



FUEL CELL TODAY

Opening doors to fuel cell commercialisation

Fuel Cell Market Survey: Military Applications

Stefan Geiger and David Jollie – Fuel Cell Today – 1 April 2004

Although fuel cells hold out the promise of clean, environmentally-friendly, efficient power generation, few of the current prototypes and early products are close enough to their full potential to attract end users. Many companies are therefore investigating niche markets as a route to early revenues, larger scale manufacturing and helping further development of the technology.

The military market is particularly attractive as it often plays the role (alongside the space industry) of a sympathetic early adopter, willing to accept high prices and limited performance if other requirements can be met. Indeed the US military establishment in particular has shown interest from as long ago as the 1960s when it operated a number of small hydrazine-fuelled alkaline fuel cells in the field in Vietnam as shown pictured below next to a rather more up-to-date portable fuel cell available now.

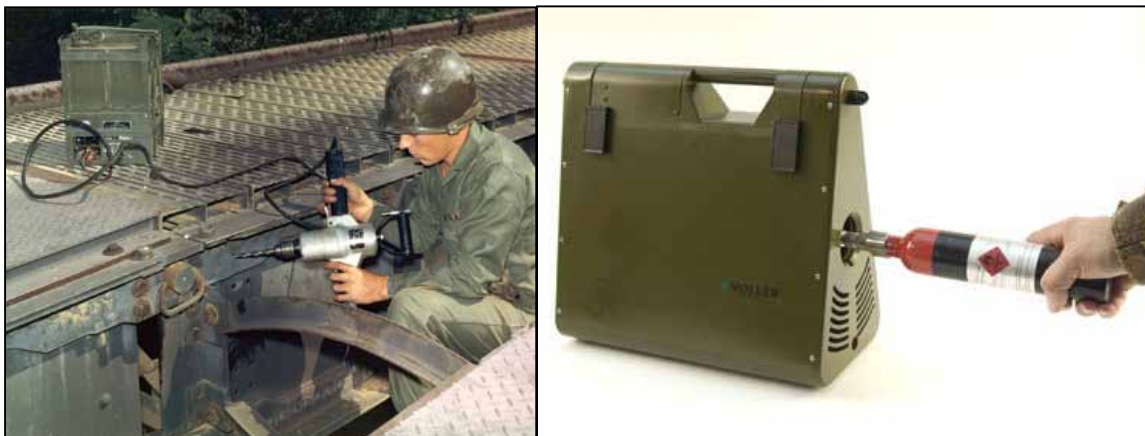


Fig.01: Portable Military Fuel Cells yesterday and today. Left 300W US Army Mobility Equipment Research and Development Center unit 1965, right 100W PEMFC Voller Energy unit 2003. Source: MERDC, Voller Energy

This segment is also promising due to the wide range of needs that different parts of the military machine have. It is in fact a microcosm of the rest of the fuel cell world, with requirements for portable power, electric vehicles or auxiliary power in

conventional vehicles and large scale power generation amongst other things. Almost all types of fuel cell could find a use here is adapted for use.

The drivers

Outside of the defence sector, the driving forces for the adoption of fuel cells are typically environmental, economic or performance-based (i.e. they are cleaner, cheaper or work better). All of these also apply here but with extra degrees of subtlety and some, at first sight, quite incredible definitions of performance.

The environmental

Although they are perhaps not the most important issue, the army has to face, environmental questions are not entirely irrelevant. Low carbon dioxide and other pollutant emission, lower use of fuel and quiet operation can all provide benefits here.

In fact, perhaps the highest profile fuel cell project yet has been run by the US Department of Defense in the form of the stationary fuel cell buy-down programme, where many fuel cells have been bought and installed at military bases and elsewhere round the world. This has helped to provide data on the units' performance and to improve reliability and durability, with UTC Fuel Cells' phosphoric acid PC25 the main beneficiary. In all of the sites where systems were installed, the benefits were almost exactly those of distributed generation, combined heat and power supply and low carbon dioxide output that the civilian sector also requires.

The economic

The military is often referred to as the highest payer for products in any market, and not without good reason. Stories abound of expensive hammers and nuts and bolts. However, there is serious interest in reducing capital, and, more importantly, operating cost, something fuel cells may be able to help with.

For instance, a litre of fuel can cost more than ten times as much at the battlefield (with transportation and logistics cost) than in a refuelling station forecourt. Even small efficiency savings, therefore, can rapidly add up large amounts of money. Likewise, a typical ground battalion uses up to twenty different types of battery. If,

instead, of being battery-powered, each portable electronic device contained a fuel cell, it might be possible to provide a single liquid to refuel them all, a huge logistical simplification and reduction of cost. Finally, low numbers of moving parts could, in the longer term, make the maintenance of fuel cell devices less costly than for their conventional analogues

Performance criteria

Performance, however, is probably the most important issue to the military. It can be difficult to quantify the financial cost of a radio or weapon not working or the benefits of being able to perform a specific mission. If a fuel cell can provide these capabilities, market introduction may be simple even at relatively high prices.

Low noise and a low heat signature are two good examples, where each makes detection by an enemy more difficult, providing a clear value to the military consumer which might not be as important to other customers. Production of water as a by-product may be of great use in some locations. Overall though, we expect the most important attribute of fuel cell systems to be their high energy density, particularly when compared to batteries.

A fuel cell, together with its fuel, could weigh less and provide power for longer than current (or foreseeable) battery designs can. This translates to a soldier being able to carry other equipment or move further and faster, again of great interest here. If fuel cells can demonstrate the right performance, we can clearly expect the market demand to be there.

The barriers

If only life were this simple, we could see fuel cells in this market tomorrow. There are, however, issues still to be solved. They are not, though, necessarily the same challenges as in other sectors of the industry. Their durability or longevity are often the key issue whereas they may not be here. For many applications, a soldier may be happy with a cell that generates power for only three days as long as it does so reliably. Durability can also mean something completely different: do filters get blocked by sand or dust; does it still work in the presence of nerve gas; can I drop it

fifteen feet onto the ground and expect it to survive? It would be surprising if many fuel cell companies had focused on these questions yet.

When, then, could we expect to see fuel cells adopted in the military or defence market? Almost all of the projects here are at a prototype stage with only a few units produced. Clearly the industry is not yet ready. In a recent conference (March 2004, Connecticut, USA, Second Annual Fuel Cell Investment Summit), though, some speakers believed that they could be making real sales within two years. Watch this space.

Region of Operation

Most of the activities in military fuel cells are taking place in the countries which are leading elsewhere in the fuel cell industry. This trend though is accentuated by the amount of money a particular country spends on its defence capabilities. Unsurprisingly therefore, the USA is in a dominant position, with a strong fuel cell industry and high spending on the military. Other prominent countries include Canada, Germany and the UK. But quite remarkably, some countries which are normally not immediately associated with the technology, such as the Czech Republic, Greece, Italy and Singapore are also interested and involved.

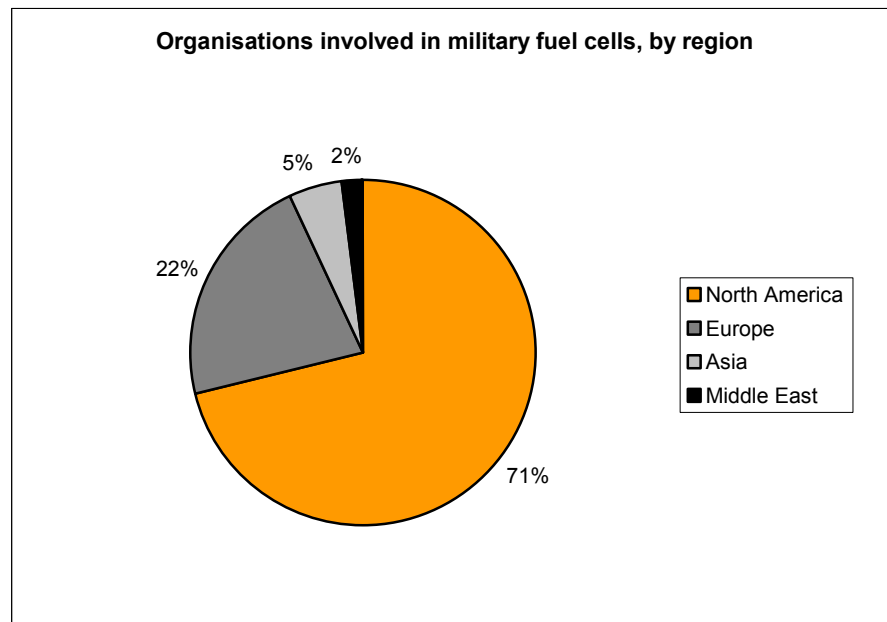


Fig.02: Geographical distribution of involved organisations

One notable difference between the military market and those for other fuel cell applications is this geographical interest. Elsewhere, Japan is a leading participant but its lack of a significant defence industry or military establishment willing to invest money leaves it conspicuously absent from this market segment.

Application

As mentioned in the introduction, the range of interest in fuel cells from the military is impressively wide and hard to categorise. Small and large stationary fuel cells are of interest, for example to provide power to military bases, much as they would be used in civilian life. Electric vehicles are another area of focus, where a fuel cell may power an autonomous plane or submarine or a more conventional car.

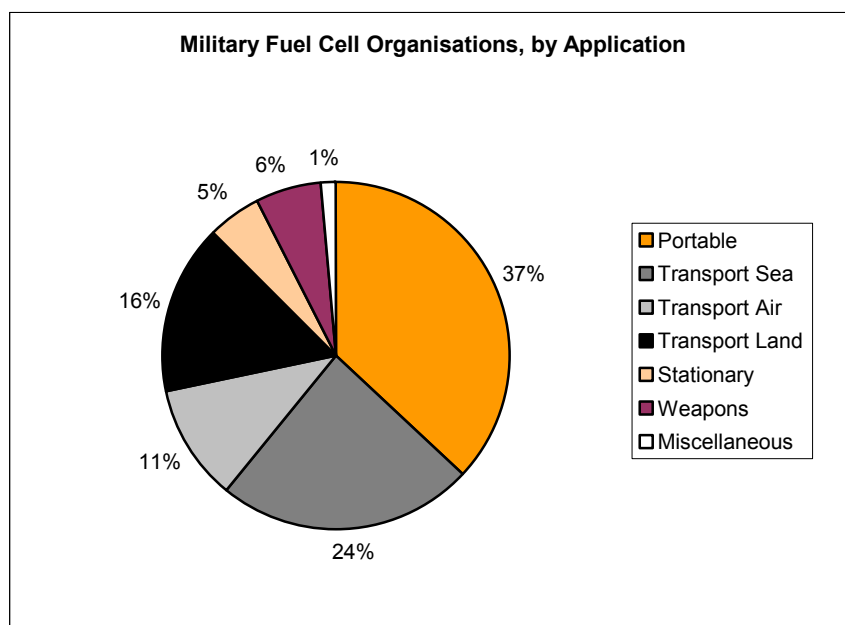


Fig.03: Application focus of companies working on military fuel cells

There are also some applications much more specific to the military. For instance, there is significant interest in auxiliary power for land vehicles, where low heat and noise are attractive. Portable electronics and weapons also feature and may provide further opportunities for fuel cells to come to market.

Key Players: Government and the Military

Compiling a list of military projects is difficult since many of them are kept confidential. As a result, this list cannot be complete. However, it does provide information on many government agencies, military organisations, industry and research organisations involved in the development and deployment of new fuel cell technology. As noted earlier, North America is particularly dominant with a very wide interest while Europe also has some strengths. Asia and the rest of the world are comparatively much weaker as can be seen by the number of governments actively pursuing military fuel cell development.

Asia

Singapore

The **Defence Science and Technology Agency (DSTA)** in Singapore is supporting work at the **Nanyang Technological University** on stationary fuel cells. Furthermore, DSTA is studying the possibility of putting fuel cells into military applications, both transport and portable, and is supporting the work of **CET Technologies**, which is testing a **Palcan** portable fuel cell for the Singapore Armed Forces.

South Korea

Like Greece and Italy (mentioned later), the **South Korean Navy** will introduce two **HDW/Siemens** fuel cell powered submarines, which will be build by **Hyundai Heavy Industries**.

Europe

France

The French **Ministère de la Défense** department "**General Armament Division**" (DGA) is working on the "FELIN" project, which aims to significantly increase the infantryman's combat effectiveness by developing advanced power sources, electronic equipment and materials. Additionally, DGA is working with French fuel cell manufacturer **Helion** and research organisation **CEA** on possibility studies on the use of fuel cells for unmanned air vehicles (UAV), unmanned underwater vehicles (UUV)

and ships. The DGA is also supporting and funding the French fuel cell network "Reseau PACo".

Germany

The German "**Verteidigungsministerium**" (Ministry of Defence) is working on a new advanced soldier concept programme (Infanterist der Zukunft – IdZ) which aims to equip soldiers with modern telecommunications technology. The ministry is looking into the possibility of using fuel cells as alternative portable power source. Additionally, money has been spent on fuel cell powered submarines, developed by **HDW** and **Siemens**.

Greece

Like Germany, the **Greek Navy** plans to introduce fuel cell powered submarines which will be built by **Hellenic Shipyards** following a **HDW/Siemens** design.

Israel

The **Israeli Ministry of Defence** is funding a project carried out by **Israel Aircraft Industries** (IAI), a developer and manufacturer of military and commercial aerospace technology, on using fuel cell technology in unmanned air vehicles (UAV). Additional interest has been shown in using portable fuel cell systems.

Italy

The **Italian Navy** has just launched its first PEM fuel cell powered submarine (November 2003), which was built by Italian shipbuilder **Fincantieri** following a **HDW/Siemens** design.

Netherlands

The **Royal Netherlands Navy** was investigating the use of fuel cells as auxiliary power units for surface ships. From 1999-2002 it was testing a 1kW **DeNora** (now **Nuvera**) PEM fuel cell stack.

United Kingdom

The UK **Ministry of Defence (MoD)** has started a two-year programme to develop a 100W PEM fuel cell power source for soldiers as a battery charger (2000-02). Partners in the project included **Advanced Power Sources** (now **Intelligent Energy**), **Black & Decker**, **DERA - Defence Evaluation and Research Agency** (now **QinetiQ**), the UK **Defence Science and Technology Lab (DSTL)** and **Ineos Chlor**.

Currently, the **MoD Defence Procurement Agency (DPA)**, **Thales** and **DSTL** are working on the "FIST" programme (Future Integrated Soldier Technology) which will provide the British Armed Forces with an integrated fighting system for dismounted, close combat troops. FIST is looking seriously into implementing fuel cells as power chargers for portable applications, but would buy the necessary technology rather than developing its own.

Another programme is the "FRES" programme (Future Rapid Effect System), which aims to deliver a family of deployable medium-weight armoured vehicles to the UK Army. The MoD has proposed using diesel hybrids and has considered fuel cells.

The MoD and the **Engineering and Physical Sciences Research Council (EPSRC)** are also funding basic fuel cell development (DMFC, PEMFC and SOFC) at **Cranfield University, Imperial College, Loughborough University**, and the **universities in Newcastle, Nottingham and St. Andrews**. Further work has been done in developing a 6kW diesel fuelled fuel cell for use in submarines, implementing a **Regenesys** energy storage system. Loughborough University has been working on a feasibility study on the use of fuel cells in surface ships for the MoD.

North America

Canada

The **Department of National Defence (DND)** in Canada has been supporting fuel cell development for some time. Between 1994 and 1998, the **Canadian Maritime Command** invested Cdn\$4.8 million in **Ballard Power Systems** for the production of a 50kW fuel cell and later another Cdn\$75 million for a 250kW system which was designed for use in a submarine.

The Canadian Army is also interested in **Hydrogenics'** APU which was used in a GM military vehicle. Canada is evaluating the idea of putting fuel cell auxiliary power units (APUs) into its LAV-3 armoured vehicle.

The DND is also supporting fuel cell research at the **Royal Military College of Canada**, which will spend around US\$750,000 over the next five years on methods of converting conventional fuel into hydrogen. Partners in the project are Hydrogenics and **Fuel Cell Technologies**. Similar research has been funded by the DND in a project lead by **Azure Dynamics**.

USA

The **US Department of Defense (DoD)** is the largest funding organisation in terms of supporting fuel cell activities for military applications in the world. The following chart gives a simplified idea of the various organisations involved in fuel cell research. In 2003, the DoD spent around US\$130 million on related research and development.

DoD organisations are using fuel cell technology for three major applications: stationary units for power supply in bases, fuel cell units in transport applications and portable units for equipping individual soldiers or groups of soldiers.

In terms of equipping individual soldiers, the DoD is working on two different programmes. The "Land Warrior" programme is an integrated fighting system for the individual infantryman and includes everything the dismounted soldier wears and carries such as weapon, helmet, computer, communications and navigation subsystems, protective clothing and other equipment. All the US armed forces are working together to achieve these goals and the DoD expects to equip up to 15,000 soldiers with these systems by the end of 2004. Various projects have started to develop power supply units, including fuel cells to this programme.

In a next step, the DoD initiated the "Future Force Warrior" programme which will basically improve the systems of the Land Warrior Programme and equip soldiers with new systems by 2010. Again fuel cells are being looked at as power sources.

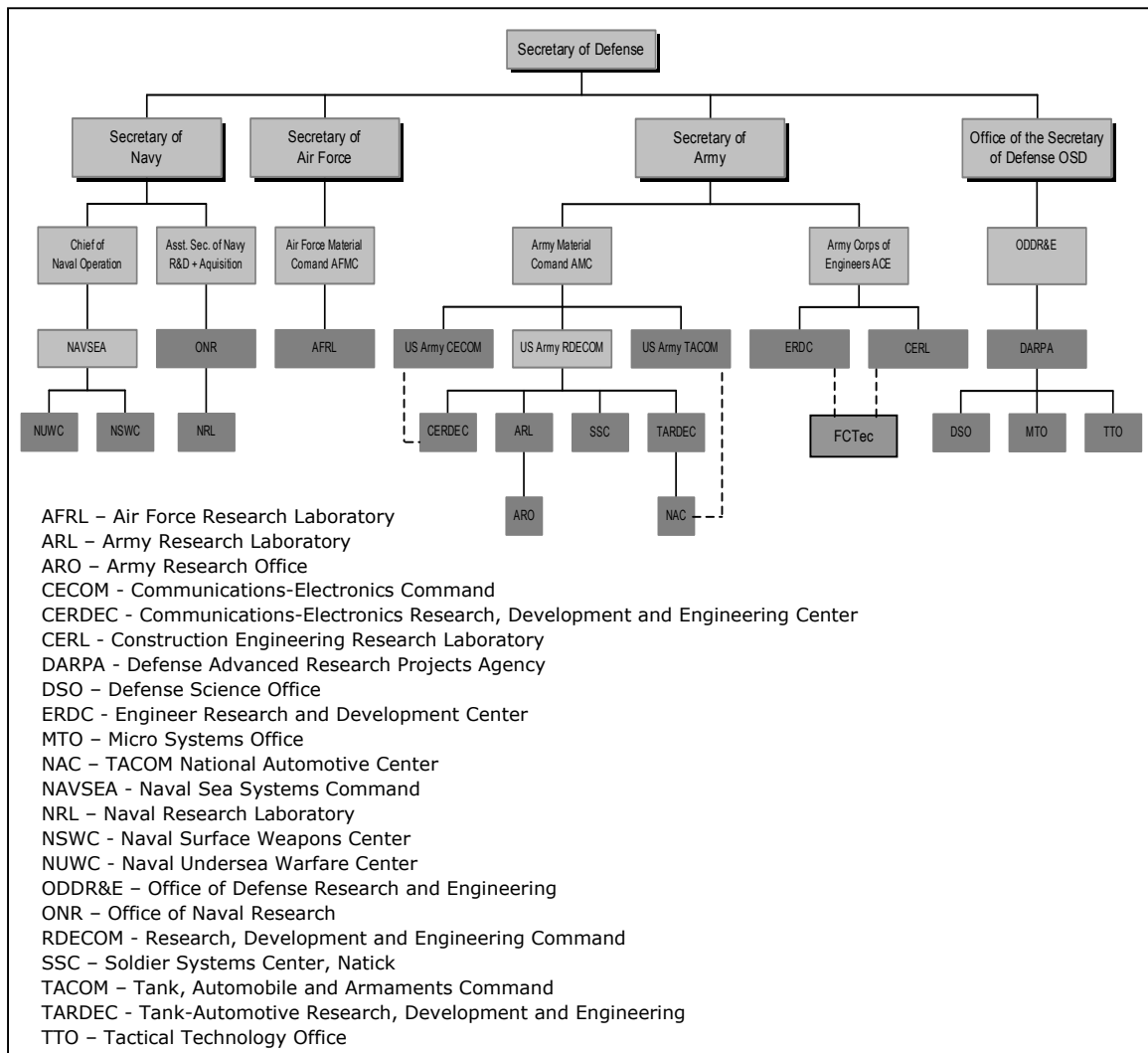


Fig.04: US DoD structure of organisations involved in military fuel cell development (dark grey).

The following pages describe the activities of DoD’s main organisations in the field of fuel cell and hydrogen related research and development:

The US **Air Force Research Laboratory (AFRL)** is currently developing electrical power for the Persistent Area Dominance (PAD) Smart Munition, The 2-year project is funded with US\$ 2.9 million and will include looking at fuel cells as propulsion.

Additionally, AFRL is developing a deployable 100kW Logistics Fuel Processor

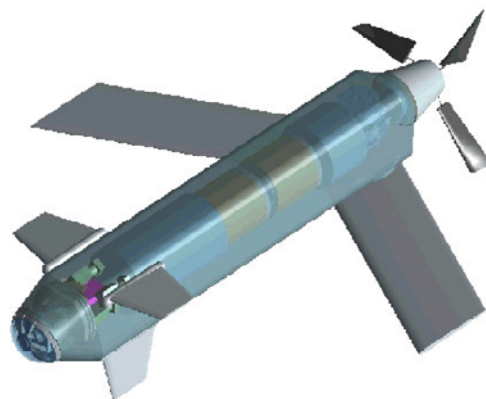


Fig.05: Fuel cell powered PAD Smart Munition model.
 Source: AFRL

that will permit development of a compact, highly reliable fuel cell power system (Mobile Electric Power – MEP) together with the Army’s **ERDC/CERL**. Together with the Army, AFRL is also involved in developing fuel cells for UAVs.

The US **Army Research Laboratory (ARL)** is working on various military fuel cell applications, including warrior power, manned/unmanned land/air vehicle power, and fuel cells for unattended sensors and munitions.

ARL is leading the “Power & Energy Consortium”, which aims to develop extremely lightweight portable power sources for individual and groups of soldiers and fuel cells for vehicle propulsion. In this project, the ARL is evaluating various technologies, such as DMFC (0.1-100W), PEM (1-1,000W) and SOFC (0.1-10kW) and is supported by various partners, including, **Case Western Reserve University, Honeywell, Illinois Institute of Technology, Motorola Laboratories, NuVant, Pennsylvania State University, Tufts University, University of Minnesota, University of Pennsylvania, University of Puerto Rico Surface Science Laboratory** and **University of Texas**. The ARL itself is working on methanol fuel cell catalysts and water gas shift catalysts for SOFC.

Together with the **Gas Technology Institute (GTI)**, the ARL is working on new membranes for DMFC and PEM fuel cells.

ARL has also been working with the US Army Communications-Electronics Command (**CECOM**) on 50W PEM fuel cell stacks for portable power (1999-2003), and with **Pennsylvania State University** on equipping the battery powered unmanned underwater vehicle (UUV) “Seahorse” with a fuel cell.



Fig.06: ARL/Penn State University fuel cell UUV “Seahorse”. Source: ARL

The ARL is getting support from its **Army Research Office (ARO)**, which is working on more basic fuel cell and hydrogen research and has been developing materials and processes with partners such as **Lynntech** and **Analytic Energy Systems**.

US Army **Communications-Electronics Command (CECOM)** engineers in the CECOM Communications-Electronics Research, Development and Engineering Center (**CERDEC**) are working in two areas of fuel cell development: soldier and sensor power (0.5 – 500W) and auxiliary power units (0.5 - 10kW). Together with engineering know-how from the **National Automotive Center (NAC)** and a 2kW PEM fuel cell from **IdaTech**, CERDEC has demonstrated an APU for a military vehicle (C2 Vehicle).



Fig.07: C2 Vehicle with PEM APU. Source: CECOM

CERDEC has been a leader in the development of fuel cell soldier power units, demonstrating a 100W fuel cell battery charger, a 20W DMFC for soldier power and 2kW portable methanol reforming fuel cell for larger applications in the field. The researchers have also been working with **ONR** on a fuel cell powered/all electric destroyer, the DDX, developed by **Raytheon**.

The **Construction Engineering Research Laboratory (CERL)** and the **Engineer Research and Development Center (ERDC)** are working on small and large stationary fuel cell demonstration programmes (“DoD Fuel Cell Demonstration Program”). The two organisations deployed 30 large stationary 250kW PAFC units from **UTC Fuel Cells** (PC25) on US military bases during 1994-97 in order to demonstrate fuel cell capabilities in real world situations.

Additionally, a demonstration project with small residential fuel cell units was started in 2001. So far 52 units have been installed in US bases, ranging from 0.5-5kW. The units were supplied by **ReliOn** (formerly: **Avista Lab**), **H-Power**, **Nuvera** and **Plug Power**.

CERL and ERDC are also founding members of and support the Fuel Cell Test & Evaluation Center (**FCTec**) which is operated by **Concurrent Technologies Corporation** (CTC).

Furthermore, CERL, the **AFRL** and **FCTec** are leading a programme to develop a JP-8 fuelled 10kW solid oxide fuel cell generator for the Army. The **Gas Technology Institute** (GTI) and partners have received a US\$3.7 million grant for this work.

The **Defense Advanced Research Projects Agency (DARPA)** is the central research and development organisation for the US Department of Defense (DoD). Three different sections of DARPA are working on fuel cells; the Defense Science Office (DSO), the Microsystems Technology Office (MTO) and the Tactical Technology Office (TTO).

The Micro Power Generation (MPG) programme examines generation of micro-scale power. DARPA-MTO is working with partners, such as **Battelle, Carnegie Mellon University, CASE Western Reserve University, Pennsylvania State University** and others on DMFC and PEMFC with a fuel processor as practical power sources.

In the water-based propulsion for Space Programme, DARPA-TTO will develop a reversible fuel cell to make future spacecraft more manoeuvrable with a longer lifetime. The fuel cell will be developed with **Proton Energy**.

The Palm Power initiative (DARPA-DSO, MTO and TTO) seeks to develop and demonstrate a 20W portable power solution with support from the **ONR** (Office of Naval Research) and the **ARL** (Army Research Laboratory). The power unit will combine a fuel cell with a JP-8 military fuel reformer and a battery. The aim is to power various portable soldier solutions, small autonomous robot vehicles and exoskeletons. **ITN Energy Systems** has been selected to develop a 20W SOFC cell system as part of the programme.



Fig.08: ITN Palm Power unit.
Source: ITN

The Mobile Electric Power project focused on the introduction of fuel cells as replacements for large diesel generator sets and smaller unit in the 500W sector.

Several successful demonstrations have resulted in technology transfer to military customers, including their use for ship service power by the US Navy.

The Portable Power programme focuses the development of small power units which will produce electricity for soldiers or small groups of soldiers. DARPA-DSO is developing 300-500W fuel cells which are intended to provide an instantly rechargeable power source. Work has been carried out by **Battelle's** PNNL and **Honeywell** to develop a SOFC generator. Additionally, 50W DMFCs are developed for soldier power.

Together with the **NRL**, DARPA-DSO is working on seafloor fuel cells for low power/long endurance ocean sensors and transponders. Furthermore, DARPA is continuing its investment in long endurance, fuel cell powered, unmanned air vehicle (UAV) technology, which can be used for surveillance, reconnaissance and communications operations. Partners include **Acumentrics** and **Boeing**.

The **Fuel Cell Test and Evaluation Center (FCTec)** is a National Resource facility for the independent testing and validation of fuel cell power systems for both military and commercial applications. The centre is supported by **Concurrent Technologies** (CTC), the US Army's **CERL** and **ERDC**. The FCTec's primary goal is to significantly accelerate the development and commercialisation of fuel cell power systems. FCTec validates pre-commercial and commercial fuel cell systems and components and has tested various **ReliOn** (formerly: **Avista Labs**) and **UTC** fuel cell units.

Although not part of the DoD, **NASA** has three different research organisations developing fuel cells for military (excluding space) applications. The **NASA Dryden Flight Research Center (DFRC)** is NASA's primary installation for flight research. Working with **Aerovironment**, DFRC has developed the Helios solar/fuel cell UAV plane. The vehicle eventually will be able to stay in the air for months and can be used for commercial or military surveillance purposes. The demonstration of the Helios plane, funded by NASA and DoD with US\$ 50 million (2000-03) is part of the larger NASA sponsored ERAST (Environmental Research Aircraft & Sensor Technology) project, which aims to develop remotely piloted aircraft. However, the Helios plane had some technical problems during its last flight in June 2003 and crashed into the sea near Hawaii.

Additionally, DFRC is sponsoring in another UAV project (UAV National Industry Team – UNITE) with partners such as Aerovironment, **Aurora Flight Systems**, **Boeing**, **General Atomics**, **Lockheed Martin**, **Northrop Grumman**, and **Scaled Composites**, which aims, among other things to implement fuel cells into commercial and military UAVs.



Fig.09: Helios UAV plane. Source: NASA DFRC.

The Electrochemistry Branch of the **NASA Glenn Research Center (GRC)** is responsible for the development of improved electrochemical technologies that result in high energy density and long life batteries and fuel cells for NASA missions, DoD or commercial applications. GRC developed various fuel cells for space missions in the 60s and 70s and is now working with DFRC and Aerovironment on the Helios UAV plane. Additionally, GRC has also been involved in developing an unmanned underwater vehicle (UUV) equipped with a 20kW PEM fuel cell (1991–1995) and together with **ElectroChem** and **NASA Lewis Research Center** a 10kW PEM fuel cell powered balloon for long-duration scientific missions.

Additionally, GRC is also leading the “Low Emissions Alternative Power” (LEAP) project, of which two sub-programmes are working on fuel cell research. The “Aircraft Fuel Cell Power System” (AFCPS) sub-programme aims to develop and demonstrate a prototype fuel cell based power generation system for UAV/small transport aircraft by around 2010; while the “University Research Engineering,

Technology Institute” (URETI) project includes the development of revolutionary aeropropulsion & power technologies (UAPT). **Georgia Institute of Technology** and **Florida A&M University** are being funded by the NASA and the DoD to develop fuel cells as part of these efforts.

The **Jet Propulsion Institute**, managed for NASA by the **California Institute of Technology** (CalTech), is working on the development of methanol fuel cells for portable applications. Work started in the 1990s, partly funded by **DARPA**. The Jet Propulsion Institute has developed a 150W portable military fuel cell together with **Giner**.

Naval Sea Systems Command (NAVSEA) engineers, builds and supports the US Navy fleet of ships and combat systems. Part of the NAVSEA is the Naval Surface Warfare Center (NSWC) and the Naval Undersea Warfare Center (NUWC) which both are working on fuel cells, batteries, chargers and power supplies for the DoD.

The **Naval Surface Warfare Center (NSWC)** has eager plans to deploy fuel cells into ships and has started the “Ship Service Fuel Cell Program” (SSFC), which aims to develop shipboard fuel cell systems as main and auxiliary/emergency power systems, fuelled by conventional Navy Diesel F-76 to decrease the money spent on fuel by approximately 60%. Together with the **ONR** and **DARPA**, NSWC has tested various fuel cell systems over the years, including a 500kW PEM developed by **Ballard** and **BWX Technologies** (**McDermott** subsidiary) but is currently testing a **FuelCell Energy** 625kW molten carbonate fuel cell (MCFC) in a land-based test facility. The Navy aims to deploy fuel cells up to 2.5MW into ships by 2007-2011, future projects beyond that plan fuel cells up to 25MW.

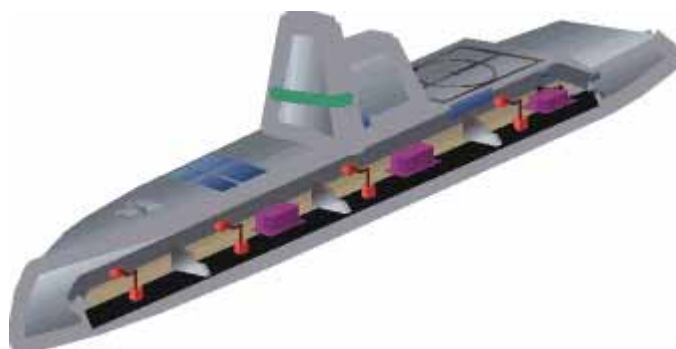


Fig.10: Model of the future fuel cell powered destroyer. Source: BWX Technology

Additionally, NSWC's Ship System Engineering Station (SSES) is working with **Ion America** on implementing a reversible SOFC into submarines as an emergency oxygen supply unit.

The **Naval Undersea Warfare Center (NUWC)** is the Navy's full-spectrum research, development, test and evaluation, engineering and fleet support center for submarines, autonomous underwater systems, and offensive and defensive weapons systems associated with undersea warfare. Together with the **ONR**, NUWC has developed and tested fuel cells and semi fuel cells for various applications, including torpedoes, UUVs, mobile mine and countermeasure applications.

The **Office of Naval Research (ONR)** together with its executive arm, the **Naval Research Laboratory (NRL)** is working with the Naval Surface Warfare Center (**NSWC**) on the Ship Service Fuel Cell Program" (SSFC) which will eventually result in the development of an all-electric fuel cell powered ship. Efforts are also being made to develop PEM fuel cells, reformers and tank solutions for an UUV (Undersea Power Source Program).

Additionally, the NRL is working with **DARPA** on an oceanic, bio fuel cell project, called OSCAR (Ocean Sediment Carbon Aerobic Reactor). These fuel cells could be used to power small remote instruments and radar/navigation sensors.

Together with **Battelle's** PNNL and **MTS Technologies**, ONR is developing a portable 100-200W direct methanol fuel cell (DMFC) system for dismounted soldiers (Expeditionary Energy Program). Further research has been carried out with the **Pennsylvania State University** and DARPA on the development of a small stationary back-up power unit which can be fuelled with conventional military fuel.

The US **Army Tank-Automobile and Armaments Command (TACOM)** is one of the US Army's largest weapon system research and development organisations. TACOM is also home to the **National Automotive Center – NAC** (although NAC is part of **TARDEC**) which is working on ground vehicle research, especially fuel cells and advanced fuel technology for military vehicle systems.

NAC has been and is involved in various fuel cell demonstration projects, including the **Fuelcell Propulsion Institute's** 1.2MW PEM fuel cell locomotive project; the development of 1.4kW and 5kW PEM auxiliary power units (APU) for two **Freightliner** long haul trucks with **Ballard**; various PEM fuel cell buses with **Xcellsis** (now Ballard) and **UTC**; development of 1-5kW SOFC APUs with **Delphi Automotive**; the implementation of a **Hydrogenics** 5kW APU into a GM combat vehicle and the development of a 20kW commercial/military PEM fuel cell demonstrated in a **John Deere** Gator vehicle. Currently, NAC is working on larger PEM and SOFC fuel cell APUs and diesel/fuel cell hybrid vehicles.

Additionally, TACOM/NAC have sponsored the development of a GEM (Global Electric Motorcar) utility vehicle at **Kettering University**. The vehicle will be equipped with a 1.2kW Ballard PEM fuel cell and is designed to be used on US Army military bases.



Fig.11: Fuel cell powered GEM. Source: NAC

Key Players: Industry and Research

Aerovironment has been working on various high altitude solar and electric planes. Together with **NASA**, the company has developed the fuel cell/solar Helios plane, a 247-foot-long flying wing which is controlled from the ground by two pilots using desktop computers.



Fig.12: Aerovironment "Hornet". Source: Aerovironment.

Furthermore, Aerovironment has been working with **DARPA** and **Lynntech** on the fuel cell powered micro air vehicle "Hornet", which can be equipped with a video camera payload for military purposes.

Agni (Advanced Energy Technology) designs and develops fuel cell and hydrocarbon processing technology. The company is working on portable power solutions for military applications, cellular and consumer electronics.

The **Ashlawn Group** is a technology company focusing its work on R&D, pilot production and process engineering for energy companies and various US DoD organisations, including **TACOM** and **TARDEC**. The company has already patented a design for a munitions fuel cell which replaces batteries to power the electronics guiding the shells or missiles accurately to the target. Together with **Case Western Reserve University**, Ashlawn has been awarded a contract by the DoD in 2004 to jointly develop fuel cells that would fit into artillery shells, mortar rounds and tactical missiles.

Astris Energi is a manufacturer of alkaline fuel cells and fuel cell systems. The company delivered a 1.5kW fuel cell to the **Czech Ministry of National Defence** in 2000. The unit, fuelled by gaseous hydrogen, is a portable generator built for evaluation of fuel cell based power sources by the military.

Ball Aerospace & Technologies has developed two small portable PEM fuel cell systems (50W and 100W) for military applications. They were designed to recharge military batteries and to power communication base stations and unmanned monitoring equipment. Ball has also designed low pressure hydrogen on demand sources for these units.



Fig.13: 50W, hydrogen storage cartridges and 100W unit. Source: Ball Aerospace & Technologies.

Additionally, Ball is developing a 20W direct methanol fuel cell for the **DARPA** Palm Power Programme.

Bertin Technologies, an engineering and consulting group, is involved in the French "Fantassin a Equipements et Liaisons Integres - FELIN" (Clothing and

equipment for future soldier) project which to significantly increase the infantryman's combat effectiveness. Bertin is working on a portable fuel cell for this project and is supported by partners including **Thomson CSF Services Industrie** (now **Thales Services Industrie**). Bertin has also been involved in evaluating the possibility of putting a small fuel cell into a French submarine as an auxiliary power unit.

Boeing is designing a fuel cell based propulsion system for an UAV. The project, called "Ultra-Leap" (Ultra Long Endurance Aircraft Program), involves a vehicle that can operate for two weeks and fly at altitudes of up to 60,000 feet. The company has received some initial funding (US\$ 300,000) from **DARPA**. Boeing plans to incorporate currently available automotive fuel cell technology into the propulsion system. Boeing and DARPA expect to present a prototype by the end of 2004.



Fig.14: Ultra-Leap UAV. Source: Boeing.

CET Technologies, a division of Singapore Technologies, is an engineering group specialising in aerospace, electronics, land weapon systems and marine industries. The company has signed an agreement with **Palcan Fuel Cells** in March 2004 to test a fuel cell system as a backup power generator for use by the **Singapore Armed Forces**.

Energy Conversion Devices has been awarded funding from the US Army Tank-Automotive and Armaments Command (**TACOM**) to partner with the Army's National Automotive Center (**NAC**). The US\$500,000 total contract will be applied towards the development by **Texaco Ovonic Hydrogen Systems** (TOHS) of a transportable solid hydrogen storage and refueling system for hydrogen fuel cell powered off-road military vehicles.

Swedish **FMV - Försvarets Materielverk** was deeply involved in fuel cell activities for submarines during the 60s. A 200kW AFC unit was built by **ASEA** (now **ABB**), although fuel cells were later abandoned for Stirling engines. In the mid-90s, FMV made another effort to investigate the potential of fuel cell systems for submarines, using PEM fuel cells. The research was again stopped due to the high costs of fuel cells for propulsion. However, FMV has evaluated other military applications in which they believe fuel cells might be useful and price competitive.

The **Fuelcell Propulsion Institute** is a non-profit organisation, aiming to bring together fuel cell technology developers, manufacturers, and end-users within an industry to plan vehicle development and demonstration projects. The institute has been working on a 1.2MW PEM fuel cell locomotive with partners such as **Aerovironment, DoD, HERA, Intelligent Energy, NAC, Nuvera, TACOM** and **Vehicle Projects**.



Fig.15: 1.2MW PEM locomotive. Source: Fuelcell Propulsion Institute.

Fuel Cell Energy is conducting a conceptual study of a marine fuel cell power plant based on its direct carbonate fuel cell technology which is in the early commercialisation phase for land-based applications. The current Phase I study is focused on a 2.5 MW Ship Service Fuel Cell (SSFC) power source for future surface combatants, lead by **NAVSEA**.

Singaporean **GasHub Power** is working on decentralised energy solutions, including the development of PEM fuel cell systems (1-5kW), graphite bipolar plates and on-site hydrogen supply. The company's target market is the premium power sector and military customers.

General Dynamics integrated a 5kW SOFC **Acumentrics** fuel cell APU into a **TACOM/NAC** project called the 21st century truck in 2002. The project aims to eventually replace diesel engines in commercial and military trucks with an alternative power source. Other partners include the US **Department of Transport** (DoT), **Environment Protection Agency** (EPA) and the US **Department of Energy** (DoE). General Dynamics is also working with **Medis** on the development of a portable DMFC military system.

Giner Electrochemical Systems is working on portable direct methanol fuel cells in a range of 0.15-5kW. The company has presented a 150W portable device which could be used in military applications. Giner has been supported and is working together with **ARL, ARO, DARPA** and the **NASA Jet Propulsion Laboratory**.

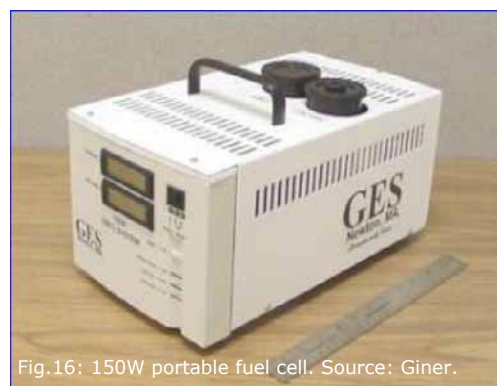


Fig.16: 150W portable fuel cell. Source: Giner.

German shipbuilder **Howaldswerke Deutsche Werft - HDW** has started working on alkaline fuel cells for submarines in the 1980s together with companies including **IKL** and **Ferrostaal**. In 1998, HDW began production of the Class 212A submarine with German shipbuilder **Nordseewerke** incorporating a fuel cell system comprising nine **Siemens** PEM fuel cell modules, each with a capacity of 30–50kW. Four submarines are being built in Germany by HDW, with deliveries from 2003 onwards, and a further two in Italy by shipbuilder **Fincantieri**, using the HDW/Siemens propulsion system. Additionally, Siemens has developed a 120kW PEM fuel cell module, and two of these modules – forming a 240kW PEMFC system – will be used for refits



Fig.17: HDW 212A class submarine. Source: HDW

of the existing Class 209 and in the Class 214 submarines. Fuel cell powered Class 214 u-boats have been ordered by the Greek and South Korean Navies and will be built by **Hellenic Shipyards** and **Hyundai Heavy Industries**. The 240kW fuel cell system will also be used in the future for the German Class 212B submarine.

The Swedish submarine manufacturer **Kockums** – now part of German shipbuilder HDW – is running a project for the Swedish, Danish and Norwegian navies to develop a new generation of submarines. Among the different submarines, there will probably be a version with electrical generation and potable water supplied by a fuel cell.

Hydrogenics and **General Motors Defence** (GMD) have developed a diesel hybrid military pickup truck equipped with a 5kW PEM fuel cell auxiliary power unit. The vehicle was presented in 2002 and will be tested for the US Army by **TACOM/NAC**. The US Navy and Air Force have shown interest as well as the **Canadian Army**. Hydrogenics has also received an order from the US Navy's **Naval**



Fig.18: GMD pickup with 5kW APU fuel cell. Source: General Motors

Surface Warfare Center (NSWC) to deliver a proton exchange membrane (PEM) electrolysis refueler.

InnovaTek develops fuel processors for PEM fuel cells. The company has received a US\$ 780,000 contract from the US Army to develop a fuel processor for small portable fuel cells.

Intelligent Energy develops complete energy solutions based on PEMFC technology initially developed at **Loughborough University** and by Loughborough spin-off company **Advanced Power Sources**. The company has developed various systems including a rugged 4kW stand-alone genset unit for military applications. Intelligent Energy is also working with **Boeing** on the development of a fuel cell for aeroplanes.

ITN Energy Systems and its sister company **Ascent Power Systems** was awarded a US\$7 million **DARPA** contract to develop a hand held solid oxide fuel cell for US military applications in 2001. The ITN/DARPA program will develop and demonstrate a solid oxide fuel cell (SOFC) system that will operate directly on JP-8 fuel and deliver 20 watts of 12 volt DC power continuously for 3 days. It may also operate for extended periods of time by simply adding more fuel. Though being developed

specifically for DARPA, future applications could include remote commercial and recreational uses.

The MST division (Materials Science and Technology) at **Los Alamos National Laboratory** has built and incorporated a 70°C DMFC stack into a complete 60W self-sustained power system developed in collaboration with Ball Aerospace. Los Alamos has also been working on fuel cell for military applications with **Motorola** and **DARPA**.



Fig.20: Medis/General Dynamics fuel cell PDA.
Source: Medis

Lynntech has been contracted by **NASA** to develop a hydrogen-air fuel cell for high altitude aircraft use. The company's system could also be deployed in commercial UAVs, which are projected to be used as telecom relay systems within the next ten years. Additionally, Lynntech has produced both high power density stacks for mobile and stationary power generation. Together with the **ARL/ARO**, Lynntech has showcased a 500W DMFC unit for military applications.



Fig.19: 500W DMFC. Source: Lynntech.

Manhattan Scientifics is a leading fuel cell manufacturer of direct methanol (DMFC) and polymer exchange membrane (PEM) fuel cells. The company has sold one of its mid-range PEM fuel cell units (NovArs) to the US Army **CECOM** for testing for the Land Warrior Programme.

Medis Technologies is applying the accumulated knowledge of leading Russian-Israeli scientists and technology developed for military use to create products for civilian use. At present, the company has two products: the Power Pack, a small portable fuel cell which can be used for powering mobile phones, PDAs, laptops and

similar devices; and the company's fuel cell military product which provides the energy for electronic applications used by foot soldiers. Medis is working with **General Dynamics** to develop a portable military fuel cell powered PDA and aims to present a first prototype in 2004.

MesoFuel is developing hydrogen reactors which can provide hydrogen from ammonia, methanol, natural gas and liquid fuels. The company has successfully tested the generation of hydrogen from a substitute of JP-8 fuel, the type of fuel used on US military bases.

MTI Micro Fuel Cells is developing direct methanol fuel cells (DMFC) as a power source for portable electronics. It also has an agreement with a major defence contractor, **ATK** (Alliant Techsystems), to explore the development of micro fuel cells for military applications. Together with a division of **Harris Corporation**, MTI has developed a micro fuel cell for portable military devices. The military product weights only half as much as the conventional BA-5590 battery used by the military currently. MTI Micro Fuel Cells is also working with **Duracell** (Gillette) to develop fuel cells for commercial portable products; Duracell is responsible for the methanol refuelling technology.



Fig.21: MTI DMFC power source.
Source: MTI.

Motorola Labs is developing fuel cells to power a range of portable electronics devices, including cell phones, two way radios, PDAs, and notebook computers. It has developed unique direct methanol fuel cell technology using a ceramic structure, which reduces size and cost. In addition, it is researching Reformed Hydrogen Fuel Cell (RHFC) technology, in which the methanol is reformed using an integrated miniature chemical reactor. Research has been partially funded by the US **Army Research Laboratory** (ARL).

Neah Power is a small fuel cell technology start-up company which is developing direct methanol fuel cells powering 0.5 to 40W portable electronic devices. The company has partnered with **Montecito Group**, a consulting firm specialising in new

military programmes and technologies, to pursue relevant research and product development opportunities within the US DoD.

Dutch PEM developer **Nedstack** is involved in a number of projects developing fuel cells for the military, including one to develop a 300kW fuel cell for a submarine, which is being sponsored by an unspecified European country. Previously involved in **Bee Power Systems**, a joint venture with **Metal-Tech** which has been dissolved in March 2004, Nedstack is working on two projects developing portable direct methanol fuel cell (DMFC) power packs for soldiers.

NuVant Systems develops and licenses advanced fuel cell components and component evaluation instrumentation. The company specialises in fully automated high throughput screening equipment for fuel cell components and is developing test stands for single cells. The company is also involved in the Power & Energy Alliance which is working on fuel cell and hybrid applications for the military.

Oak Ridge National Laboratory is working on carbon composite bipolar plates for PEM fuel cells. Additionally, the organisation is leading a major project for the US Army to create "exoskeletons" powered by small fuel cells to enable soldiers to run faster and farther while carrying heavier loads.

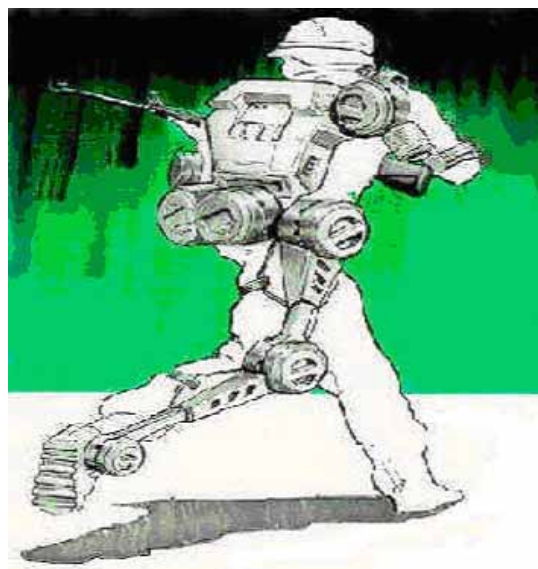


Fig.22: Fuel cell powered exoskeleton. Source: ORNL.

The **Pacific Northwest National Laboratory (PNNL)**, operated by Battelle, is working on a 10-500mW system fuel processor which converts methanol into hydrogen and carbon dioxide for **DARPA** and **CECOM**. The device can be used in very small fuel cells to generate electric power. Additionally, PNNL is working with the CECOM, **ONR** and **MTS Technologies** on the development of a 100-200W portable fuel cell system, powered by JP-8 fuel for the dismounted soldier. The project is funded with US\$ 2.8 million by the DoD.

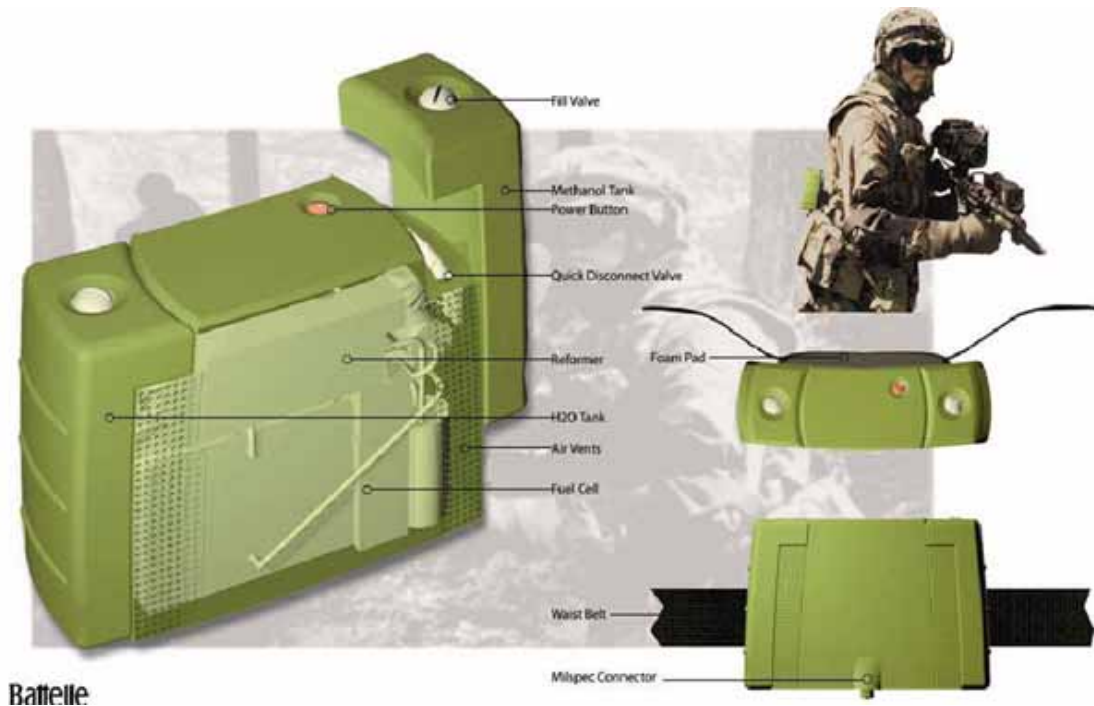


Fig.23: Battelle 100-200W portable power system. Source: Battelle.

PNNL is also involved in a joint effort with **NASA** and **Boeing** to develop fuel cells for aircrafts.

Patria Vehicles, a manufacturer of defence and armoured vehicles is taking part in the Finnish FinSOFC programme, a five-year project with the goal of developing SOFC systems. Patria aims to use this knowledge to implement a small SOFC APU (Auxiliary Power Unit) in its AMV 8x8 tank vehicle.

The Advanced Research Laboratory at the **Pennsylvania State University** is working on hydrocarbon, hydrogen and liquid metal combustion; thermal energy conversion systems; fuel cell, thermophotovoltaic and thermoelectric systems and related technologies. Some of the technologies have been used to build underwater vehicle power systems, underwater rockets and remote, autonomous power systems. The University maintains a special long-term strategic relationship with the US Navy Research Laboratory (**NRL**) and the Army Research Laboratory (**ARL**).

Proton Energy designs, develops, and manufactures PEM electrochemical products that it employs in hydrogen generating devices and in regenerative fuel cell systems that function as power generating and energy storage devices. Together with **DARPA**

and **NRL**, the company is working on a DoD funded project (US\$4.8 million) for the development of a reversible fuel cell to make future spacecraft more manoeuvrable.

Protonex Technology, a developer of DMFC and PEM fuel cells (10-1,000W), is working on portable solutions for military and commercial customers. The company has just recently received additional funding by various venture capitalist companies and previously by unspecified US Army research organisations to develop portable military fuel cell units.

QinetiQ comprises the greater part of what was the UK **Defence and Evaluation Research Agency (DERA)**. It has programmes developing materials for PEMFC, DMFC and SOFC, novel stack designs, systems integration, diesel processing and small-scale hydrogen generators. QinetiQ has developed a series of portable fuel cell systems for military applications as well as a fuel cell powered battery charger for laptop computers. These are based on its own PEM fuel cells, which can be made almost entirely from plastic and are simple to assemble. QinetiQ has also developed reduced temperature SOFCs with proton conducting ceramic electrolytes. QinetiQ is also working on reformers which convert hydrocarbon fuel (diesel, natural gas and NATO fuels), to purified hydrogen which can then be used in fuel cells on board an all-electric ship.

The company is also working with **Boeing** to explore potential collaboration on the development of a variety of technologies, including fuel cells. The company has also developed a 100W PEM fuel cell which has attracted interest from the military. The **British Army** is interested in powering the various electronic devices that are part of the modern soldier's basic equipment. Additionally, QinetiQ has been awarded a contract from the UK MoD to analyse the performance of hybrid/fuel cell vehicles for military purposes.

Quantum manufactures fuel storage system technologies for fuel cells. In 2003, Quantum was awarded a US\$ 2 million contract by the **US Army** to design and demonstrate a self-sustaining, transportable integrated energy generation and refuelling system for fuel cell applications operating in remote locations. The company has also been awarded a contract by the **NAC** to develop a hydrogen fuel cell powered light-duty, special operations off-road vehicle.

Raytheon is a defence and aerospace systems supplier, and is going to build the US Navy's all-electric/fuel cell powered next generation destroyer DX together with **Northrop Grumman**. The project is lead by the **ONR**. The company is also working on direct methanol fuel cells for small portable electronic devices for the military.

Rubin Central Marine Design Bureau and **Admiralty Shipyards** have developed the new Russian Amur 1650 class submarine. Both companies have decided to propose an alternative to the conventional propulsion by offering an air-independent propulsion (AIP) plant using a fuel cell. Research is still at an early stage, but Rubin is confident of offering a fuel cell module which can also be used to replace existing conventional propulsion units on board submarines.



Fig.24: Amur 1650 class submarine. Source: Rubin.

Perry Technologies (which became Energy Partners, and more recently part of **Teledyne**) successfully tested the first submarine powered exclusively by a fuel cell power system in 1989. The two man submersible was powered by a **Ballard** PEMFC, which tripled endurance over existing battery systems.

Sandia National Laboratories' Intelligent Systems and Robotics Center (ISRC) has developed the "Rattler" (Robotic All Terrain Lunar Exploration Rover) vehicles to fulfil a wide variety of military functions, such as surveillance, perimeter control, localisation of chemical sources, and search and rescue missions. In 1998, a contract was written between Sandia and the **Fuelcell Propulsion Institute** to coordinate the



Fig.25: PEM "Rattler" vehicle. Source: Sandia

design, procurement, and fabrication of a prototype PEM fuel cell for the vehicle. Currently, Sandia is working on alternative catalysts for methanol and proton exchange membrane fuel cell. Sandia National Laboratories are operated by **Lockheed Martin**.

SOFCo-EFS is developing a liquid fuelled processor that yields hydrogen gas for PEM fuel cells. The programme is jointly funded by the US Navy's Office of Naval Research (**ONR**) and will culminate with a 500kW integrated fuel processor that could supply hydrogen for Navy ship service PEM fuel cells.

Ultralife is a leading developer and manufacturer of a wide range of lithium rechargeable batteries. The company is supplying the UK Ministry of Defence (**MoD**) and US Department of Defense (**DoD**) with various models of its advanced HiRate military batteries. Furthermore, Ultralife is working on the integration of its batteries into fuel cells and the possibility of using fuel cells as rechargers for batteries.

United Defense is a leader in the design, development and production of combat vehicles, artillery, naval guns, missile launchers and precision munitions. The company is participating in several Tank Automotive Command (**TACOM**) and **DARPA** programs to demonstrate the automotive and operational advantages of alternative power supplies for combat systems. United Defense is also working with the National Automotive Center (**NAC**) to integrate hybrid electric technology for increased performance, greater fuel economy, enhanced reliability and reduced emissions. Together with organisations such as **Honeywell, Motorola, NuVant, SAIC** and various US universities, United Defense is part of the "Power & Energy Alliance" which aims to develop extremely lightweight portable power sources and to incorporate onboard reformation of logistic fuels in order to provide hydrogen rich reformate gas to the fuel cell, and develop a compact, light weight, robust logistic fuel reformation system

In the 1980's, **UTC Fuel Cells** designed and delivered a complete 30 kW fuel cell power system to the **US Navy** for the Lockheed Deep Quest vehicle. The alkaline electrolyte fuel cell was packaged in a pressure-tight containment vessel, which also served as a heat exchanger. Hydrogen and oxygen were provided from pressurised gas tanks.

In the early 1990's UTC Fuel Cells developed and demonstrated a 10 kW PEM prototype unit for a Navy unmanned undersea vehicle.



Fig.26: 10kW PEM prototype for undersea vehicle (1990) and 30kW alkaline fuel cell unit for UUV (1980). Source: UTC Fuel Cells

Valence is a leader in the development of rechargeable batteries. Research has been done in the field of developing fuel cells with battery backup to handle the peaks. The company is also linked to contracts with the **US military** in this field.

Voller Energy is a manufacturer of portable fuel cell systems for industrial and military use. The company has introduced its portable "Portapak" fuel cell unit, powered by a **Palcan** PC-150 fuel cell stack in 2003, and is selling it for US\$6,000. A more rugged unit for military applications has been developed as well.



Fig.27: 150W military Portapak. Source: Voller Energy.

Acknowledgement

We would like to thank everybody involved in putting this report together, especially Simon Robeson from Core Technology Ventures.

About the authors

Stefan Geiger and David Jollie both work for Fuel Cell Today, the global Internet portal bringing you free, comprehensive and authoritative fuel cell news, commentary, resources and business opportunities. To contact the authors, please send an email to: survey@fuelcelltoday.com © Fuel Cell Today, 2004