Molten Carbonate Fuel Cell Product Design & Improvement - 2nd Quarter, 1995

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Statement of Cooperative Agreement Objectives

The primary objective of this effort is to establish, by 1998, the commercial readiness of MW-class IMHEX® MCFC power plants for distributed generation, cogeneration, and compressor station applications. Commercial readiness will require an advanced IMHEX® technology base, lower-cost manufacturing processes, verified balance-of-plant components, proven packaging and assembly approaches, demonstrated prototype power plants, finalized manufacturing and market distribution plans and a committed commercialization team. The M-C Power Team's supporting objectives are:

- ▶ To finalize product definition, complete detailed product design, identify and evaluate balance-of-plant components, and generate power plant manufacturing and market distribution plans which will result in successful transition from development into commercial market entry;
- ▶ To develop and optimize fuel cell component manufacturing processes and power plant assembly and packaging methodologies which will provide a market-responsive MW-class power plant in low production volumes appropriate for the initial stages of commercialization;
- ▶ To advance and improve the IMHEX® stack technology, balance-of-plant components, and power plant integration which will provide the technology basis for a reliable, cost-effective MW-class product;
- ▶ To demonstrate and verify the reliability, performance, and cost-effectiveness of these technologies in a prototype IMHEX® fuel cell power plant which will establish the marketplace confidence needed for successful entry into the commercial market; and
- ▶ To establish the necessary infrastructure and strategic alliances with vendors/suppliers to support market entry and commercialization.

The work to be performed by M-C Power and the subcontractors is divided into the six tasks listed below. The objectives for each task, along with a brief update, where appropriate, is shown on the following pages, which constitutes this technical report. A breakdown of the subtasks is included in this report.

Task 1:	Product Definition and Planning
Task 2:	System Design and Analysis
Task 3:	Manufacturing Process Development
Task 4:	Packaging and Assembly
Task 5:	Test Facility Development
Task 6:	Technology Development, Improvement, and Verification

Summary of Work Accomplished During the Reporting Period By Task (4/1/95 - 6/30/95)

TASK 1 PRODUCT DEFINITION AND PLANNING

Objective: The objectives of this task are to provide the product definition and plans necessary to ensure that the MW-class power plant developed and verified during this activity is responsive to the marketplace needs and conforms to M-C Power's existing Commercialization Plan and to prepare a report to satisfy the requirements of the National Environmental Policy Act.

Subtask 1.1 Identify Requirements

Objective: The contractor shall update existing product requirements based on marketplace input and document the requirements of a MW-class market-responsive MCFC power plant through market surveys, product option evaluations, and analysis of applicable codes and regulations. The contractor shall prepare a market analysis report that identifies product requirements, analyzes the survey results, and identifies applicable codes and regulations.

Subtask 1.1.1 Market Surveys

Objective: Bechtel will assist M-C Power to conduct a market survey. In this survey, potential users of the fuel cell unit in different business segments and different regions will be contacted to obtain pertinent information about current utility usage, needs and costs.

Status: *M-C Power is developing a preliminary market survey, which will be issued to a variety of potential customers.*

Subtask 1.1.2 Analyze Market Surveys, Codes and Regulations

Objective: Bechtel will assist M-C Power to analyze the data collected in Task 1.1.1 to identify the business segments and regions which have the highest market potential and to estimate this potential market size.

Status: *This task is dependent on the completion of task 1.1.1 above.*

Subtask 1.1.3 Generate Product Requirements Document

Objective: Bechtel will assist M-C Power to summarize the analysis conducted in tasks 1.1.1 and 1.1.2 into a cohesive document. A final document will be issued by incorporating the comments received.

Status: *This task is dependent on the completion of tasks 1.1.1 and 1.1.2 above.*

Subtask 1.2 Generate Product Definitions

Objective: The contractor shall generate product options based on market requirements and technical feasibility, select a market entry product approach based on its cost-effectiveness and market responsiveness, and prepare a product description document.

Subtask 1.2.1 Product Options

Objective: For the fuel cell unit to be a viable commercial product for on-site and distributed power generation, it has to compete with purchased power from grid, reciprocal engines and small gas turbines. Bechtel will determine the acceptable cost range for the fuel cell unit by conducting

an economic comparison with the competing power supply and generation options.

Status: *Bechtel is currently conducting a product option trade-off study for this task. The final product definition is also dependent on the results of subtask 1.1.*

Subtask 1.2.2 Product Option

Objective: Based on the market analysis done in task 1.2.1, Bechtel will define the commercial unit in terms of the following items:

- ▶ Power generation capacity of the unit
- ▶ Desired steam, hot water and hot gas production rates and delivery pressures and temperatures
- ▶ Acceptable thermal efficiencies
- ▶ Acceptable capacity rating with ambient temperature
- ▶ Acceptable turndown ratio
- ▶ Acceptable load following capability
- ▶ Minimum thermal cycling capability
- ▶ Minimum availability required for the unit
- ▶ Noise and emission limits
- ▶ Applicable codes and standards
- ▶ Maximum plot area allowed
- ▶ Acceptable cost range of the unit

Bechtel will issue a report which summarizes the economic comparison conducted in task 1.2.1 and the product definition in task 1.2.2.

Status: *Depends on the results of subtask 1.2.1.*

Subtask 1.4 Commercialization Plans

Objective: M-C Power will develop a commercialization business plan which addresses those steps taken to develop/obtain the competencies (packaging, distribution, sales and services) to commercialize the MCFC technology based on the market surveys and product definition work completed in previous tasks.

Subtask 1.4.7 Product Environmental Plan

Objective: Environmental compliance regulations of representative locations within the U.S.A. regarding the operation of IMHEX® fuel cell power plants and their fabrication and decommissioning will be assessed. A plan will be developed to address requirements of the conceptual manufacturing facility, including the recycling of decommissioned stacks and expended components.

Status: *Depends on the results of the market survey that will be done in subtask 1.1.1.*

Subtask 1.4.9 Product Cost Reduction Plan

Objective: M-C Power will develop a cost reduction cost benefit analysis showing the steps required to achieve user performance and cost requirements.

Status: *Depends on the findings of the market survey that will be done in subtask 1.1.1.*

Subtask 1.5 **Task Management & Reporting**

Objective: M-C Power and its contractors will perform general management efforts, prepare required financial, schedule and management reports as required. Also, work necessary to keep management information up to date will be performed.

Status: *Monthly and quarterly reports have been submitted to the DOE for the PDI cooperative agreement as specified within the agreement. Also, M-C Power prepares and submits a weekly report to D. Hooie, of the DOE, which provides additional information on the PDI project, where appropriate.*

TASK 2 **SYSTEM DESIGN AND ANALYSIS**

Objective: objective of this task is to conduct a system optimization study to evaluate various process options for maximizing plant performance and minimizing plant cost of the commercial unit. Based on the selected operating parameters and plant configuration, a preliminary design and cost estimate will be prepared to analyze the overall plant performance and economics.

Subtask 2.1 **System Optimization**

Subtask 2.1.1 **Power Plant Baseline Design**

Objective: Bechtel will use the design and cost estimate in a recently completed GRI fuel cell balance of plant (BOP) cost analysis study as the baseline system against which trade-off studies will be performed.

Status: *No significant progress to report on this subtask during the current reporting period.*

Subtask 2.1.2 **Power Plant Performance Trade-Off Studies**

Objective: Bechtel will perform several trade-off studies to determine the optimum operating parameters and process configuration for the commercial unit. A single variable will be changed at a time to identify its impacts on the plant performance and cost. Any efficiency improvement will be weighed against the increase in plant complexity, cost and physical dimensions. The trade-off studies to be conducted are listed below:

- ▶ Current Density Optimization
- ▶ Pressure Optimization
- ▶ Optimum Combustion Temperature in the Reformer
- ▶ Adding Shift Catalyst to the Reformer

Status: *M-C Power is currently working with Bechtel to provide input for these trade-off studies.,*

Subtask 2.2 **Generate Preliminary Design**

Objective: Based on the process configuration selected in task 2.1, Bechtel will prepare a preliminary

design for the commercial unit. Bechtel will confirm, jointly with DOE and M-C Power, the design basis to be used. The basis of the design will follow the product definitions established in task 1.

Subtask 2.2.1 Power Plant Process Design

Objective: In this task, Bechtel will first prepare a detailed process flow diagram and develop the heat and material balance over a wide range of operation including the normal operation, startup, and shutdown.

Bechtel will then size the equipment, including those items required for startup and shutdown. The equipment specification will contain sufficient details for suppliers to estimate the costs and develop preliminary sketches of the equipment dimensions.

Status: *M-C Power is currently working with Bechtel to provide input for the power plant design work.*

Subtask 2.2.2 Power Plant System Engineering

Objective: In this task, Bechtel, with support from Stewart & Stevenson (or others), will specify the piping, valves, insulation, structural steel, instruments, control, and electrical requirements for the commercial unit. Bechtel and Stewart & Stevenson will also develop a layout.

Status: *No significant progress to report on this subtask during the current reporting period.*

Subtask 2.3 Generate Preliminary Cost Estimate

Subtask 2.3.1 Power Plant Capital Cost Estimate

Objective: In this task, Bechtel will prepare jointly with Stewart & Stevenson (or others), a capital cost estimate for the commercial unit.

Status: *No significant progress to report on this subtask during the current reporting period.*

Subtask 2.3.2 Power Plant Operating Cost Estimate

Objective: Bechtel will, jointly with M-C Power, estimate the operating labor and establish the maintenance schedule, labor, and materials requirements for the commercial unit. The maintenance requirements will be extrapolated from plants with similar service severity and operating environment. The chemicals and catalysts consumption will be calculated. M-C Power will project the cell life as to determine the stack replacement cost.

Status: *No significant progress to report on this subtask during the current reporting period.*

Subtask 2.3.3 Power Plant Economic Analysis

Objective: Based on the capital and operating costs developed, Bechtel will conduct an economic analysis to determine the cost of electricity. This analysis will follow the methodology established in EPRI's Technical Assessment Guide (TAG).

Status: *Depends on the completion of subtasks 2.3.1 and 2.3.2.*

Subtask 2.4 **Performance Analysis**

Subtask 2.4.1 **Power Plant Design Performance**

Objective: Based on the design conducted in subtask 2.2, Bechtel will calculate and summarize the plant performance of the market entry unit at the rated capacity.

Status: *Depends on the completion of subtask 2.2.*

Subtask 2.4.2 **Power Plant Off-Design Performance**

Objective: The off-design performance to be evaluated for the market entry unit include:

- ▶ The minimum turndown ratio
- ▶ Part load efficiency
- ▶ Capacity rating as a function of ambient temperature

Status: *Depends on the completion of subtask 2.2.*

TASK 3 **MANUFACTURING PROCESS DEVELOPMENT**

Objective: The objectives of this task are to reduce stack costs and improve quality by optimizing existing cell and stack manufacturing processing, assessing and implementing in-house processing of separator plates, implementing advanced, high-speed low-cost cell manufacturing processes, and to design a conceptual stack manufacturing factory.

Subtask 3.1 **Cell Component Manufacturing Process Simulation**

Objective: Active component manufacturing processes will be optimized through the use of simulations, modeling, and testing and implemented to reduce cost, increase through-put, and improve quality of the baseline manufacturing processes.

Subtask 3.1.1 **Computerized Cell Component Manufacturing Process Simulation**

Objective: Discreet system simulation programs and analytical modeling programs for the evaluation of statistical variability within the linked manufacturing processes will be evaluated. When this information is combined with the normal manufacturing process routings, the analysis will project manufacturing throughput and will allow for the study of capacity and labor costs in a realistic environment.

Capital equipment utilization will be examined to determine the effect on product cost and quantity. These studies will lead to a definition of future equipment and staffing needs and provide a basis for a conceptual factory design.

Status: *M-C Power is developing a computerized process simulation that will be used to analyze the current manufacturing process as well as optimize this process. M-C Power is also investigating ways to automate the current manufacturing processes in order to reduce the*

overall cost per kW for the fuel cell stack.

Subtask 3.1.2 Analyze Cell Component Manufacturing Process

Objective: The object of this task is to conduct a detailed evaluation of the current manufacturing processes so that areas for improvement can be selected and prioritized. Statistical methods will be used to determine key process parameters, to assess control philosophies, and to reduce active component variation. Design of Experiment Techniques and Statistical Process Control will be used as the basis for improving the manufacturing process.

Status: *M-C Power is developing a computerized process simulation that will be used to analyze the current manufacturing process as well as optimize this process. M-C Power is also investigating ways to automate the current manufacturing processes in order to reduce the overall cost per kW for the fuel cell stack.*

Subtask 3.1.3 Optimize Current Cell Component Manufacturing Process

Objective: Based on the analysis and simulation of Task 3.1.1 and 3.1.2, on-line control and process improvements will be selected which optimize yields while maximizing throughput without impacting quality. The optimization of the process will focus on problem definition and solving, evaluating options, statistical testing, updating control documentation, and selecting process improvements which can be implemented to enhance baseline production facilities without impacting delivery schedules or quality.

Status: *Depends on the completion of subtasks 3.1.1 and 3.1.2.*

Subtask 3.1.4 Automate Current Cell Component Manufacturing

Objective: Optimization and automation of the current manufacturing processes which improve cost, quality, production rate, and safety in active cell component production will be implemented. This includes decreasing direct labor costs, combining tasks, installing process instrumentation and controls, improving handling systems, and adopting on-line quality controls.

Status: *M-C Power is investigating ways to automate the current manufacturing processes in order to reduce the overall cost per kW for the fuel cell stack.*

Subtask 3.1.5 Maintain Manufacturing Equipment

Objective: The manufacturing facility will be maintained according to a regularly scheduled maintenance program has been developed and will be followed to ensure proper and reliable operation.

Design, procurement, and refurbishing of the sintering furnace and other key manufacturing equipment will be accomplished under this task. Cost covers labor, services, materials and subcontractor labor.

Status: *M-C Power is working with the sintering furnace manufacturer to engineer and upgrade the existing sintering furnace.*

Subtask 3.2 Cell Stack Hardware Manufacturing

Objective: Existing plate processing and fabrication techniques will be evaluated. Appropriate technologies and equipment will be implemented and brought in-house to improve quality control and reduce cost.

Subtask 3.2.1.1 Improved Plate Manufacturing Process

Objective: Advanced, cost-effective manufacturing processes for plate hardware to reduce cost and improve quality will be evaluated. Four steps have been identified: forming, trimming, joining, and aluminizing.

Status: *M-C Power is reviewing and investigating the four (4) steps listed above for alternate, more cost effective processes.*

Subtask 3.2.1.4 Verify Improved Plate Manufacturing Techniques

Objective: Plates and sections of plates will be tested in out-of-cell and in-cell tests to verify dimensional quality and operational performance. Improvements will be selected which can be implemented and will reduce fabrication cost.

Status: *Depends on the completion of subtask 3.2.1.1.*

Subtask 3.2.2 Implement Improved Plate Manufacturing Phase I Processes

Objective: Improved plate designs will be combined with selected advanced plate fabrication techniques and implemented in order to reduce costs. Successful evaluations of advanced plate processing techniques and material suppliers will result in a formal recommendation to adopt and implement these new process technologies or fabricators.

Status: *Depends on the findings found in subtask 3.2.1.1.*

Subtask 3.3 Develop Advanced Manufacturing Processes (Cell/Stack Components)

Objective: The market entry product potentially requires advancements in the baseline manufacturing processes currently being utilized and optimized. Optimizations being implemented are projected to reduce stack costs to below \$4,000/kW in low production volumes. To achieve the \$430/kW cost target for market entry, advanced processes and designs need to be evaluated and qualified. The objective of this task is to identify, evaluate, and qualify potential advanced processes.

Subtask 3.3.1.1 Identify Advanced AC Candidate Manufacturing Processes

Objective: Processes will be identified and qualified at subscale levels for the rapid, low-cost fabrication of electrodes, electrolyte, matrix tapes, and separator plates. Advanced manufacturing techniques will be evaluated for achieving high-rate, durable manufacturing processes. The goal is to achieve an order of magnitude increase in throughput with no adverse impact on quality or performance.

Status: *Advanced manufacturing techniques are currently being investigated.*

Subtask 3.3.1.3   **Procure Advanced AC Candidate Manufacturing Equipment - Phase I**
Objective: After identification and evaluation of improved processes subscale equipment will be procured for verification trials. Evaluation and qualification of new equipment in these processes at sub-scale sizes will be conducted to verify process acceptability and cost-effectiveness prior to full scale implementation. A thorough costing analysis will be conducted prior to the adoption of advanced manufacturing processes to ensure the viability of the selected option.

Status: *Depends on the completion of subtask 3.3.1.1.*

Subtask 3.4   **Manufacturing Process Scale Up**
Objective: Manufacturing system simulations will be used to define scale-up goals and achievable targets for the advanced processes qualified and selected in Task 3.3.

Status: *Depends on the completion of subtask 3.3.1.1.*

Subtask 3.4.2   **Implement Advanced Manufacturing Process Scale Up Phase I**
Objective: Full-scale equipment for advanced processes which can be cost-effectively scaled up and implemented into existing facilities will be procured and installed. Advanced equipment will be shaken down, tested, and used for component production to verify cost savings in low production volumes. Advanced component technologies developed under subtask 6.1 will be evaluated in commercial-scale stack hardware under this or parallel programs.

Status: *Depends on the completion of previous subtasks.*

Subtask 3.5   **Cost Reduction**
Objective: The contractor shall evaluate and implement stack cost reduction technologies including recycling of materials, recovery of processed raw materials and recycling, implementing advanced component technologies, and verifying advanced plate engineering designs and concepts.

Subtask 3.5.2   **Develop Advanced Plate Design**
Objective: Advanced design and cell package concepts have the greatest potential for decreasing the cost of the IMHEX® stack. Modified and innovative plate concepts that illustrate the potential for order-of-magnitude cost reductions (such as one piece plate design) will be evaluated. Engineering drawings will be prepared and implemented in commercial-scale hardware if appropriate. These concepts may first be implemented in sub-scale tests if the costs and risks of commercial-scale hardware implementation are inappropriate.

Status: *M-C Power is developing a "Mod-4" plate, which will incorporate several design improvements to the current plate design. M-C Power is internally reviewing the overall schedule and use of this design in mock-up tests and a future 250kW fuel cell.*

Subtask 3.5.2.1

Identify Advanced Plate Manufacturing Candidate Processes

Objective:

Under the Product Development Test Program, M-C Power developed an advanced separator plate design, MOD 4. A prototype trial to define pressing, welding, cutting, and aluminizing parameters was also made.

Under this task, design modifications will be incorporated to address the deficiencies noted above. Finally, tests to quantify clamping force distribution and improvement made to the plate will be conducted. A second prototype run (50 plates) will be made in accordance with the revised design specifications. Once completed, the prototype run will be used to conduct an advanced full area stack test (AS-1).

Status:

M-C Power is developing a "Mod-4" plate, which will incorporate several design improvements to the current plate design. M-C Power is internally reviewing the overall schedule and use of this design in mock-up tests and a future 250kW stack.

Subtask 3.5.3 **Verify Advanced Component Cost Savings**

Objective:

Advanced component technologies developed and verified in bench-scale hardware under subtask 6.1 which have the potential to provide cost savings (either capital cost or operating cost) to the product will be transferred and scaled up to production in commercial-scale manufacturing equipment. Advanced component technologies will be evaluated in sub-scale stacks to verify performance, durability, manufacturability, and cost.

Status:

M-C Power is developing a "Mod-4" plate, which will incorporate several design improvements to the current plate design. M-C Power is internally reviewing the overall schedule and use of this design in mock-up tests and a future 250kW fuel cell.

Subtask 3.5.3.1

Select Advanced Component Materials and Processes

Objective:

Under this task, scale up of the NiCaO cathode and the LiNa electrolyte will continue. M-C Power has developed, under the PDT program, the know-how required for tape casting the NiCaO cathode and the LiNa electrolyte. Scale up to full area size components will be made under this subtask. Additionally, the sintering parameters of the NiCaO cathode will be characterized. Once the scale-up is completed enough, components to conduct a full area stack test (AS-1) will be manufactured.

Status:

M-C Power is continuing to experiment and test advanced components.

Subtask 3.5.3.2

Define and Use 100cm² and 1000cm² Processes

Objective:

The allocation provided under this subtask covers labor, materials and services needed to conduct bench scale test(s) in support of advanced development, manufacturing scale up or other technical issues needed by the program.

Status:

The near term advanced cell package has been defined as a stabilized cathode, a Li/Na electrolyte system, and a low Cr anode. This package was selected based on the recent cell tests at IGT which has exhibited stable performance for over 13,500 hours (test is ongoing) with one thermal cycle under atmospheric conditions and over 6,700 hours at 3 atm. with system conditions.

Li/Na Electrolyte

Vendors who can supply the Li/Na electrolyte powder in quantities to manufacture the components for a 250kW fuel cell stack are currently being evaluated. The

characteristics being measured to help determine a suitable supplier for the electrolyte powder are the moisture content, melting characteristics, bulk density and sieve analysis. Bench top casting trials were successfully completed with the Li/Na powder to verify compatibility of this powder with the binder systems currently in use.

Stabilized Cathodes

The powder specification was developed based on the laboratory manufacturing procedures and work was completed with a vendor to scale these procedures for manufacturing stack quantities of stabilized nickel powder. The powder for scale up tape casting and sintering trials are due during the next quarter

Work was completed toward developing and testing a lower cost stabilized cathode. Tape casting and sintering trials were completed and an electrode was selected for testing in 100cm² cell test M0195003.

Low Cr Anode (Ni+3Cr)

Scanning electron microscopy (SEM) analyses were received of a low Cr anode, the same type of anode being tested in 100cm² cell test M0195003. No residue Cr particles were apparent. The alloy composition was measured quantitatively using an EDX line scan of the cross section of five (5) particles: $2.98 \pm 0.13\%$ chromium with the balance nickel. The results indicate that the manufacturing procedures developed for the PDT-1 Ni+6 Cr anode, including tape casting, sintering and the chromium milling procedures are also acceptable for the Ni+3 Cr anode.

Subtask 3.6   Quality Assurance/Quality Control

Objective: M-C Power has chosen to follow the American National Standard/American Society for Quality Control (ANSI/ASQC) Q91-1987 quality standard, a technical equivalent of the International Standards Organization (ISO) 9001 standard, ("Quality Systems - Model for Quality Assurance in Design/Development, Production, Installation, and Servicing"). The Q91 standard provides requirements for quality program development and maintenance, while allowing the flexibility to meet the specific needs of M-C Power. ISO registration is planned.

Subtask 3.6.1   Outline QA/QC Program Requirements

Objective: Quantitative goals such that progress can be objectively assessed will be developed.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 3.6.3   Update QA/QC Procedures and Methods

Objective: Existing QA/QC procedures will be reviewed and revised to cover improvements made under previous DOE contracts. A primary focus of these procedures will be the planning and control of processes rather than inspection and remedial action. The revised procedures will then be integrated into M-C Power Quality Assurance Manual.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 3.7   Analytical Testing

Objective: Improvement and upgrading of analytical capabilities has been ongoing at M-C Power and investigation into new or improved analytical methods to meet the increasing analytical needs in a cost-effective and timely way has been a priority and will be addressed in a systematic

approach.

Subtask 3.7.1 Identify QA/QC Analytical Equipment Requirements

Objective: Future analytical needs will be assessed. The need for specific tests will be evaluated and the adequacy of analytical testing in providing useful data will be confirmed.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 3.7.6 QA/QC Equipment Maintenance

Objective: The manufacturing facility will be maintained according to a regularly scheduled maintenance program has been developed and will be followed to ensure proper and reliable operation.

Status: *Regular maintenance is done on existing QA/QC equipment.*

TASK 4 PACKAGING AND ASSEMBLY

Objective: The objectives of this task are to improve and verify efficient and low-cost packaging and assembly methodology for the BOP and the stack module and to design a conceptual power plant factory.

Status: *M-C Power does not anticipate completing or spending any money on task 4 activities in budget period 1. Therefore, these tasks are not shown in this report.*

TASK 5 TEST FACILITIES

Objective: The objective of this task is to provide the facilities necessary to support cell technology and stack verification and power plant distribution. The facilities will consist of new facilities and upgraded existing facilities.

Subtask 5.1.1 Develop 50/250kW Pressurized Test Facility

Objective: Initial efforts to define and develop a pressurized 250 kW test facility to verify MCFC stack endurance in a plant configuration which could also simultaneously operate 50 kW pressurized stack tests are planned for the first budget period.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 5.1.2 Maintain 20kW Atmospheric Test Facility

Objective: The existing DOE owned 20-kW atmospheric test facility is capable of testing commercial-area (1 m²) stacks. The facility will be maintained to ensure safe and reliable operation. Testing will be performed under subtask 6.4.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 5.1.3 Maintain Acceptance Test Facility (ATF)

Objective: The ATF is a DOE-owned facility was built under DOE Contract No. DE-AC21-90MC27394 for conditioning and acceptance testing of 50-kW and 250-kW MCFC stacks. The ATF will be maintained to ensure safe and reliable operation.

Status: *General maintenance and improvements are being done to the ATF for future fuel cell stack conditioning needs.*

Subtask 5.1.4 Develop Pressurized Bench-Scale Facility

Objective: Several 100 cm² test stands and one 1000 cm² stand will be designed, procured, and installed to support MCFC technology development. The test stands will be capable of simulating system operating conditions at elevated pressure. These stands will be used to generate performance data to assist in projecting the impact of improved cell technology on system performance.

Status: *Three (3) tests have been started this year under the PDI program. Updates on these tests are shown below.*

100 cm² Cell Test M0195001

This was the first test at M-C Power using thinner cell components. The cell was terminated after 1851 hours of pressurized operation due to wet seal failure caused by an uneven and overly thick flame sprayed aluminization. A new method of aluminization will be employed next test.

The steady state performance was 776 mV, at 3 atm system gases at 160 mA/cm², 60% fuel utilization and 40% oxidant utilization. Post-test analysis revealed that the active area components were strong, with good contact and good carbonate retention properties: the matrix was 100% full, the cathode was 48% full, and the anode was 43% full. The electrode fill is higher than the 30% fill target. Performance can be improved by lowering the carbonate loading. Ni dissolution was 10.9 mg/cm², which is consistent with the trend for higher dissolution for pressurized tests compared to those run at 1 atm.

100 cm² Cell Test M0195002

This cell test was the test of a cost effective market entry pre-prototype (MEP) cell without an anode current collector. This cell stack also reduced the number of matrices to two (2) 0.33mm matrix layers, instead of three (3) 0.41mm layers. A stabilized cathode and low Cr anode were utilized with the 70/30 Li/K carbonate electrolyte. After 300 hours of operation, the performance was 772 mV on systems gases at 160 mA/cm², 60% fuel utilization and 40% oxidant utilization. Soon after the cell performance began to decay due to a matrix crack and lower wet seals efficiencies. The cell test was terminated after 1126 hours of operation, following a large decrease in the performance from 727 mV to 705 mV in one week.

Post test analysis revealed that the anode did not sag into the rib channels but substantial sagging and matrix cracks were apparent in the inlet and outlet gas channels. Unlike previous tests conducted at IGT without a current collector, a good anode-matrix contact was maintained in the active area.

100 cm² Cell Test M0195003

This cell test includes the first Li/Na electrolyte tested at M-C Power and a lower cost version of the stabilized cathode. Cell M0195003 has completed approximately 1125 hours of pressurized operation. The steady state performance at 60% fuel utilization, system gases and 3 atm. remains steady at 765 mV at 16A with an OCV of 1029 mV.

Subtask 5.2.1 Review and Update 250-kW Facility

Objective: Under the PRDA program, M-C Power constructed and operated a 250 kW facility. The facility is located at the Unocal Fred L. Hartley Research Center, Brea, CA. The facility, after significant efforts, was commissioned and successfully operated very briefly. As a result of this

effort, the start-up team (Bechtel, M-C Power, Stewart & Stevenson, and Unocal) believes that this facility represents the best chance of achieving timely testing of full-area, full-eight stacks - 250 kW class - in a cost effective way.

Status: *M-C Power has shut down the UNOCAL 250kW stack and is currently conducting a thorough evaluation.*

TASK 6 **TECHNOLOGY DEVELOPMENT, IMPROVEMENT AND VERIFICATION**

Objective: The overall objective of this task is to provide the cell, stack, and BOP component technology developments, improvements and verifications and to provide the power plant product verification to bring a multi-fueled, integrated, simple, low-cost, modular, market-responsive IMHEX® molten carbonate fuel cell power plant to the marketplace. This task includes design, fabrication, construction, testing, and analysis of a MW-class (nominal 1 MW) power plant demonstration.

Subtask 6.1 **Cell Package**

Objective: The contractor shall improve cell package cost, performance, stability, and durability using evolutionary approaches with existing technology and innovative approaches to achieve breakthroughs. Materials, geometrics, and microstructures will be addressed. Out-of-cell, single-cell, and subscale stack tests will be used to verify and implement improvements. The contractor shall address cathode dissolution and performance, cell sealing, thermal cycling, cell package simplification, cost reduction, and component strengthening.

Subtask 6.1.1 **Active Component Unit Improvement**

Subtask 6.1.1.1 **Active Area Component Improvements**

Objective: To complete development and verification of "Second generation" active components. IGT to document results and transfer data to M-C Power Corporation.

Status: *Six cell tests were put in the PDI program, which will be operated at IGT as per M-C Power's specification. Six flanges were machined this quarter and were inspected to verify compliance with the specification. All were acceptable and all but one were sent for aluminization.*

Pre-test Manufacturing Trials

Prior to testing, preliminary manufacturing trials of the selected materials technologies were completed to demonstrate the probability of success during cell testing.

Lower Cost Matrix

Two (2) versions of lowering the cost of the matrix were evaluated using bench top casting trials. One lower cost matrix was qualified for bench scale testing and is being tested in cell test IM9501.

Ni-Al Pre-alloyed Powder

Ni-Al anodes are candidates for use in stacks without an anode current collector. Ni-Al anodes have not been tested with the Li/Na electrolyte either at IGT or M-C Power. During this quarter powder samples were obtained from a powder vendor capable of manufacturing stack quantities of pre-alloyed powder. SEM and

particle size analyses were obtained. Bench top casting and sintering trials were completed and an in-spec 100cm² size Ni-3 Al anode was successfully manufactured.

The carbonate fill and post test analysis computer programs were modified to accommodate the advanced active area components, including the Li/Na electrolyte, stabilized cathode and the Ni-Al anode.

100cm² Cell Test IM9501

The purpose of this test is to determine the baseline operating characteristics of a lower cost matrix. This test will be directly comparable to cell test M0195001 except for the use of the lower cost matrix. Matrices were cast and porosimetries obtained of all of the pre-test active area components. This cell has completed initial start-up, but baseline performance data has not been obtained as of this report.

100cm² Cell Test IM9502

The purpose of this test is to determine the baseline operating characteristics of a Ni-Al anode with the Li/Na electrolyte. A stabilized cathode was manufactured to match with the Ni-Al anode obtained from the manufacturing trials. This test will be started in the next few weeks.

**Subtask 6.1.1.1.1
Objective:**

Improved Cathode Performance

Contractor (IGT) shall continue efforts to improve cathode performance and endurance, including creep resistance and microstructure. Contractor (IGT) shall document the effect of CaCO₃ addition to the cathode on cathode microstructure and wetting properties, primarily with Li/Na electrolytes. Contractor (IGT) shall document results with both physical mix and solid solution stabilized cathodes, clearly indicating any test conditions or post-test analyses which could confuse the conclusions.

Contractor (IGT) shall use the existing cathode microstructure and performance model to guide this effort.

Status:

See status update under subtask 6.1.1.1.

**Subtask 6.1.1.1.2
Objective:**

Alternate Electrolyte

Contractor (IGT) shall review the need for pre-wetted (with Carbonate) matrix when fiber reinforcement is used using out-of-cell tests. Contractor (IGT) shall continue evaluation of alternate electrolytes, specifically the Li/Na/K/Ca system. Contractor (IGT) shall document ionic conductivity, liquids temperature, wetting properties, cathode dissolution, and cell corrosion as a function of melt composition through literature survey updates and cell testing results. Cell testing at the 100 cm² level will be conducted under Task 6.1.1.4.1 with post-test analysis conducted under this Task.

Contractor (IGT) shall continue operation of cell IGT-BSTC-66-93-4 and perform post-test analysis of cell IGT-66-94-1.

Status:

See status update under subtask 6.1.1.1.

Subtask 6.1.1.1.3

Objective:

Strengthened Anode Fabrication

Contractor (IGT) shall provide a detailed written summary and oral presentation of the status of Ni-Al anode fabrication techniques, creep data, and cell test results. Contractor (IGT) shall critically compare competing techniques on a technical basis and relative to MAUS testing performed under a previous GRI program. Contractor (IGT) shall report on results using a Ni-CrOx anode.

Contractor (IGT) shall support M-C Power's evaluation of anodes made from pre-alloyed Ni-Al powders for compatibility with MCFC requirements. Such support will consist of participation in analysis of powder morphology and pre-test and post-test anode characterizations as well as definition of processing (sintering) conditions.

Status:

See status update under subtask 6.1.1.1.

Subtask 6.1.1.1.4

Objective:

Cathode Dissolution

Contractor (IGT) shall quantify the effect on cell performance and cathode dissolution of CaCO₃ addition to the electrolyte through cell testing under Task 6.1.1.4.1. Contractor (IGT) shall identify cost-effective approaches to the CaCO₃ addition to the electrolyte and establish electrolyte taping procedures. Contractor (IGT) shall use Li/Na as the bulk electrolyte.

In addition to the work being performed by IGT, Argonne National Laboratory will perform work related to cathode dissolution.

Status:

See status update under subtask 6.1.1.1.

Subtask 6.1.1.1.5

Objective:

Alternate Cathode Material

Contractor (IGT) shall procure samples of alternate cathodes from Argonne National Laboratory and, if possible from ECN in the Netherlands. Contractor (IGT) shall perform the necessary characterizations to ensure proper matching of cathode, anode, and matrix. Contractor (IGT) shall perform parallel cell tests under Task 6.1.1.4 to compare Ni cathodes and CaCO₃ in the electrolyte, ANL's cathode, ECN's cathode, and NiO-CaO cathodes. Contractor (IGT) shall perform post-test analysis for these tests and report the results in a Topical Report.

Status:

See status update under subtask 6.1.1.1.

Subtask 6.1.1.2

Objective:

Alternate Cell Package Development

To simplify cell and stack fabrication, assembly, and conditioning through modified cell package and component design, integrated manufacturing, and out-of-cell conditioning.

Subtask 6.1.1.2.1

Objective:

Alternative Cell Package Design & Development

Contractor (IGT) shall continue development and evaluation of cell package designs which involve elimination of electrode ledges to reduce differences in stiffness between the wet seal and active areas of the cell. Contractor (IGT) shall quantify the effect of direct contact of electrodes with the opposing gas (i.e., anode and oxidant, cathode and fuel). Contractor (IGT) shall evaluate cell sealing approaches including a matrix "gasket", electrode densification (coining), and "welding" of electrode and/or current collector to the plate. Contractor (IGT) shall conduct verification testing in 100 cm²

under Task 6.1.1.4.2 with appropriate atmospheres and pressure differentials. Contractor (IGT) shall design and construct out-of-cell screening tests for edge sealing evaluation.

Status: *M-C Power and IGT have been investigating ideas for this subtask.*

Subtask 6.1.1.2.2 Advanced Cell Package Fabrication

Objective: Contractor (IGT) shall, under the IHI program, define and evaluate approaches and techniques for laminating active cell components during initial manufacture. Contractor (IGT) shall address cutting and handling of "green" laminates.

Contractor (IGT) shall process "green" laminates into cell packages and conduct verification testing in 100 cm² single cells under this Task.

Status: *Dependent on the completion of subtask 6.1.1.2.1.*

Subtask 6.1.1.2.3 Out of Cell Component Preconditioning

Objective: Contractor (IGT) shall, under the IHI program, define and evaluate techniques for out-of-cell conditioning of the laminated cell packages prepared under Task 6.1.1.2.2. Contractor (IGT) shall demonstrate the performance in 100 cm² under this Task. Contractor (IGT) shall address cutting of conditioned laminates using techniques amenable to mass production at commercial scale.

Status: *Dependent on the completion of subtask 6.1.1.2.2.*

Subtask 6.1.1.3 Corrosion, Modeling and Performance

Objective: To test separator plate materials in bench-scale fuel cells. To maintain and upgrade the Cathode Performance Model. To increase and optimize the active cell package performance.

Subtask 6.1.1.3.1 Corrosion

Objective: Contractor (IGT) shall analyze post-test separator plate materials from 100 cm² cells operated under Task 6.1.1.4. The separator plate materials will be specified by Professor Robert A. Rapp of Ohio State University under a parallel subcontract with M-C Power. Contractor (IGT) shall supply post-test metallographic analysis and cell operating data to Professor Rapp and participate in a review meeting at M-C Power.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 6.1.1.3.3 Performance

Objective: Contractor (IGT) shall continue efforts to improve MCFC performance including stability.

Subtask 6.1.1.3.3.1 Define Baseline Cell Package

Objective: Contractor (IGT) shall define the Baseline Cell Package and propose improvements within 30 days of contract execution. The definition shall include raw materials, processing procedures, component dimensions, startup procedures, and typical performance and stability.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 6.1.1.3.3.2

Define Initial Advanced Cell Package

Objective:

Contractor (IGT) shall define an initial Advanced Cell Package using Li/Na electrolyte, NiAl anode, and cathode stabilization (either by CaCO_3 in the electrolyte or the cathode) based on data obtained in prior programs. Contractor (IGT) shall perform cell tests of the advanced cell package under subtask 6.1.1.4 and use the results to modify and improve the Advanced Cell Package. Post-test analysis will be conducted under this subtask.

Status:

No significant progress to report on this subtask during this reporting period.

Subtask 6.1.1.3.3.3

Define Performance Limits

Objective:

Contractor (IGT) shall estimate the limits of performance (current density, voltage) at present systems conditions and propose ways to achieve the limit, emphasizing cell components. Contractor (IGT) shall propose approaches to double the current density.

Status:

No significant progress to report on this subtask during this reporting period.

Subtask 6.1.1.3.3.4

Optimize Cell

Objective:

Contractor (IGT) shall fabricate components based on the finding of Task 6.1.1.3.3.3 for testing in 100 cm^2 cells under subtask 6.1.1.4.

Status:

No significant progress to report on this subtask during this reporting period.

Subtask 6.1.1.4

Verification Testing

Objective:

To provide cell testing support for subtasks 6.1.1.1, 6.1.1.2, and 6.1.1.3 and for M-C Power.

Contractor (IGT) shall conduct 100 cm^2 single-cell tests in support of the other tasks in this program. Contractor (IGT) shall install and commission four pressurized 100 cm^2 single cell test facilities.

Status:

Several 100 cm^2 tests are ongoing at IGT to support this subtask.

Subtask 6.2.1

Buss Bar Material Selection

Objective:

Designs will be developed and materials selected to connect the stacks in series, to minimize resistance and to minimize the complexity of vessel penetration.

Status:

Preliminary investigation work is ongoing to support this activity.

Subtask 6.3

Balance of Plant Component Development

Objective:

In this task, Bechtel's first year activities are as following:

- Screen and select the major BOP component developers
- Define the overall development program, scope of work, and budget with each developer
- Conduct contract negotiation with each developer
- Coordinate the technical support from the developers for the trade-off studies and the preliminary design and cost estimate in Task 2

Status:

Bechtel has been contacting and working with several vendors on this subtask.

Subtask 6.4 Full-Area Stack Tests

Objective: Commercial-area stack tests are used to verify improvements in the design, fabrication, and performance of full-area components and processes and to verify operational advancements in the technology.

Subtask 6.4.1 Fabricate and Operate 20kW Non Pressurized Stacks

Objective: Two commercial-area short stacks (20-kW) will be fabricated and operated at atmospheric pressure to verify new separator plate concepts, advanced component technologies, manufacturing scale-up, modified stack start-up and operating procedures, and commercial stack fixturing.

Subtask 6.4.1.1 Stack AS-1 (20kW) Fabricate and Operate

Objective: Stack AS-1 will be used to qualify the baseline cell package. Preliminary work effort will be performed during the first budget period; however, fabrication and testing will occur in a later budget period.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 6.4.4 Stack Failure Mode Verification

Objective: M-C Power, under the Product Development Test Program, completed a highly successful full-area, short-height stack test - MCP-7. Under this subtask, an allocation is provided to continue stack operations. The purpose of the continuing stack operations is to validate, if necessary, the Unocal failure mode. M-C Power believes that confirming the failure mode in a full-area stack is necessary to develop customer confidence.

Status: *M-C Power did continue the stack test to collect additional data. The test has since been shut down.*

Subtask 6.5 MW-Class Power Plant Demonstration

Objective: The major purpose of this demonstration unit is to verify commercial readiness of M-C Power's IMHEX® fuel cell power plant by demonstrating the characteristics, performance, and operability of a prototype market-entry unit at a customer site.

Status: *No significant progress to report on this subtask during this reporting period.*

Subtask 6.5.3.2.2 Manufacture 1 MW Electrolyte Matrix Tapes

Objective: Repeat components will be fabricated for the power plant. Some initial production techniques will be tested prior to full production.

Status: *No significant progress to report on this subtask during this reporting period.*

Description of Attachments

★ U.S. Department of Energy, Morgantown Energy Technology Center, Contract Report Transmittal Checklist

Joseph A. Scroppo - Date
Senior Project Manager

DOE Reviewing Representative