planning. The PDI project has been structured into six tasks directed at successfully developing a commercially viable MCFC power plant. These tasks are: Product Definition and Market Assessment; System Design and Analysis;

Manufacturing Process Development; Packaging and Assembly Verification; Test Facility Design and Development; and Technology Development Improvement and Verification. The interrelationships between the program tasks are illustrated in Figure 3.

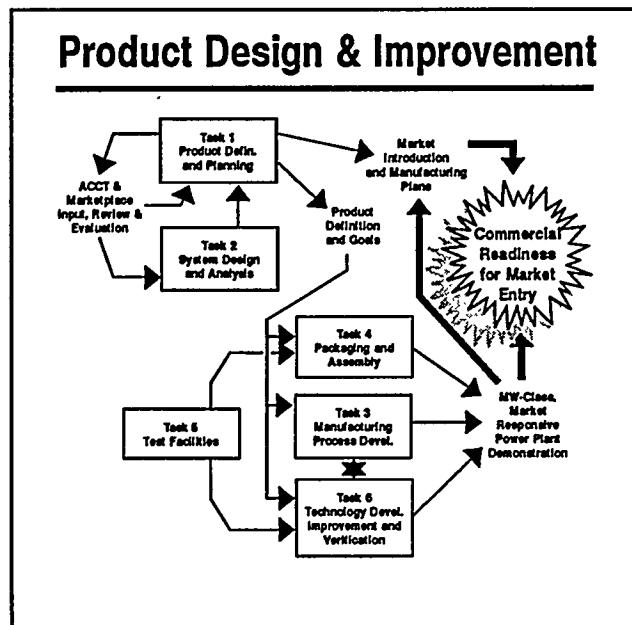


Figure 3. Product Design and Improvement Project Flow

Task 1. The product definition and market assessment involves the definition of a market driven power plant and the planning required to successfully introduce the power plant into the marketplace. Development of a market-driven product is enhanced by bringing the end users into early planning, product definition, and design phases. Preliminary marketplace inputs have emphasized the importance of reliability, durability, and cost. Although the initial introduction may require an elevated pricing structure in comparison to conventional technologies, reliability and durability of the power plant cannot be compromised.

Market surveys are being developed to identify the marketplace requirements for a MW-class MCFC power plant for distributed power generation, cogeneration, and compressor station applications. The surveys will address such issues as capacity, footprint, operating characteristics, interface requirements, and product trade-offs such as cost vs. efficiency. The results of the market surveys, in conjunction with applicable codes & regulations and design optimization from Task 2, will be analyzed to define preferred market entry power plant options.

The preferred power plant characteristics will be used to establish performance, life, and cost goals for the stack, mechanical skid equipment, and the power plant system. An ongoing technical progress evaluation are being maintained to measure development status compared to goals.

Task 2. System Design and Analysis will culminate in design and costing of a market-entry MW-class power plant. A preliminary baseline system has been selected against which trade-off studies will be performed. This baseline system expands upon design experience from Phase I (Technology Development) activities of the overall commercialization program.

Bechtel Corporation has developed design documents for the baseline system which include: a process flow diagram of the baseline design, complete with process flow characteristics (compositions, pressures, and temperatures); a description of the process; and a list of major equipment. Trade-off studies are being performed to determine the optimum operating parameters and process configuration for the market entry unit. Variables are independently changed to identify their impact on plant performance, reliability, and cost. Efficiency improvements will be weighed against increases in plant complexity, cost, size, reliability, and operating risk.

A design and cost estimate of the optimized plant has been generated. The cost estimates currently includes capital cost. Operating cost estimates and economic sensitivity analysis programs are being developed. The performance (design, off-design, and reliability, availability, maintainability, and safety) will be evaluated and dynamic simulations will be run to analyze the system behavior during normal and off-design conditions.

Task 3. The primary focus of the Manufacturing Process Development is to reduce the cost of the IMHEX® stack. This effort will build on the component and stack manufacturing capabilities developed at M-C Power since 1989, the year in which we established our first manufacturing facility dedicated to developing full area MCFC. This facility has been producing full area components and test stacks since 1991. In 1994 the largest MCFC stack was manufactured and conditioned in the facility and subsequently shipped to Unocal's Research Center in Brea, California. Currently, M-C Power is preparing to assemble the first of two 250-kW stacks to be tested at the Miramar Naval Air Station in San Diego, California. Progress in cost reduction from the initial 250kW stack (Unocal) to through the manufacturing of the two San Diego stacks is illustrated in Figure 4.

The optimization and automation of active cell component manufacturing process, consolidation of in-house separator plate manufacturing, and upgrade of QA/QC and analytical laboratory capabilities will enhance cell component manufacturing for the prototype power plant. The identification, qualification, and implementation of advanced component formulations and manufacturing processes will further reduce cell costs for market entry.

The manufacturing processes developed will be used to prepare a conceptual design for M-C Power's market entry stack manufacturing facility. The conceptual design will include site and facility

layouts, staffing requirements, inventory and throughput analysis, and manufacturing cost analysis.

Stack's Major Cost Elements

Progress Being Demonstrated Today

- Separator Plate Assembly
 - 47% Reduction: Unocal to SDG&E-1
 - 74% Reduction: Unocal to SDG&E-2
- Non-Repeat Parts
 - 15% Reduction: Unocal to SDG&E-1
- Repeat Parts
 - 50% Reduction: Unocal to SDG&E-1
 - 73% Reduction: Unocal to SDG&E-2
- Performance Improvements
 - 120 W/ft² Achieved in 20kW Stack/Lab Cells
- Life Improvements
 - 4mV/1000hr Achieved in 1ft² Stack/Lab Cells

Figure 4. Reductions in Stack Costs

Task 4. Packaging and assembly techniques used for the IMHEX® power plant will affect cost, footprint, weight and heat loss from the plant. Stewart & Stevenson will build on their experience with packaging of the Unocal and San Diego Gas & Electric demonstration units, along with their proven expertise with packaged power generation systems, to develop optimized packaging and assembly techniques.

Definition, verification, and implementation of packaging concepts and assembly methodologies will reduce the size and cost of the fuel cell power module, mechanical skid, and electrical module through efficient integration and assembly. Packaging concepts will be confirmed by scale models. The packaging concepts will be translated into three-dimensional computer models for verification of the assembly methodology and will be