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TECHNOLOGY DEVELOPMENT AND VALIDATION OF INDUSTRIAL FUEL CELL VEHICLES - PHASES II/III

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Abstract

The status and plans to develop and validate a light industrial vehicle powered by a fuel cell with on-board storage of hydrogen fuel as a metal hydride are described. Work began in August 1998 and this phase of the project is scheduled to end in September 2000. The first of two prototype vehicles has been assembled and is undergoing testing and evaluation. Performance agrees well with a steady state computer model developed to aid in evaluation and design. Several opportunities have occurred for display and demonstration of the first vehicle. A number of operating problems have been encountered requiring modifications or repair. Lessons learned from this experience are being factored into the design of the second prototype vehicle which employs more advanced fuel cell and metal hydride storage technologies. Assembly of the second vehicle is in progress and expected to be complete in early summer 2000. A market evaluation is being performed by Deere & Co., the vehicle manufacturing participant in the project, to determine the prospects for an ultimate commercial version of the vehicle. Technical and business plans leading to commercialization will be developed as warranted by the outcome of this evaluation, also scheduled for completion this summer.

Project Status and Plans

Project Participants

A total of seven organizations are participating in the Phase II/III Industrial Fuel Cell Vehicle (IFCV) Project. These include, together with their individual areas of interest and expertise:

- Deere & Company — IFCV manufacturing and sales
- Energy Partners — PEM fuel cells

• Westinghouse Savannah River Co.	Metal hydride hydrogen storage system
• Teledyne Brown Engineering	Hydrogen generator design and sales
• University of South Carolina-Center for Electrochemical Engineering	Performance modeling & testing, H2 storage/refueling testing
• York Technical College	IFCV validation testing
• Southeastern Technology Center	Project management and integration

As project manager, Southeastern Technology Center (STC) serves as the applicant for the DOE Cooperative Agreement under which the project is sponsored and funded. The non-federal participants provide nominally a 50% cost share of the total Phase II/III project budget, which is approximately $1.25 million.

Long-Term Goals

The fundamental goal of the project is to develop and validate small commercial electric vehicles utilizing hydrogen fuel cell power and on-board storage of fuel as a metal hydride. The concept of solid state storage of hydrogen is being employed to provide inherent safety advantages. This technology, developed originally for national defense purposes, is provided by the Westinghouse Savannah River Co. (WSRC) as a technology Transfer initiative.

A corollary goal is to develop and validate a compatible hydrogen generator system that could be used to provide refueling for limited numbers of IFCVs in commercial service locations. The generator used for this purpose in the project is an electrolyzer designed and manufactured by Teledyne Brown Engineering Energy Systems (TBEES), one of the project participants.

A number of potential applications are envisioned for a commercial IFCV, such as in landscaping, airports, warehouses, maintenance, and various other off-road uses.

FY 2000 Objectives and Rationale

The Phase II/III IFCV Project has a number of objectives to be accomplished during FY 2000. The first is to complete design, assembly, testing, and evaluation of the first prototype IFCV, designated Gator 1 (“Gator” is a trademark of Deere & Co., which manufactures and sells a line of small Gator vehicles for a variety of customer applications). The purpose of Gator 1 is not only to determine the validity of the IFCV concept, but also to provide feedback to improve the design of the more advanced second prototype.

The second major objective in FY 2000 is to design, build, and test Gator 2, which employs more advanced designs for the fuel cell power system and the metal hydride storage system. The purpose of testing and evaluating Gator 2 is to provide a basis for a reference design of a commercial vehicle.

The third major objective this year is to evaluate the readiness of the IFCV concept to enter the pre-commercialization phase of the long-term program. A number of factors will affect this

evaluation, such as design, performance, reliability, cost, market prospects, and business criteria important to the ultimate vehicle manufacturer. The last major objective, then, following the readiness determination is to decide the path forward beyond FY 2000 and to define the business strategy and plan for ultimate IFCV commercialization.

FY 2000 Tasks

The tasks in place for FY 2000 are designed to accomplish the project objectives. Two prototype vehicles, Gator 1 and Gator 2 are scheduled to be built and tested. Gator 1 represents an extension of the technology demonstrated when two previous vehicles were built and tested with fuel cell power systems and on-board pressurized gas storage. Gator 1 incorporates a more advanced fuel cell than the previous units as well as a solid state metal hydride storage system with inherent safety advantages. In turn, Gator 2 includes yet more advanced designs of both the fuel cell and the metal hydride storage units, and its scheduled completion is later than Gator 1 to permit incorporating design improvements suggested by experience with the first prototype.

Several tasks are designed to help evaluate the readiness of the IFCV concept for pre-commercialization. Results from the design and testing activities are major inputs. Both performance and reliability will be evaluated. The market evaluation of the prospects for a commercial IFCV constitutes an extremely important task, as does other business factors to be weighed by Deere & Co. The outcome of these considerations by Deere is expected to be definition of the corporate position, strategy, and long-term business plan for commercialization. When available, all these inputs will determine the recommendations for the path forward beyond FY 2000 that will be made by the project.

Progress and Accomplishments

Significant progress has been made this year. Assembly of Gator 1 was completed by Energy Partners and the vehicle successfully passed the checkout tests of all on-board systems. Refueling tests were run at the University of South Carolina-Center for Electrochemical Engineering (USC-CEE). Two types of tests were conducted. The first was on a sample of the metal hydride material (a La-Ni-Al compound) used in Gator 1 which was provided by WSRC in a test bed. The bed was connected to the TBEES electrolyzer and runs were made at different rates, pressures and temperatures to define the adsorbing/desorbing characteristics of the hydride material. The electrolyzer was subsequently connected to the metal hydride beds in Gator 1 to check refueling times. Gator 1 performance tests were conducted by USC-CEE to verify the output of the fuel cell, parasitic loads of auxiliary equipment (primarily the air compressor), overall vehicle performance, and benchmark the steady state computer model developed by USC-CEE.

Gator 1 was then transferred to York Technical College (York Tech) for reliability testing, which is still in progress. These tests, to determine range, operating time, speed, endurance and other characteristics have been extremely valuable in identifying problems for feedback into the Gator 2 design process. Many of these problems have been of a systems integration nature, very difficult to predict in advance, and this validated the original project plan to design and build the two prototypes sequentially rather than simultaneously. Some typical examples of problems encountered to date are:

- High compressor noise levels
- Overheating of the compressor motor during idling
- High fuel cell temperatures due to a faulty cooling water bypass valve
- Starting difficulties caused by excessive hydrogen purging
- Fuel cell shutdowns on low voltage, due to flooding

There has been considerable public and corporate exposure of Gator 1 this year. The IFCV concept was reviewed in a paper presented by Energy Partners in Switzerland (F. Barbir et. al., 1999). Additional information is contained in another Energy Partners paper scheduled for presentation in Las Vegas in July 2000 (F. Barbir et. al., 2000). Gator 1 was displayed in two technical exhibits. The first was by WSRC in Augusta, GA in February 2000 in connection with Savannah River Site Engineers Week. The second was by York Tech during the Earth Day celebration at Fort Mill, SC in April 2000, attended by both South Carolina Gov. Jim Hodges and U.S. Representative John Spratt from South Carolina. Also in April, Gator 1 was shipped to Aguila, AZ for demonstration to senior corporate and engineering management at an internal Deere & Co. review of developmental agricultural equipment. This latter event will undoubtedly prove to be of high importance in the management decisions within Deere regarding the future of the IFCV concept.

Much progress has also been made this fiscal year on Gator 2, assembly of which is in progress. The fuel cell and stack design and system configuration have been finalized. The fuel cell stack and related support systems are being built. A more advanced, higher capacity metal hydride material was selected and procurement of the material from the German company GfE is in process. This material, called Hydralloy C, is a Ti-Mn-V compound capable of storing 1.8% hydrogen by weight as opposed to about 1.3% for the material in Gator 1.

An IFCV market evaluation was undertaken by Deere & Co., which assembled an interdisciplinary team for that purpose. Results from this evaluation are expected to be available in the summer of 2000. An interim update of the potential unit cost of a commercial IFCV produced in large numbers was made in January 2000. This estimate showed that progress is being made toward the cost goal of about $5,000 per vehicle, but the overall cost is still higher than the goal. The cost estimate ranged from about $13,000 to $19,000 per vehicle depending on manufacturing volume. The projected costs of both the fuel cell and the metal hydride storage systems appear to be satisfactorily approaching their targets. The two areas most responsible for the current high cost estimate are the fuel cell support systems (electrical, humidification, etc.), which ranged from $5,000 to $9,000, and the base vehicle cost which was about $5,000. These areas are planned to be addressed in the ongoing market evaluation, particularly from the standpoint of potential cost reductions that might be achieved using manufacturing engineering techniques for the support system subassemblies. A subsequent update is planned based on Gator 2 performance.

Basic Design Requirements

Some of the more important design requirements for Gator 1 and Gator 2 are compared in Table 1.

Table 1. IFCV Design Requirements

	Gator 1	Gator 2
Power System:		
Fuel cell type	PEM	PEM
Nominal stack power	8 kw	8 kw
Fuel cell operating temperature	60 °C	60 °C
Fuel cell operating pressure	15 psig	8 psig
Air compressor type	Twin screw	Vane type
Nominal bus voltage	40 VDC	40 VDC
Environmental:		
Gaseous emissions	Zero	Zero
Noise	90 dBA	80 dBA
Storage System:		
Metal hydride material	La-Ni-Al	Ti-Mn-V
Discharge temp./press. @ 50% loading	43 °C/100 psig	57 °C/100 psig
H_2 storage capacity	4.3 lbs	4.0 lbs
Max. refueling time @ 300 psig	60 minutes	60 minutes

Status of Business Plan and Safety Review

The original business plan for the commercialization of an Industrial Fuel Cell Vehicle was incorporated in the Phase II/III Project proposal issued in January 1998. However, that plan was developed by a different vehicle manufacturer that participated in the Phase I Feasibility Study, thereby preceding Deere & Co.'s involvement in the project. Updating the plan is one of the principal goals of the project in FY 2000, and it depends on business decisions currently pending at Deere & Co. Management feedback is expected in the near future as a result of the Gator 1 demonstration in Arizona during April. Further, the results of the IFCV market evaluation, expected in the summer of 2000, will play a major role in shaping the management decision on pursuing the concept beyond 2000.

A preliminary safety review of the IFCV metal hydride system was proposed by WSRC as a task in FY 2000, but was not funded due to budget constraints. The present plan is to propose this task again for FY 2001.

Plans and Objectives for FY 2001

The overall objective of the project is to continue the development , validation, and commercialization of an IFCV with on-board metal hydride storage of hydrogen fuel. Initial results from the first prototype have been encouraging, problems notwithstanding, and a wide

variety of potential applications are envisioned. Specific objectives will be developed that appropriately reflect the corporate strategy now under consideration at Deere & Co. Commensurate with that decision, an important objective is to begin the transition from project management to a corporate management structure. The main technical goal remaining is to continue developing the power and hydrogen storage systems, together with the supporting infrastructure, to the point where commercialization appears viable with a satisfactory level of confidence.

As stated earlier, updating the business plan for IFCV commercialization to reflect Deere & Co.'s decisions and preferences is expected to be one of the major activities in FY 2001. Within the overall business plan a range of specific plans potentially exists, depending on corporate feedback. At one end, for example, the plan might be to simply continue reliability testing of Gator 2 to gain additional confidence on performance and endurance and perhaps to identify and implement minor improvements. A more comprehensive plan might be to develop a third generation prototype, or "Gator 3," designed for high volume manufacturing, perhaps for more rapid refueling, and with which to address safety issues including applicable codes and standards. A still more ambitious plan would be to target specific potential customers and applications and take steps toward small fleet testing of IFCVs. When the corporate response is available from Deere, the actual plan that will be created may contain elements of any or all of these possibilities. At that time, decisions will be made concerning the appropriate participants, schedule, budget and funding for continuation of the IFCV Project.

References

F. Barbir, M. Nadal, and M. Fuchs, 1999, "Fuel Cell Powered Utility Vehicles," in Proceedings Fuel Cells 1999 Conference, Lucerne, Switzerland.

F. Barbir, M. Nadal, and M. Fuchs, 2000, "Fuel Cell Powered Utility Vehicle with Metal Hydride Fuel Storage," in Proceedings GlobeEx 2000 Conference, Las Vegas, NV, July 23-28, 2000.