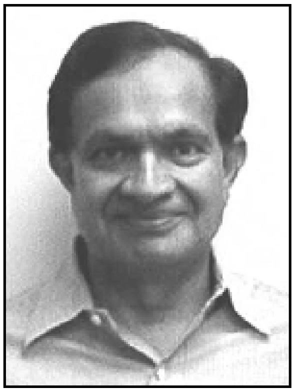
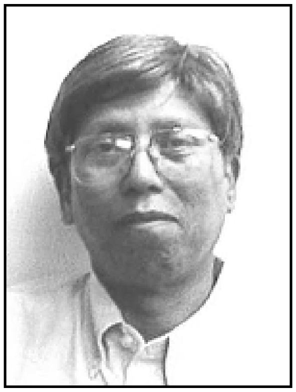
Molten Carbonate Fuel Cell Product Design Improvement





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Objectives

The overall program objective is to advance the direct carbonate fuel cell technology to commercial entry level. The specific objectives to attain the overall goal are as follows:

- Define power plant requirements and specifications.
- Design low-cost, modular, market-responsive DFCÒ power plants.
- Resolve power plant manufacturing issues and design the commercial-scale manufacturing facility.
- Define the stack and balance of plant (BOP) equipment packaging arrangement, and the stack module designs.
- Acquire capability for developmental testing of stacks and critical BOP equipment to support product design.
- Resolve stack and BOP equipment technology issues, and design, build and field test a prototype power plant to demonstrate readiness for commercial entry.

Key Milestones

- Select a product definition and specifications with input from potential users and define the commercialization plan.
- Design sub-MW and MW-class standard DFCÒ products for market entry.
- Acquire manufacturing capability for market-entry products.
- Develop stack module design(s) and establish product packaging configuration.
- Acquire capabilities for (1) stack developmental testing, (2) product stack and BOP design verifications, and (3) stack module conditioning and performance verification.
- Develop stack and BOP equipment technology (commercial design) to achieve market entry cost and performance goals.
- Conduct prototype modular power plant field trial(s).

Approach

The product design improvement (PDI) program sponsored by government and private-sector cost-share draws on the manufacture, field test, and post-test

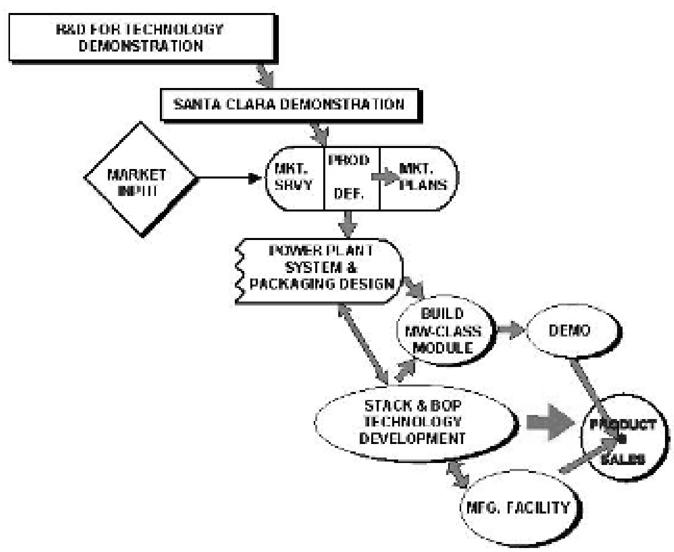

Figure 1. *Effort and interaction of key project elements. The program will result in the market entry commercial product.*

experience of 1.9-MW proof-of-concept power plant operated by FuelCell Energy (FCE) at a utility site in 1996-97. The efforts are focused on stack technology, manufacturing facility, and system developments leading to DFC® product designs, and prototype system field trials. Figure 1 shows key program elements (shaded) and their interrelationships.

Results

Products: In collaboration with potential users, FCE has defined three modular products: MW-class products rated at 1-MW (single module, 4 stacks) and 2-MW (2 modules, 8 stacks), and a sub-MW class product with a rating of 250-kW (single stack).

Final design of the 2-MW product has been developed. If high quality waste heat is utilized for cogeneration, overall thermal efficiency will be >80%. Early market entry versions of the system will have 2-MW net AC output at appx. 50% LHV efficiency. The 1-MW product is configured in a similar fashion as the 2-MW product. The DC power section is a 4-stack cylindrical module. FCE's technology partner has developed the sub-MW power plant design. FCE has upgraded the design for conformance with U.S. codes and regulations. Field trial of this product has already been initiated. Future efforts in plant design will include component vendor feedback in the construction phase of MW-class plants, and upgrading a sub-MW plant design based on field trial lessons learned.

Establishment of near and long-term strategic supplier relationships is also being pursued. Duke/Fluor Daniel, and Jacobs Applied Technology have been FuelCell Energy partners for system engineering and packaging, respectively. Discussions are being held for selecting additional organizations for electrical and/or mechanical equipment supply. FCE has been actively participating in the efforts to develop codes and standards for acceptance of fuel cell power plants in the market place, which will continue.

Product Manufacturing: FCE's overall manufacturing strategy includes assembly of a BOP equipment skid at the equipment manufacturer and/or packager sites, and stack manufacturing, conditioning and performance verification at FCE factory. The sub-MW plant will be integrated and performance tested at the factory, whereas the MW-class power plant modules will be integrated in the field. FCE manufactures fuel cells in Torrington, Connecticut, where considerable resources have been devoted to satisfy production requirements in a cost-effective manner. The FCE products are modular and maintain a high level of component commonality to avail cost advantage of mass production. Stacks used in all products are built with identical cell packages. The highly evolved processes, and the standardized component design have already resulted in very competitive stack costs.

The stack manufacturing capability has been significantly enhanced at Torrington by relocating to a new 65,000 ft^2 building, acquiring new tooling and equipment, and automation of key manufacturing processes and quality check procedures. The equipment necessary to produce 50-MW fuel cells per year has been installed. Each of the process lines has been tested and has achieved the 50-MW run rate. Equipment and processes were developed to allow for assembling multiple horizontal- and vertical-type power plants simultaneously. FCE is now capable of assembling two stacks simultaneously and handling six stacks in various stages after the assembly. The Torrington facility has added ~200 new employees. The company continues to train staff for three shift operations, and will assess production rates based on the market outlook. Future efforts will focus on production rate increase, yield increase and cost reduction.

Power Plant Packaging: FCE's product packaging approach has been defined. The MW-class products will include truck-transportable stack, mechanical, electrical, and instrumentation skids. These skids will be field-installed and interconnected. The sub-MW product will comprise a single skid, which will be field-installed. The MW-class stack module design has been developed that features truck transportability with access to potential power plant sites in the U.S., and low field installation costs. The unit is designed per NFPA 69 to contain the worst-case deflagration from mixing and combustion of fuel and oxidant gases. A prototype 4-stack (MW-class) module has been fabricated to ASME code standards. The fabricated unit was transported on a double drop lowboy truck to the FCE facility, showing that the module design is fabricable, compact, and transportable within the U.S., with minimal permitting. The transportation and handling logistics were further checked out when the unit was moved from the Torrington manufacturing facility to the Danbury site for a simulated hot test. The hot test has been completed demonstrating the module's readiness for product use. Future efforts will include design improvement based on initial test results available in late 2002.

Facilities: Under this effort, 3 subscale (10-kW, 20-kW, and 30-kW) stack test facilities were made available for technology development testing. The major effort in test facility development area was to modify an existing 100-kW class facility to represent the commercial power plant, incorporate SCDP BOP experience, and accept 9000 cm^2 cell area stacks with a capacity of up to 400-kW. The 400-kW facility has been used for system integrated operation of BOP equipment, product building-block stack design evaluation, and verification of power plant control and operational parameters. These test results have provided the basis for design of full-size stack, oxidizer, natural gas prereformer, natural gas cleanup beds, natural gas humidifying heat exchanger, water conditioning subsystem, and inverter incorporated in the DFC® products.

The construction of facilities for conditioning and performance verification (acceptance) test of sub-megawatt and MW-class products has been completed. The MW-class facility can have one module in operation while the other module is being connected/disconnected. Commissioning of this facility is in progress. A photograph of the facility is shown in Figure 2. Conditioning of the first MW-class module M10-1 is planned during the second half of 2002. The sub-megawatt facility can accommodate eight modules (250-kW each) with one bank of four units in operation while the other bank of four units is being connected/disconnected. These two facilities together can provide 50-MW/year total stack conditioning and performance verification capability.

Figure 2. *The megawatt-class testing and conditioning facility is ready.*

Technology Development: FCE has made significant advances in the area of cell technology improvement/refinement directed towards commercial products. Under the present program efforts, the cell area has been scaled up 50%, stack power increased by >100%, endurance capability enhanced by at least 100%, and materials cost also reduced to <50%. The full-size stack design has been defined based on total of >20,000 hours of system integrated test results. The critical BOP equipment designs have also been evolved based on system tests. The highlights of more recent accomplishments are included below.

- Detailed analysis of test results and post-test of materials from endurance stacks (12,000h and 17,700h) have confirmed that the stack life goal could be met.
- New inactive end cell (assembly) design was verified in subscale stacks, showing very low, stable end cell resistance through stressed testing (20 thermal cycles). The design has been incorporated in product stacks.
- Alternate low-cost (at least six times lower) bipolar plate material has been successfully evaluated in subscale stacks, showing very low corrosion in post-test examination.
- The full-height Stack FA-100-2 demonstrated endurance characteristics, operability under all conditions in the DFC/T hybrid system, and performance of the low-cost, value-engineered, non-repeat stack hardware. Based on these test results, the MW-class power plant stack module M10 design has been finalized, and the stack fabrication has been launched.
- An advanced low-cost adsorbent—with three times higher capacity than the baseline material—has been identified for further evaluation in field trial operations in removing sulfur from natural gas pipeline.
- FCE has evaluated four alternate inverter systems and qualified three designs for DFC® power plants. Operation of one of the designs in grid-connected and grid-independent modes has also been successfully verified in conjunction with the 250-kW DFC/T test.

- Several field trials of the sub-MW products are ongoing in the U.S. and Europe, and additional units have been planned.

Future efforts will focus on further cost reduction, endurance enhancement and upgrading of the full-size stack for improved performance.

Conclusion

The program defines three DFC® low-cost, modular, environmentally-friendly power plant products for distributed power generation, offering approximately 50% electrical efficiency and >80% system efficiency with cogeneration. The corresponding fuel cell stack module and BOP equipment designs, including the power plant packaging arrangements, have been developed, based on developmental testing at subscale level and verification testing in 250-kW integrated system. In parallel, the manufacturing technology has been developed leading to acquiring 50-MW/y production capacity. Field trials of sub-megawatt products are ongoing in U.S. and Europe. Field trial of a megawatt-class product is planned in second half of 2002. The product designs will be upgraded based on power plant construction and field trial experiences. Parallel efforts to develop technology for further improving fuel cell performance and reducing power plant costs will continue, to bolster the launch of commercial products.

References

1. H.C. Maru, "Status of Carbonate Fuel Cell Development at FuelCell Energy," Japan Fuel Cell Symposium, Sendai, Japan, February 2002.
2. H. Maru, M. Farooque, and J. Leitman, "Progress in Direct Carbonate Fuel Cell for Distributed Generation," IEEE Summer Power Meeting, Vancouver, Canada, July 15-19, 2001.
3. C. Bentley, M. Farooque, H. Maru, and J. Leitman, "Direct Fuel Cell Commercialization," 2000 Fuel Cell Seminar Abstract, Portland, Oregon, October 30-November 2, 2000.
4. DOE, "Molten Carbonate Fuel Cell Product Design Improvement," Technical Progress Reports 1 (Dec. 1995) through 7 (Dec. 2001).