Power Technology Branch
Army Power Division
US Army RDECOM CERDEC C2D
Fort Belvoir, Virginia

APPT - TR – 08 – 01

History of Fuel Cell R&D at Fort Belvoir, Virginia

Walter G. Taschek

UNCLASSIFIED UNLIMITED DISTRIBUTION

Approved for public release; distribution is unlimited.

AMSRD-CER-C2-AP-PT

APPT - TR – 08 – 01 History of Fuel Cell R&D at Fort Belvoir, Virginia

HISTORY OF FUEL CELL R&D
AT FORT BELVOIR, VIRGINIA

By

Walter G. Taschek
US Army CERDEC
Army Power Division
Power Technology Branch

Army Power Division

GLOSSARY OF COMMON FUEL CELL TERMS

FUEL CELL	A device that converts chemical energy into electricity. Like a battery it contains an anode (+) and a cathode (-) separated by an electrolyte. Unlike a battery, fuel and oxidant are supplied externally so that continuous power can be maintained. Fuel, most commonly hydrogen derived from hydrocarbons, is supplied to the anode and oxidant, most commonly oxygen or air, is supplied to the cathode.
FUEL CELL STACK	A stack contains multiple fuel cells combined in electrical series or parallel arrangements sharing common supplies manifolds for fuel and oxidant. A stack can thus be designed for virtually any desired voltage and power output.
FUEL CELL (FC) CLASSIFICATIONS	Fuel Cells are commonly termed by the electrolyte used. There are many with widely varying properties and design considerations. The most common are described below.
PROTON EXCHANGE MEMBRANE (PEM) OR SOLID POLYMER ELECTROLYTE (SPE) FC	PEM fuel cells operate below 100 Cº. They are high performing and considered for wide variety of applications ranging from soldier power to automotive use. They are intolerant to carbon monoxide. SPE is the trademark of General Electric Corporation which founded SPE fuel cells during the GEMENI Space Program.
HIGH TEMPERATURE PEM FUEL CELL (HTPEMFC)	A membrane fuel cell that allows operation at temperatures over 100 C. Performance is lower than PEMFC but BOP is reduced. In many respects it behaves like a PAFC.
MOLTEN CARBONATE FUEL CELL (MCFC)	The MCFC operates at high temperature (`650 Cº) and requires a carbon dioxide and oxygen supply to the cathode. Consequently, these systems typically operate on clean hydrocarbon or on reformed hydrocarbon fuels. Spent fuels are burned with excess air and this stream is supplied to the cathodes. These systems have very high potential for efficient operation.
SOLID OXIDE FUEL CELL (SOFC)	The SOFC typically operates between 700 & 1000 Cº. It has considerable interest for a wide range of applications. It can utilize reformed hydrocarbons or clean hydrocarbon fuels directly. Because of it high operating temperature, it integrates well with fuel processing systems allowing very efficient operation.
PHOSPHORIC ACID FUEL CELL (PAFC)	The PAFC operates between 150 and 200 Cº. It can tolerate 2-3 % carbon monoxide in the fuel stream allowing use of reformed hydrocarbons without the need for substantial fuel clean up as required by the PEMFC. It can utilize air cooling without concern electrolyte control which greatly eases BOP issues. The PAFC is highly developed but has fallen out of favor because of high costs.
BALANCE OF PLANT (BOP)	BOP is a catchall to include all the components (heat exchangers, plumbing, electrical, pumps, fans, blowers, controllers, etc.) necessary to integrate a fuel cell stack and a fuel processor into a fuel cell power plant.
FUEL PROCESSOR/REFORMER	Fuel processors are devices which convert fuel into a reformed fuel suitable for fuel cell use. This typically involves converting a hydrocarbon fuel such as propane, natural gas, gasoline, diesel fuels, etc. into a hydrogen rich stream.
STEAM REFORMER	Reforms hydrocarbon fuels using steam typically at temperatures of 650 – 800 Cº. The process requires an external heat source but is capable of providing a rich hydrogen stream. Complex hydrocarbons and sulfur found in diesel fuel are very difficult to reform.
AUTOTHERMAL REFORMER (ATR)	Reforms hydrocarbon fuels using steam and air. An external heat source is not required. Fuel quality is not as good as a steam reformer but BOP is less.
PARTIAL OXIDATION (POX)	POX fuel processor utilizes air (or oxygen) to convert more difficult fuels. Catalytic processes operate usually over 800 Cº. Non catalytic processes must operate at higher temperature. The product is low in hydrogen content.
SHIFT REACTOR	Fuel processors for PEM, PAFC, and HTPEM Fuel Cells typically utilize a down stream shift reactor to enrich the hydrogen content of the reformed stream. Steam reacts with carbon monoxide to form additional hydrogen.

Army Power Division

History of Fuel Cell R&D at Fort Belvoir, Virginia

Prolog

Fuel cell R&D in the United States before 1958 was minimal but, with the advent of Sputnik, interest in fuel cells exploded. While NASA pursued fuel cells for space applications, and the US Navy for marine applications, US Army Labs at Fort Monmouth[1] and Fort Belvoir[2] pursued air breathing fuel cells for tactical and ground applications. By the mid 1960's, both Army Labs had strong efforts and each had staffs of over eight researchers directed at fuel cell technology. Programs were aimed at the respective missions of the two laboratories. Monmouth was primarily interested in battery chargers and man portable power sources to augment batteries. Belvoir was involved with mobile electric power, electric drive vehicles, and larger power sources in general. Circa 1967, the two Labs agreed that Monmouth would work on fuel cell power sources 500 watts and less while Belvoir would work on larger fuel cell power sources.

In the early 1960's, both laboratories pursued a wide range of fuel cell efforts. Both had strong in-house and contractual efforts with industry. Monmouth pursued programs with Engelhard for a hydrogen generator ammonia cracker[3], with Pratt & Whitney for a 500 watt power source, with Electrochimica for ammonia fuel cell[4], a direct sulfuric acid methanol fuel cell with Esso[5] (now Exxon), and an array of research programs.

Belvoir pursued hydrocarbon fuel cell research for electric drive[6] and portable applications. While the goal was to operate on logistic fuels[7], hydrazine fuel cells provided a means for vehicular electric drive and portable power research. Union Carbide, Allis Chalmers and Monsanto were early leaders on hydrazine technology. Several of key Belvoir sponsored programs follow.

Texas Instruments pursued partial oxidation of hydrocarbon fuels for their molten carbonate fuel cell (MCFC). The Institute of Gas Technology was also developing MCFC. A liquid hydrocarbon fueled reformer developed by Engelhard was sized to run with a 5 kVA alkaline fuel cell from Allis Chalmers[8]. General Electric conducted research on direct hydrocarbon fuel cells.

---

[1] Then the US Army Signal Research & Development Laboratories, Fort Monmouth, NJ. Now known as the US Army RDECOM, Army Power Division, Fort Monmouth

[2] Then the US Army Engineer Research & Development Laboratories, Fort Belvoir, VA. Now known as the US Army RDECOM, Army Power Division, Fort Belvoir

[3] Emerson, E.J. et al; "Hydrogen Generation For Fuel Cells", Final Report AD-462470, Sep 1964

[4] Eisenberg, M.; et al, "Direct Ammonia-Air Fuel Cell", Electrochimica Corp. AD-445865, Jun 1964

[5] Heath, C.E.; "Methanol Fuel Cells", Proceedings of the 18th Annual Power Sources Conference, May 1964

[6] Kirkland, T.G: Gaddy, L. Jr: Roesler, D. IEEE "Hydrocarbon Air Fuel Cell Electrical Propulsion Systems" IEEE Transactions 1965

[7] Logistic fuels are typically diesel and jet fuels commonly used by DOD acco. Specifications exist for those under widespread use by DOD

[8] Kirkland, T. G; Smoke, W.G., Jr. "5 kVA Hydrocarbon-Air Fuel Cell System", 19th Annual Power Sources Conference Proceedings, 1965

Army Power Division

Allis Chalmers, which demonstrated a fuel cell powered tractor in 1959, had an aggressive program in many areas. They actively pursued the Apollo fuel cell development contract. They lost out to Pratt & Whitney which had secured the patent rights to the Bacon cell[9]. This led to an exodus of several key Allis Chalmers personnel to Belvoir Labs starting in 1964.

Figure 1 Allis Chalmers 5kVA Fuel Cell

The author joined the Belvoir Systems Branch in January 1966 after 5 years with the Monmouth Fuel Cell Group. T. G. Kirkland headed the Systems Branch. Branch members were Ed Gillis, Marshal J. Armstrong, Dick Belt, Walt Taschek, Milt Jakola, Bob Chapman, Bill Carlton and Don Fetterman. The primary effort was fuel cells but Stirling and Rankine cycle, and non conventional electric power sources were part of the Branch's mission. The research group at Belvoir included Dr. Maxine Savitz, Hugh Barger, and Amos Coleman. Both groups formed the Electrochemical Division that had been under the direction of Dr. Galen Frysinger who resigned to accept a position at Fort Monmouth.

1965-1970

Alkaline Fuel Cell Programs

A 5 kW hydrocarbon reformer (Engelhard Industries) and a 5 kW alkaline fuel cell stack (Allis Chalmers) were being tested in-house. Fuels used were sulfur & lead-free versions of combat gasoline and JP-4. A strategy to operate on sulfur fuels was not available. The alkaline fuel cell was not tolerant to CO_2 consequently a pure hydrogen purifier and an air scrubber were required. Tests provided valuable insight to fuel cell power plant operation, controls, and electrical system requirements. It became clear that the alkaline electrolyte fuel cell used for Space applications was not suitable for ground power source applications. Removing CO_2 from processed fuel and air streams and controlling electrolyte concentration added considerable complexity to the system.

Molten Carbonate Fuel Cell Programs

Texas Instruments in previous efforts had established an innovative fuel cell stack design with cells connected in a unique electrical series/parallel arrangement[10].

Army Power Division

[9] United States Patent 4513066,Thin-film, high pressure fuel cell

[10] Truitt, J.K.; Gray, F.L. "Molten Carbonate Cell"; Chem. Eng. Prog. May 1966

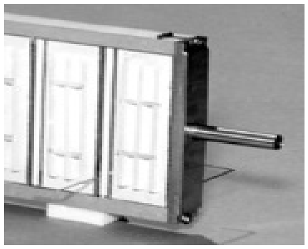

Figure 2 Texas Instruments MCFC Section

They also showed promising results on a catalytic partial oxidizer (CPOX) that could reform liquid hydrocarbons using only air. Belvoir started a 15 kW Tactical Power Source Development program and Texas Instruments won the competition. Operation on fuels JP-4 (a logistic fuel at that time) and lead-free combat gasoline was required. A 1 kW prototype was delivered following the first phase. The prototype included a MCFC, and a compact catalytic partial oxidation (CPOX) unit to convert lead-free gasoline to reformate, and Balance of Plant (BOP) required for operation.

Figure 3 Texas Instruments 1kW Hydrocarbon Fueled MCFC

The fuel, while lead-free, contained sulfur. The high temperature CPOX had no trouble processing gasoline. The use of a shift catalyst in the manifolds was found to enhance fuel cell performance. While originally delivering 1 kW net power, unacceptable power losses occurred after several hundred hours of operation.

The cause was attributed to electrolyte loss in the MCFC and poisoning by sulfur and other constituents. The unit toppled off a fork lift while being moved. The unit survived without performance loss**.** The fuel cell was donated to the Smithsonian and was fondly called the “Yellow Bird” [11] or the “600 lb. Canary”.

Concurrent work at the Institute of Gas Technology on a conventional molten carbonate fuel cell design provided mapping of fuel cell performance as a function of H_2, CO, concentration at the anode, O_2 & CO_2 concentration at the cathode, fuel and air utilization.[12]

Development efforts on MCFCs demonstrated the possibility of operating on logistic fuels and high efficiency potential[13]. However, low power density without promise of significant improvements was the primary reason for halting development for military application in the late 1960’s.

Hydrazine Fuel Cell Programs-M37 Truck and 300 Watt Power Unit

Hydrazine fuel electrochemically reacts directly at alkaline fuel cell anodes without any pretreatment. Hydrazine

---

[11] Truit, J. K., “15-KW Hydrocarbon-Air Fuel Cell Electric Power Plant Design”. Final Report, AD-827947, 1968.

[12] Marianowski, L.G., “JP-4 Fueled Molten Carbonate Fuel Cells”. AD -827948, 1967

[13] Taschek, W.G., “Evaluation of Molten Carbonate Fuel Cells”, Proceeding of the 23rd Annual Power Sources Conference, May 1969

hydrate was used because it is safer than neat (undiluted) hydrazine. Fuel was supplied via a circulating electrolyte through the anode. Many components used for alkaline fuel cells could be used by hydrazine fuel cells. This provided a means to quickly develop high performance systems for test bed evaluations for electric vehicles and for special purpose portable power sources. The 1967 photo shown in Figure 4 is a working hydrazine truck model that was widely used for demonstrations. I recall the headline "100 miles per Gallon" and indeed this car ran around a track for days at a time with low fuel consumption.

Figure 4, Hydrazine Fuel Cell Car shown with members of the Systems Branch. From left to right O. Fred Kezer, Ed Gillis, Don Fetterman, Dick Belt, John Orth (Chief), Oscar Cleaver (Technical Director), Walter Taschek, Bob Trader, & Marshall (Jack) Armstrong, 1967 Photo

Ed Gillis and Lon Gaddy led a team from the Electrotechnology Department, Power Equipment Laboratory, US Army engineer Research & Development laboratories refitting a 3/4 ton M-37 Truck with hydrazine fuel cells and an electric drive system. Ed Gillis designed the hydrazine fuel cell stacks that were made by Monsanto R&D and was responsible for the system design. Lon Gaddy was responsible for the electrical system which was supplied by General Electric. George Sisk was involved with the installation and drove the vehicle. The photo shows three of the four 5 kVA stacks mounted in the vehicle.

The test vehicle along with a convoy of electric vehicles made a seven-mile trip through the streets of Washington, DC to the Capitol where they were inspected by members of the Senate Committee on Commerce and the Subcommittee on Air and Water Pollution of the Committee on Public Works.

Figure 5 M37 Truck with Hydrazine Fuel Cell Modules

Details of the M-37 Fuel Cell Vehicle were published in news releases from the Information Office, US Army Engineer R&D Laboratories; Monsanto Research Corporation; and General Electric[14].

The M-37 was tested at Belvoir's Engineer Proving Ground. George Sisk, who drove the truck for many tests and demonstrations, iterated that the fuel cell truck outperformed its conventional counterpart. Electric drive options were

[14] A. Boldgett, General Electric Press Release Monday, P.M. March 13, 1967

considered for PATRIOT but not selected because the technology was deemed not ready.

An Urgent need for silent power sources arose in Vietnam. The North Vietnamese & Viet Cong could easily locate American Units by the sound of noisy generator sets and the perimeter was too large to defend by US Forces.

In response to this need, Belvoir developed prototype units at Monsanto and Union Carbide. Initial success led to aggressive development of 300 Watt units with Union Carbide the prime contractor. Environmental and ruggedness heat/cold/dust/impact testing was performed. Units met rigid military acoustic signature requirements. It was the first fuel cell with a Federal Stock Number (FSN). A packaged fuel/electrolyte supply system featuring polyethylene 1 gallon fuel and electrolyte milk carton type containers was developed and approved for use. In all, 30 units were produced and delivered to the field.

The modular construction allowed untrained GI's to replace failed components and reassemble with screw driver and pliers. It was the first fuel cell to be used in multiple combat situations - from drift boats in the Delta to fire support bases, etc.

Ed Gillis was architect and technical leader of the program. Ted Perkins provided technical support for units in Viet Nam. All 30 units were used, then when failed were cannibalized for parts to keep others running. Biggest problem, recalled by John Orth, was caustic creep on the encapsulated printed circuit boards killing the fuel control or voltage regulation. In general, the reviews were good from the troops. Problems identified were correctable but with the war winding down, so did funding and interest in a special fuel power source. Attention turned to logistic fueled systems.

General Electric 1.5 kW Circulating Sulfuric Acid Fuel Cell with an integrated Steam Reformer.

In the late 1960's GE developed a 1.5 kW prototype for Belvoir that could operate on clean hydrocarbon fuel. The fuel cell featured an ion exchange membrane electrolyte with a circulating sulfuric acid electrolyte system to manage temperature and membrane conductivity. The reformer was a state-of-art system that performed well on clean hydrocarbons. A purifier was used to provide pure hydrogen to the fuel cell. Testing showed reasonable performance but electrolyte leakage problems ensued. While the approach was reasonable in size and weight, a reasonable strategy for managing sulfur and other fuel impurities did not exist.

Figure 6 GE 1.5 kW Hydrocarbon Fuel Cell

Army Power Division

AD HOC Study of Silent Power Sources

The need for a quiet tactical family of power sources were identified as most important in the 100 watts thru 15 kW power range. It was clear from the Viet Nam experience that technologies were not available. To address this need, Don Looft, Chief, Electrotechnology Laboratory, US Army Mobility Equipment Command, charged Messers. Kirkland, Jokl, and Belt to perform an ad-hoc silent power study. The group gathered input from in-house subject matter experts and industry and wrote a report[15] characterizing the salient characteristics of candidate generators. The study was expanded in 1966-67 to establish the best approaches for development.

Quiet operation was considered a premium, particularly for the lower power range. Generator sets in Vietnam were too noisy and made it easy for the enemy to locate US troops without being detected.

Results were briefed to Subcommittee on Antitrust and Monopoly, United States Senate. The "Statement Concerning Department of Defense Portable Electric Power Plants" presented Mr. Looft. The outcome of this study and briefings to Congress resulted in a formal requirement for "Silent Lightweight Electrical Energy Plants" SLEEP. Logistic fueled fuel cells and Rankine Cycle Engines were recommended for development at the 1.5, 3.0 & 5 kW ratings. A 10 kW turbo-alternator was selected for the 10 kW rating. The Silent Power Survey was published in 1969[16]

Phosphoric Acid Fuel Cells (PAFC)

Because of problems with electrolyte control, thermal management, and carbon dioxide rejection, alternatives to more developed alkaline electrolyte fuel cell were pursued. PAFC eased all of these problems but baseline technology was in its infancy. Belvoir supported initial work at Engelhard, Onan, American Cyanamid, and in-house. Performance was not as high as alkaline fuel cells but PAFCs were CO_2 rejecting, could operate on reformed hydrocarbons containing CO, and could operate with excess air to control temperature without concern for electrolyte control. Balance of Plant (BOP) benefits more than outweighed lower PAFC performance. By the late 1960s, PAFCs became the standard bearer for R&D work on SLEEP fuel cell development.

Logistic Fuel Processor Hydrogen Generator

Some success was achieved with earlier fuel processors based on steam reforming or partial oxidation. Clean hydrocarbon fuels could be steam reformed but logistic fuels (JP-4 & Combat Gasoline) containing sulfur and lead could not be reformed. Partial oxidation demonstrated some potential to operate on logistic fuels but fuel quality was too poor for PAFC's. High temperature fuel cells were not suited to

[15] A. L. Jokl, T. G. Kirkland,&R.N. Belt, "Report on AD HOC Study of Silent Power Sources, 15 Feb. 1965

[16] Silent Electric Power Generators for Tactical Applications Special Study", Coordinated by Richard N. Belt, Report 1954, U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA, June 1969

Army Power Division

the demands for high power density and rapid start up required by tactical sets.

To address this deficiency, Belvoir initiated R&D on regenerative thermal cracking hydrogen generators circa 1968. Regenerative thermal cracking involved heating logistic fuel to high temperatures (+1000C) over a catalyst substrate. The theory was that relatively pure hydrogen could be produced leaving the carbon soot behind on the substrate. This endothermic process would cool the reactor. After a period of several minutes, the fuel would be shut off and air introduced to burn out the soot and reheat the reactor.

Several preliminary contracts were initiated with Pratt & Whitney, Engelhard, and the Institute of Gas Technology. Also, supporting investigations were conducted in-house. Ed Starkovich and Mike Callahan, using gas chromatography, optimized cracking and regeneration cycle times[17]. The result was that the regenerative thermal cracking process was validated. The process required no water and high quality hydrogen was produced with most of the sulfur remaining in the bed. Remaining sulfur was easily removed in an adsorption filter. The air burn-out regeneration step provided sufficient energy to reheat the reactor for the next cracking cycle. Efficiency was much lower than steam reforming; however, at that time, efficiency was far less a factor because fuel was readily available on the battlefield but water was not.

[17] Callahan, M, Starkovich E., "Catalytic Pryolysis: Hydrogen from Liquid Hydrocarbon Fuels". Proceedings 25th Annual Power Sources Conference, May 1972

SLEEP – Logistic Fuel Cell Development 1969-1974

The "Silent, Electric Power Generators for Tactical Applications Special Study", concluded for the mid term (10-20 years), the phosphoric acid fuel cell (PAFC) was favored at low power applications (up to 3 kW) and the silenced Brayton Cycle was favored at the higher power levels. The decision was reached to abandon work on high temperature and alkaline fuel cells. For the near term (2-5 years), the Closed Rankine Cycle technology was favored at the lower power ratings.

A further recommendation of the Study was to pursue improved power conversion and control using solid state power conditioning which was in its infancy for use in the Army. Carbon pile and relay type voltage regulators were being replaced by solid state devices in conventional generator sets. Increased capability of solid state switches and integrated circuits were regularly being seen in real application. However, the challenge of regulating and converting the fuel cell dc voltage to regulated ac output was a long way from being met.

A major program was initiated in 1969 to develop a 1.5 kW fuel cell based on regenerative thermal cracking and a cathode air cooled PAFC[18]. The program comprised two phases with a one year design effort and demonstration of a breadboard system. The second phase was 18 months resulting in Advanced Development of a 1.5 kW system with delivery of four units for

[18] Gillis, E. A. Kezer, O. F, Taschek, W. G, "Open Cycle Hydrocarbon-Air Fuel Cell Power Plant", Army Science Conference, June 1970.

Army Power Division

test and evaluation. Phase I contacts were awarded to United Aircraft (now UTC) and Engelhard. Breadboard tests confirmed that the PAFC could be integrated with the regenerative thermal cracker and gave enough confidence to proceed to Phase II. It also pointed out the necessity to improve start up time, automate controls particularly associated with switching streams into and out of the thermal cracker. Power conversion and management were also identified as important issues.

UTC was the successful bidder for Phase II. Considerable progress was made with the PAFC stacks, regenerative thermal cracking, controls and balance of plant (BOP). Reactor designs were modeled in-house to see if start up times could be substantially reduced from the 40 minutes demonstrated on breadboard units. An alternate design was found to have the potential reduce start up to 15 minutes[19]. Valves required to switch thermal cracking beds, particularly on the downstream side had fouling problems which required unacceptable down time for maintenance. Solutions to this problem were not on hand and the urgency of the requirement diminished with the downturn of the Vietnam conflict. Low efficiency was a contributing factor in not continuing development. In 1974, work ceased on regenerative thermal cracking but not on PAFC.

SLEEP Methanol Fuel Cell (MFC) Development 1973-1984

The need continued for Silent Power plants. Alternative approaches were under way for silent generator sets but it was clear they could not meet the non-detectability requirement at 100 meters. The program to develop a closed Rankine Cycle generator had ended several years earlier when the Prime Contractor halted development.

Belvoir initiated an in-house effort to develop low temperature methanol fuel reformers starting about 1973. Stan Kurpit, with funding from EPA, showed that a low temperature reformer using a shift catalyst would reform a 67% methanol water solution at temperatures of about 250 C to a hydrogen rich stream. Further, this stream could be used directly by a PAFC without further pretreatment. While methanol was not a logistic fuel it was in the Army Supply System. Provisional authority was given to initiate an Advanced Development Program.

Over the next several years, major efforts were contracted with UTC and Energy Research Corporation (ERC) centered on 1.5 kW and 3 kW systems. A great deal was learned regarding power conditioning and the need for microprocessor controls required to obtain adequate power quality and transient behavior.

The system featured low temperature reforming of a 67% methanol in water solution (1:3 H_2O:CH_3OH molar ratio). The high quality product gas was cooled and utilized by the PAFC. Cathode air cooling was utilized by both UTC and ERC. Recycle of a portion of the air enabled preheat of the air stream entering the fuel cell. Heat exchange of the spent air stream and burning of the

[19] Taschek, W., Jacobs, R., "A Thermal Analysis of a Fuel Cell Power Plant Start-Up", US Army Mobility Equipment Command Technical Report, 9 February 1973

Army Power Division

anode exhaust provided the energy needed to vaporize and reform the fuel.

By 1979 advances were sufficient to justify entering into an Engineering Development Program. The SLEEP Required Operational Capability (ROC) was coordinated with the Army community and the go ahead was given to develop the 1.5 kW power plant. In 1978, a “Formal Validation In-Process Review on Silent Lightweight Electric Energy Plants (SLEEP) (1.5 kW)” was held at the US Mobility Equipment Research & Development Command, Fort Belvoir VA. The IPR position recommended Full Scale Engineering Development (ED) for the 1.5 kW Methanol Fuel Cell. A Cost & Operational Effectiveness Assessment (COEA) for the methanol fuel cell family of 1.5, 3, & 5 kW ratings was developed.

UTC won the contract for ED of the 1.5 kW and later ERC won awards for Advanced Development of the 3 & 5 kW methanol PAFC power plants. Over the next few years, a military specification for methanol water fuel was established that was a 58% methanol by weight in water. Development continued in earnest. By late 1981, the first 1.5 kW ED unit was fabricated and rushed to Fort Leavenworth for demonstration at the C4I conference.

The 1.5 kW program was set back temporarily when failures occurred to the reformer. A reformer redesign corrected the problem and the program got back on track. Meanwhile the work was continuing at a slower, lower funded pace on the 3 & 5 kW Advanced Development Units.

By 1982 early Engineering Development units were delivered and subjected to a variety of operational and environmental tests. The Chief of the Test & Evaluation Branch reported that the PAFC units performed admirably. Few problems required correction which is often not the case with a new power plant.

Then the Department of Army established the One Fuel Forward Policy. This marked the beginning of the end for the 1.5 kW Methanol Fuel Cell and Fuel Cell R&D at Fort Belvoir. On 30 Nov. 1983, the DOD Project Manager-Mobile Electric Power forwarded a letter to US Army Troop Support Command stating: “Unless otherwise directed, I intend to cease funding the 1.5 MFC program and apply the funds to other tasks”. The door was left open to continue Tech Base investigations. Further development on the 1.5 KW Engineering Development Programs was terminated but in-house environmental and operational tests continued to completion.

Army Power Division

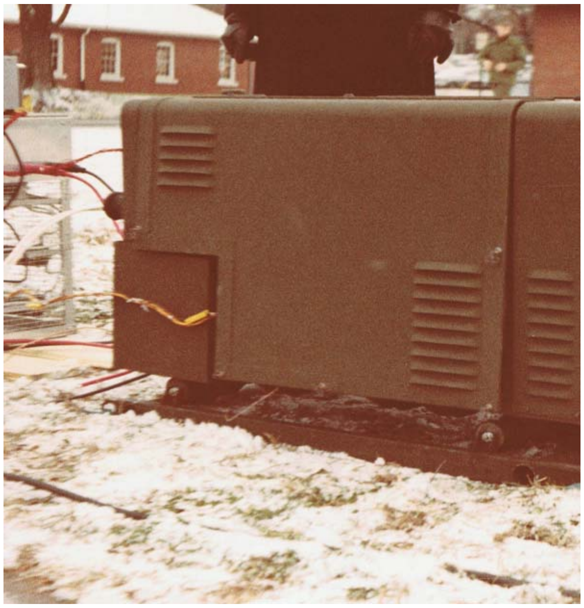

Figure 7 -1.5 KW Methanol Fuel Cell at Fort Leavenworth, KS, 1981

A summary of the final specifications is listed below:

Nomenclature And Specifications

Power Units, Fuel Cell: 1.5 Kilowatts, Methanol Fueled, 60 Hertz and 28 Volt Direct Current.

NSN's:
(AC) 6116-01-112-2926 (Model MEP031A)
(DC) 6116-01-106-1900 (Model MEP030A)

Startup:
Full Power Obtained in Less Than 15 Minutes at All Environmental Conditions at Ambient Temperatures between 125°F and −25°F, Using On Board Start-Up Battery between −25°F to −65°F, Auxiliary Battery Required.

Fuel:
A Pre-mix Containing 58% By Weight Methyl Alcohol (Federal Specification O-M-232E) and the Balance Being Water.

Fuel Consumption:
0.55 Gallons Pre-mix Per Hour At Full Load.
0.15 Gallons Pre-mix Per Hour At 15% Load.

Weight: 265 Pounds

Noise: Inaudible at 100 Meters

Figure 8 - 1.5 kW MFC Specifications

Work continued on 3& 5 kW programs with emphasis on obtaining neat methanol systems. In-house efforts centered on process design of alternate waterless approaches. PSI developed a model for Belvoir suited for PC use that facilitated fuel cell process analysis. At this point, PCs were in their infancy. Requests to obtain a PC were denied by the computer center because they stated the program could be run on main frame hardware. (The modeling effort was caught in the PC versus Mainframe competition. The merits of the PC were not appreciated at that time.) Repeated attempts to run the program on the main frame failed. Finally, authority was given to purchase a PC. A state of the art IBM PC XT with a 10 mb hard drive was obtained. Terry DuBois. Reggie Tyler, and the author developed and optimized system concepts using the computer program. Encouraging results were achieved and published. [20] [21] Encouraging results were also obtained by ERC. ERC tested variations of recycling a portion of the air cathode stream or using air partial oxidation that were successful in producing a suitable fuel for the PAFC. The conventional approach of recovering water from exhaust streams and mixing with methanol proved feasible but too cumbersome for portable applications.

PEM Fuel Cell Development 1971 – 1984

Concurrent with SLEEP fuel cell programs a smaller effort aimed at soldier portable power sources was

---

[20] T. DuBois, et. Al, "Computer Analysis of Integrated Neat Methanol Fuel Processing Techniques", 1985 Fuel Cell Seminar Proceedings.

[21] R. Tyler, et al, "Parametric Analysis of Three 5 kW Neat Methanol Fuel Cell Power Plant Configurations", Proceedings of the 20th IECEC Meeting, 1985

initiated 1971. Small single or dual cell PAFC models directly fueled with Calcium Hydride were fabricated for demonstration purposes. Calcium Hydride, CaH_2, adjacent to the anode would react with water vapor to form hydrogen which was used by the PAFC. The devices operated at ambient temperatures. These small cells typically would operate for over one month on a continuous basis powering a low wattage fan. Ed Gillis crafted several of these and they were used for demonstration purposes. One was made out of an Esquire shoe polish can.

The Project Manager for the Remotely Monitored Battlefield Sensor System (REMBASS) was highly impressed with this capability and asked Belvoir to address a power source for the Exray radio. This radio collected information from a variety of sensors and relayed them from an unmanned site. The power requirement was reported at 2 watts. We felt this was a reasonable application for the low power calcium hydride systems and accepted a modest program to develop the power source. Later it was found that electrical requirements were much higher. A higher power hybrid approach featuring a PAFC, a Calcium hydride fuel cartridge, a nickel cadmium battery for start up, and a small blower to circulate anode gas through the fuel cartridge was designed and fabricated in-house.

Figure 9: Esquire H3PO4 Fuel Cell

This unit worked well on laboratory bench tests and proved to have high energy density for long missions. However, when exposed to sudden ambient temperature drops, power level dropped temporarily probably due to the lower water vapor pressure of the phosphoric acid electrolyte. Power would restore after a period of about 30 minutes as the electrolyte equilibrated at the lower temperature. During the field tests at Fort Bragg, the electronics did not allow for automatic restart when voltage/power was restored. This meant an operator was required to flip a switch to restore the relay. While a fix would have been straight forward, not enough time remained for successful completion of the field test.

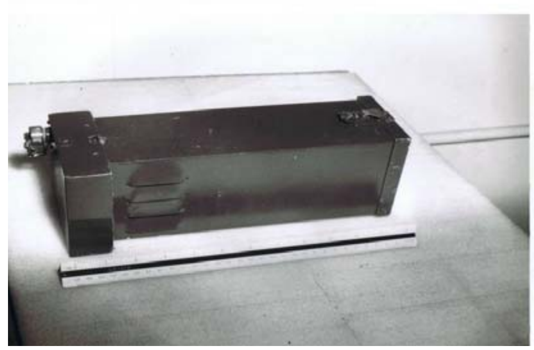
Figure 10 EXRAY Power Source

Army Power Division

While the low temperature Calcium Hydride fuel cell was intriguing, it was recognized that it would only be useful for low power requirements, i.e. less than 15 watts or so. Higher power options were reviewed. Of interest was GE's Solid Polymer Electrolyte (SPE) fuel cell.

An experimental hydrogen-air SPE fuel cell was purchased from General Electric and tested. The SPE was found to have excellent performance but the air breathing cathode was sensitive to dry out when operated at high current densities with subsequent performance loss. This performance loss could be restored with hydration of the SPE. At that time, GE was the only company working with SPE. They developed an earlier version for the Gemini fuel cell. Their primary focus was for Space Applications. An RFP was issued for small SPE fuel cell stack with a nominal output of 6 VDC at 3 watts. This was approximately equivalent in power and output to lantern batteries. Engelhard won the award and successfully delivered approximately 20 stacks.

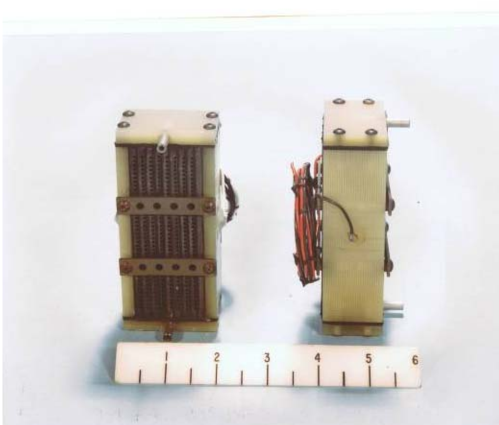

Figure 11 Three Watt, 6V SPE Fuel Cell Stack

In-house efforts focused on small water activated hydrogen generators using chemical hydride fuels. Stacks and in-house miniature hydrogen generators were integrated into portable Landing Lights.

The hydrogen generator[22], while having some of the same principals of a Kipp generator, utilized a porous Teflon barrier to separate the liquid water from Calcium Hydride fuel. This allowed better control for low power applications. Additionally, the unit could be shut down for long periods without loss of fuel. The Kipp Generator, on the other hand, could not be shut down without loss of fuel. Further, the reaction product was more difficult to disposal of the reaction product was difficult.

Landing Light power sources were developed based on this principal and 3 watt, 6 VDC SPE fuel cell stacks. The Landing Light demonstrations fostered interest in both SPE fuel cells and chemical hydrides. Testing of fuel cell powered Landing Lights routinely showed the capability of delivering 500 watt hours per pound of fuel and per pound of water.

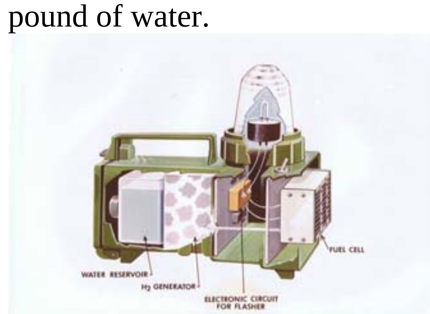

Figure 12 Fuel Cell Powered Landing Light

Engelhard was awarded a series of small contracts to improve fuel cell life and

Power Division

[22]Taschek, W.G., US Patent # 4,155,712, "Miniature Hydrogen Generator" May 1979

performance and develop cell stacks resistant to freeze thaw and dry out. In-house work continued on Miniature Hydrogen Generator Development and SPE fuel cells. [23]

It became apparent that SPE fuel cells could offer potential application for missions requiring more power than was feasible using batteries. They also had potential for power levels too low for MIL Standard Engine Generators. Power capability of various military and commercial batteries was examined. The best batteries tended to fall on the lower line of the Gray Area Plot. The break in the curve represents rechargeable batteries to the left and primary to the right.

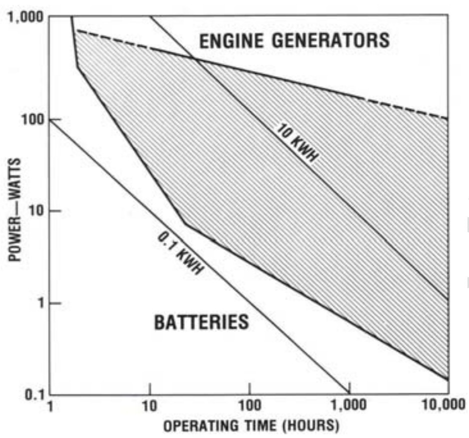

Figure 13 Power Source Gray Area

Correspondingly, the 1.5 kW gasoline generator set was the smallest standard generator at that time. The upper curve is the author's estimation of the minimum WH level practical for using generators. In between was labeled the "Gray Area" were no practical power sources existed.

Over the next several years, prototype 30 watt SPE fuel cells were developed and tested outdoors and in an environmental chamber[24]. Dry out problems were avoided by operating the stack in an air breathing mode with restricted air access. This required operating at lower current density. Excess water produced by the fuel cell reaction simply collected on the bottom and wicks provided moisture to cells during dry periods. About this time, it was required to halt use of the name SPE which was a GE trademark. To honor GE's trademark the term PEM became accepted standing for either Proton Exchange Membranes or Polymer Electrolyte Membranes.

A dialogue was established with the Signal Center at Fort Gordon, GA. It was found that a draft Letter of Agreement (LOA) existed but no current action was being taken. The LOA became titled as SIESTA (Silent Energy Sources for Tactical Applications) Briefings were conducted on the PEM power source capability and interest was resurrected. The initial approach was to establish a family of three power sources with power outputs of 10, 50 & 100 watts with a variety of standardized fuel packages for use with any of the power sources. This would enable the ability to address a wide range of missions. Eventually, it was decided to incorporate the SIESTA into SLEEP.

A program was initiated with GE to examine PEM potential for higher power

[23] Taschek, W.G. "High Energy Metal Hydride Fuel Cell Power Source", 1978 Army Science Conference, AD A056491

[24] O. J. Adlhart, "Environmental Testing of SPE Fuel Cell Assemblies" Proceeding of the 1980 Power Sources Conference. Work performed under Contract DAAK 70-77-C022.

Army Power Division

air breathing applications[25]. Tolerance to CO, current density, fuel utilization, cell voltage, operating temperature, air humidity, and ability to maintain moisture balance under condition performance as a function of CO content were all tested. In general, the outcome showed very high performance potential with CO free fuel. Even small amounts of CO reduced performance and this was much more magnified as the temperature was reduced. The conclusion was that while it had excellent power density it could not operate directly on reformed methanol. Future efforts with PEM fuel cells then focused only on smaller power sources.

The Defence Research Establishment (DRE) of Canada stated a requirement for a radio repeater requiring 30 watts. Primary zinc-air batteries were unsatisfactory and they expressed interested in Belvoir's PEM fuel cell.

First, a 3 watt PEM stack was provided to DRE for test. Belvoir also provided DRE with an estimate for a 30 watt fuel cell for an arctic radio repeater power source application. In a letter dated 3 March 1977, DRE offered to participate with Belvoir in the development of a system. Subsequently, Belvoir revised the contract with Engelhard to provide additional units to DRE. Environmental tests were conducted by DRE on insulated fuel cells. One 30 watt unit operated for more than 4000 hours. [26]

[25] "Evaluation and Optimization of Solid Polymer Electrolyte (SPE) Fuel Cells", Final Technical Report, Contract DAAK 70-77-C-0128, May 1978.

[26] E.A. Criddle et al, "Small SPE Fuel Cells for Arctic Applications", 29th Power Sources Conference, 1980

Eventually, with encouragement from DRE, Ballard stepped into the PEM fuel development and today they are recognized as the World's PEM fuel cell leader.

In 1983 The 1.5 kW MFC program was terminated and in house personnel were redirected to neat methanol approaches. Also, Belvoir accepted a large scale program from the Air Force to develop logistic fuel cells for remote sites. With the loss of the 1.5kW MFC program, the Sleep ROC which had incorporated SIESTA was essentially abandoned. In 1984, all work on PEM fuel cells ended at Fort Belvoir.

Hybrid (Fuel Cell-Battery) Vehicles

The Belvoir R&D Center pursued the development of a variety of electric vehicle drives for military applications. As a result, the Material Handling Equipment (MHE) Group became interested in a power source that would solve some of their endurance problems. Battery powered lift trucks could not perform, for a full shift, aggressive tasks such as ramping ammunition pallets into and out of storage magazines.

MHE power requirements are very broad ranging from ramping while loaded to driving while empty. These extremes would require the fuel cell, if sized for peak load, to be larger than needed for normal use. A hybrid approach with the fuel cell in parallel to a battery was selected whereby the battery provided peak power while the fuel cell provided power for operation and recharge of batteries.

Extensive testing was performed to establish detailed power requirements of

Army Power Division

the fork lift, and power delivery of the fuel cell and battery combinations[27]. Effects of deep discharge effects on batteries were also evaluated.

A hybrid lift truck was designed, built, and tested by Belvoir personnel. This lift truck used an existing 4000 lb. capacity unit. The lead-acid traction battery was removed and replaced with 4 kW of fuel cells. These were four 1 kW PAFC units in parallel supplied by Engelhard Industries. In parallel, two series strings of 12 V automotive (SLI) batteries were installed. The high rate capabilities of these readily supported the power demands of the lift truck during ramping. The lift truck was “very high performance” it could spin its tires going up a steep ramp. The fuel cells were fueled by hydrogen from compressed gas A--cylinders. Additional weights were added as well since the fuel cell-battery-fuel tanks were lighter than the removed battery. The counter-weight was needed for stability during lifting. The hybrid lift truck was operated at Belvoir for a period of time to determine if any problems were apparent. No changes to the performance of the batteries were observed during testing. [28]

Data was accumulated in real time with a multi-channel tape recorder (and later digitized and analyzed). Precise measurements of energy flow were obtained. The efficiency of energy flow through the battery was surprisingly high - much higher than normally measured under standard charge-discharge conditions. This phenomenon results from the unusual character of hybrid operation. A brief discharge period is followed immediately by charging and before significant diffusion of the reactants in the electrolyte has occurred resulting in a reduction in the charge energy required. Similarly the following discharge occurs prior to diffusion within the electrolyte and thus more energy is obtained than normal.

The hybrid lift truck was demonstrated to most of the major U.S. lift truck manufacturers. A high level of interest was obtained but unfortunately the major fuel cell developers were unable to deliver a satisfactory product at an acceptable cost.

Figure 14 Hybrid Fuel Cell Battery Fork Lift Truck; Ed Dowgiallo briefing Congressman Mike McCormick,

Remote Site Fuel Cell Development Program 1984-1987

The US Air Force was charged by Congress under Senate Appropriation Bills 97-580 and 98-292 to design, test, evaluate and develop fuel cell power plants for demonstration in Alaska. A Memorandum of Understanding (MOU PO-84-06) was established 16 August 1984. Under the MOU, the Air Force

[27] Dowgiallo, E. J., “A Fuel Cell Battery Power Source for Electric Vehicles”, The Fifth International Electric Vehicle Symposium, AD782407(E). Oct 1978

[28] O’Sullivan, J. B., Dowgiallo, E. J., et al,“Hybrid Power Source for Material Handling Equipment”, 10th Energy Conversion Engineering Conference Proceedings, Paper 759037, 1975

Army Power Division

Wright Aeronautical Laboratories (AFWAL) provided program management and Belvoir RDE Center was responsible for technical execution. A five year program plan was developed and approved by the Air Force. The tasks are discussed below.

<u>40 kW Power Plant Demonstration</u>

In 1984 many on-site 40 kW PAFC units were being demonstrated at commercial facilities and a few more at DOD facilities. UTC with support by the Gas Research Institute (GRI) and the Department of Energy (DOE) developed and fabricated the units. Under the Remote Site Fuel Cell Program, funds for a one year demonstration were planned for Alaska. Other DOD demonstrations were planned including one at Fort Belvoir and another at Wright Patterson AFB. The 40 kW units typically used natural gas. High efficiency was achieved particularly when one could utilize waste heat. Lower heating value efficiencies of 40% electrical and 80% thermal plus electrical were demonstrated.

Figure 15 - 40 kW Installed at Elmendorf AFB in Shelter to Protect Test Equipment

The 40-kW fuel cell was shipped by barge to Anchorage. While docking, the barge slammed into the pier causing considerable damage to the barge and pier. While no outward damage was noted to the power plant, all the shock sensors on the fuel cell had tripped. Problems with electrical controls and sensors slowed installation but these were eventually overcome.

Once in operation, it ran for over 8000 hours with maintenance performed by personnel under the direction of Garry Lynch at the Elmendorf AFB power plant. This was certainly one of the best in the 40-kW fleet. SAIC performed site preparation and provided a data acquisition system which allowed monitoring of the fuel cell at UTC's facility and also at Fort Belvoir. This remote capability enabled a fix to a problem before it became serious.

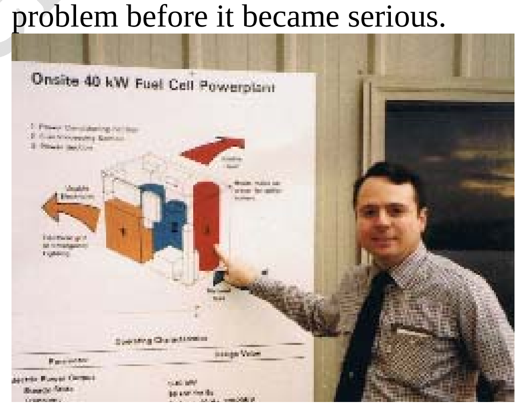

Figure 16 Garry Lynch Briefing the 40 kW at Elmendorf AFB, Alaska

<u>Fuel Conditioning Process Demonstration</u>

Technology to reform logistic fuels was lacking. As a first order of business, statements of work and contracts were awarded for early process demonstration of three approaches.

Contracts were awarded to Energy Research Corporation, International Fuel

Power Division

Cells and R.M Parsons Company in late 1985. The aim was to establish a process that had the best prospect for the planned 100 kW demonstration. ERC and their sub contractor Haldor Topsoe were successful in demonstrating a suitable approach based on hydro-desulphurization followed by conventional steam reforming and water gas shift.[29] This gave confidence that the fuel processing approach was suitable for the 100 kW development and planned demonstration. [30].

<u>Site Evaluation Requirements Definition and Life Cycle Cost Assessment</u>

In 1984, Remote radar sites in Alaska were newly modernized, highly energy efficient structures, requiring only a staff of about five to provide maintenance and keep the runway clear for supplies. The site shown consists of two connected geodesic domes of approximately 100 feet diameter. One dome included the power plant, and maintenance facility. The other included the kitchen, dining room and lodging facilities. All radar operations and controls had been moved to Anchorage. The sites used four diesel generator sets of 175 or 250 kW ratings.

Figure 17 Modern Air Force Remote Site in Alaska

[29] 21st Intersociety Energy Conversion Engineering Conference, San Diego, CA 1896

[30] Some eight years later, Haldor Topsoe was awarded a contract by DARPA to develop this approach for demonstrations with Westinghouse's SOFC and Energy Research's MCFC

Typically two generators operated at half load, a third generator was on hot stand-by while maintenance was performed on the fourth. A glycol coolant loop was circulated through the three generators and directed through heat exchangers which heated a secondary loop that provided heat for hot water or space heating. Boilers were also available to provide heat during periods of extreme cold.

Previously, these sites required a staff of over 100. Some sites had access only by air transportation requiring a huge operation to keep facilities supplied with goods, fuel and personnel.

SAIC was contracted to perform an energy audit at the Fort Yukon site. Instrumentation was installed on the diesel power plant, piping and heat exchangers to monitor power, fuel flow, temperatures, flow rate of streams into and out of the generators and heat exchangers. A remote data acquisition system was developed that collected, down loaded and sent data to SAIC offices in La Jolla, California for analysis. A preliminary life cycle cost assessment regarding energy usage and power plants was also conducted. These results are discussed in the final technical report.[31]

<u>Remote Site Fuel Cell Power Plant Development.</u>

The plan with input from the previous tasks called for development of three prototype 100 kW logistic fuel cell power plants to be installed at a selected

[31] R. Taylor et al., "Analysis of Fuel Cell Power Plants for DOD Applications", Contract DAAK70-64-84-D0053, April 1987.

Power Division

site for demonstration and test in 1991. The Procurement Acquisition Plan was approved on 19 February 1986. A comprehensive RFP was issued. Proposals were reviewed and a suitable candidate established.

In 1986, Belvoir's Technical Director decided to end fuel cell R&D work stating that other projects had greater priorities for personnel and funding. The Air Force decided not to go ahead with the development citing lack of available personnel as a principal reason. Projects were shut down and personnel were reassigned to other Branches. By early 1987, all work on fuel cells at Fort Belvoir ceased. The 40 kW demonstration at Elmendorf AFB continued and turned out to be one of the best of the 40 kW fleet.

Electrochemical Division Concepts Branch Research, 1966-1986

The Electrochemical Division Concepts Group conducted a wide variety of electrochemical investigations to improve electrode structure and optimize catalyst loadings for a wide array of fuel cell and battery technologies

In the early 1970's a search for an acid electrolyte which could replace phosphoric acid in a military fuel cell system was initiated. The work was undertaken under Contract No. DAAK-72-C-0084 with American University, Washington, DC[32]. Phosphoric Acid had shown some features which limited its use as an electrolyte including, adsorption of anions, cycling of the potential during operation with hydrocarbons, and low solubilities of oxygen and propane.

Trifluoromethanesulfonic acid monohydrate. (TFMSA) was found to be electrochemically stable up to 135C for long periods of time. In addition, the limiting current density for the oxidation of propane at 135C was approximately 15 times that observed in phosphoric acid at the same temperature.

Several fluorinated organic super acids were also identified and evaluated during the mid 70's, however TFMSA was found to be the best "super acid for the application as an electrolyte for the oxidation of propane[33] [34] [35]. The oxidation of hydrogen and propane and the reduction of oxygen (air) were studied in TFMSA using the galvanostatic pulse technique, the potential ramp technique, and cyclic voltammetry. Enhanced electrochemical activity of propane was defined in TFMSA as compared to phosphoric acid.

In1975 the evaluation methanol oxidation in TFMSA and the possible interference with the air electrode was initiated. Methanol did exhibit some "crossover to the cathode but the use of

[32] Research on Electrochemical Energy Conversion Systems" DAAK02-72-C-0084, Reports Nos.1, 2, 3, 4, 5, 6, 7 A. A. Adams and R. T. Foley

[33] A. Adams and H. Barger, Jr.,"A New Electrolyte for Hydrocarbon-Air Fuel Cells" US Patent # 3,948,681, April 6, 1975. A. A. Adams and H. Barger, Jr.

[34] A.A. Adams, G. W. Walker and R.T. Foley. "Improved Acid Electrolytes for the Hydrocarbon- Air Fuel Cell." 27th Proceedings Army Science Conference. , June 1976

[35] G. W. Walker, A.A. Adams and R.V. Lawrence "An Improved Acid Electrolytes for Direct Oxidation Fuel Cells." Proceedings Army Science Conference, 1976.

Army Power Division

methanol was considered to be an engineering possibility at 135C. During 1975 and early 1976 the oxidation low molecular weight hydrocarbons were evaluated in TFMSA with propane, ethane, n-butane, and methane.
The search for advanced liquid acid electrolytes lost momentum when the proton exchange membranes (PEM) became available for terrestrial use. The membrane technology was far superior especially from a manufacturability perspective.

Life testing was conducted using accelerated testing to examine aging phenomena on single 2"x2" single fuel cells. This work is described in the reference[36].

Research on freeze tolerant PAFC electrodes were conducted over several years in the early 80"s[37]. The military concerns for low temperature operations and storage of fuel cells for use in power generation equipment. Temperatures in the -25C range were replicated in the laboratory and electrodes evaluated for performance after low temperatures were maintained for long periods of time.

Research areas also included novel electrolytes and high temperature batteries, i.e. Sodium Sulfur. Some research was directed at reforming reactions and generation of hydrogen from various metals and hydrides. Many programs were aimed at University and small business research.

The Concepts Group also pioneered work on developing test methods and testing electric battery operated cars.

POST LOG

Fuel Cell work at Fort Belvoir re-emerged in 1989 as Soldier power became an issue. Dick Jacobs of the System Assessment Team was the fuel cell representive of the Soldier Power Team. He was joined by the author and Ed Starkovich, also of the System Assessment Team, over the next several years. All three were members of the Belvoir Fuel Cell Group dating back to the 1960's. By 1994, Belvoir served as the technical agent for the Defense Research Projects Agency and the Army Research Office for programs on Direct Methanol Fuel Cells (DMFC), large scale diesel fuel processing, and Solid Oxide Fuel Cell (SOFC). The Systems Assessment Team took responsibility.

In 1996, a new Fuel Cell Team was established and continues to the present day. A Base Realignment and Closure Commission (BRAC) decision will transfer electric power R&D which includes fuel cells to Aberdeen Proving Ground (APG), MD. A large share of the Fuel Cell Team has already relocated to Aberdeen Proving Ground.

---

[36] A.A. Adams, J. A. Joebstl, A. J. Colman and G. W. Walker "Accelerated Testing of Fuel Cell Components in 2x2 Inch Fuel Cells." 29th Proceedings Power Sources Conference, June 1980,

[37] , A.A, Adams, A. J. Coleman and L. S. Joyce "Carbon Monoxide Tolerant Anodes and Freeze Resistant Electrodes." National Fuel Cell Seminar, November 1983

Army Power Division

ACKNOWLEDGEMENTS

My sincere appreciation goes to Dr. Alayne Adams, Dick Belt, Ed Dowgiallo, Ed Gillis, John Orth, Dr. John O'Sullivan, and George Sisk, for providing information, pictures, and their recollections from early work at Fort Belvoir on fuel cells. Dick Belt provided many helpful suggestions and served as a sounding board while writing this report.

This report would not have been written without the encouragement and support of Dr. H. Scott Coombe, Leader of the Power Technology Branch and Elizabeth Ferry, Leader of the Fuel Cell Technology Team.

AUTHOR:

Walter G. Taschek resides in Haymarket, Virginia with his wife Hilda. He started his fuel cell career in 1960 at the US Army Signal Research and Development Laboratory at Fort Monmouth, NJ while serving in the US Army. He stayed on at Fort Monmouth after completing his military tour in 1962. In 1966 he joined the fuel cell group at the US Army Engineer Research and Development Laboratory at Fort Belvoir. From 1988 until his retirement from Federal Service in 1995, he headed The Systems Assessment Team. In 1989 the Systems Assessment Team took on fuel cell responsibility. Today, he continues to support the Belvoir/Aberdeen Fuel Cell Team as a part time advisor. He holds a BS(59) and a MS(72) degrees in Chemical Engineering from the University of Wisconsin, Madison. He is a past member of the American Institute of Chemical Engineers and the American Chemical Society.

Army Power Division