FUEL CELL TODAY

Opening doors to fuel cell commercialisation

Alkaline Fuel Cells (AFC)

Gemma Crawley, Fuel Cell Today – March 2006

Introduction

This is the second of a series of six articles designed to focus on each of the fuel cell technology types in turn. The reviews are intended to provide a brief overview of the technical aspects of each system, the developmental milestones achieved, an estimate of the number of units currently in operation and a review of the key companies involved in the development, manufacture and commercialisation of each fuel cell type. Looking forward, the reports will also aim to provide details of any goals set by fuel cell companies for each system.

The first of the articles focussed on proton exchange Membrane fuel cell (PEMFC) technology and this second instalment takes an in-depth look at alkaline fuel cell (AFC) systems. The remaining articles will eventually cover SOFC, DMFC, MCFC, and PAFC over the course of the next year.

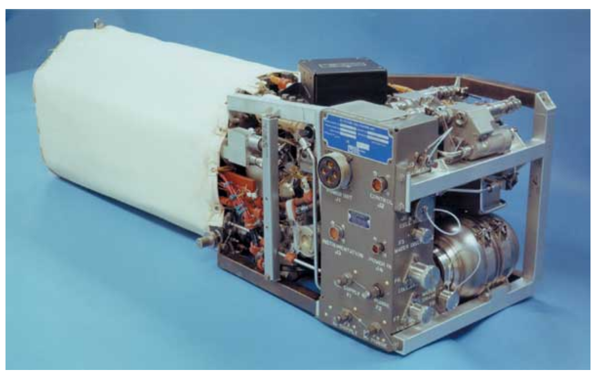
Technological Overview

All fuel cell systems are based on a central design where two electrodes, a negative anode and a positive cathode, are separated by a solid or liquid electrolyte that carries electrically charged particles between them. The AFC uses an alkaline electrolyte such as potassium hydroxide (usually in a solution of water) in order to operate.

AFC systems are classified as low temperature fuel cells and usually operate between 60 and 90^{0}C. As a result of the low operating temperature, it is not necessary to employ a platinum catalyst in the system and instead, a variety of non precious metals can be used to speed up the reactions occurring at the anode and cathode. Nickel is the most commonly used catalyst in AFC units.

Due to the rate at which the chemical reactions take place within the cell AFC systems usually demonstrate efficiencies between 45 and 60%. AFCs can produce up to 20kW of electric power and some newer designs have been reported to operate at temperatures as low as 23-70^{0}C.

The disadvantage of using AFCs is that these particular systems are easily poisoned by carbon dioxide. The strongly alkaline electrolytes adsorb even the smallest amount of CO_2 which in turn eventually reduces the conductivity of the electrolyte. Consequently pure hydrogen (rather than that impure, CO_2 containing hydrogen) must be used as the feedstock. For effective operation it is also necessary to purify the oxygen used in the cell and together these purifications can be very costly. Furthermore, susceptibility to poisoning can also reduce the AFC lifetime meaning AFC units have to be replaced at a faster rate than some other fuel cell types. The electrolyte material is also corrosive and, being in liquid form, makes the sealing of the anode and cathode gases more problematic than when a solid electrolyte is used.



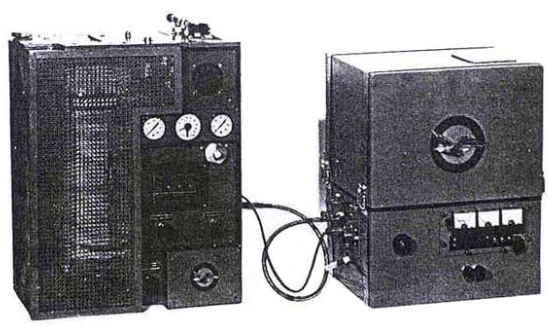
An AFC Power Plant used by NASA to provide auxiliary power and drinking water to each spacecraft in the space shuttle fleet (Courtesy of UTC Fuel Cells)

The AFC was originally used by NASA on space missions to provide electric power and drinking water to the shuttle. Today, the AFC is used predominantly in niche transportation applications, powering forklift trucks, boats and submarines. It is still used in space applications and NASA continues to operate several AFC units. To become competitive in mainstream commercial markets, AFCs have to become more cost effective and reach operating times of over 40,000 hours. Previously, the AFC has demonstrated stable operation for more than 8,000 hours but this number has not been improved upon due to material durability issues.

AFC Developmental Milestones

The AFC was developed in the 1930s by F.T. Bacon and is one of the oldest fuel cell technology types. In 1954 Bacon demonstrated a six cell battery that produced 150W and in 1956 his team built a 40 cell unit based on the same design. The larger unit produced 6kW and was used to power a fork-lift truck, welding equipment and a circular saw. In 1961, Bacon formed Energy Conversion (Ltd) and the company began to develop fuel cells which could be produced commercially.

Whilst development work was progressing on Bacon's larger unit, two licenses were granted on the technology patents. One of these licenses went to Pratt & Whitney in 1959 and then three year later, in 1962, the company started to develop an AFC power plant for the Apollo space programme. Three AFC units were employed to supply drinking water and power for life support, guidance and communications functions to the shuttle during its two week expedition to the moon and the AFC unit became the first type of fuel cell to be widely used in the U.S space programme.



Pratt & Whitney 500W Alkaline Fuel Cell with Steam Reformer
(Courtesy of Pratt & Whitney Aircraft)

In 1959, Allis-Chalmers Manufacturing Company developed and demonstrated the world's first fuel cell powered vehicle. The AFC powered tractor was used to successfully plough a field in Wisconsin, USA before being donated to the Smithsonian Institute. The tractor was followed by an AFC powered golf cart in 1962 where the AFC unit was fuelled by hydrazine and provided 4kWe of continuous power and 10kWe peak power. The buggy was used in several demonstrations and promotion events between 1962 and 1963 and the company went on to manufacture several other AFC powered vehicles including forklift trucks and a submarine.

Allis-Chalmers AFC Golf Cart (Courtesy of Edward Gillis)

In 1967, Dr Karl Kordesch of Union Carbide developed and built an AFC motorbike. The machine used hydrazine as a fuel and could travel 200 miles per gallon of hydrazine. In total, the motorbike travelled over 300 miles at a top speed of 25 miles per hour. Whilst at Union Carbide, Kordesch went on to develop an alkaline fuel cell vehicle based on the Austin A40. The car was used by Kordesch for his own personal transportation around Ohio for three years. It had a driving range of 180 miles and was capable of seating four people.

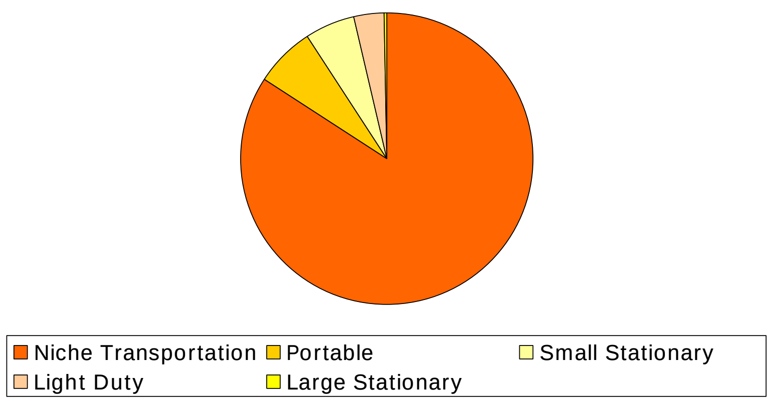
Dr Karl Kordesch of Union Carbide driving his AFC powered motorbike (Courtesy of Smithsonian Institute)

Despite the AFC being the earliest fuel cell type to be developed the system does not enjoy as widespread application today as when it was first introduced. Due to the cell's susceptibility to CO_2 and the need to purify the hydrogen fuel, the AFC has so far only conquered niche markets. Despite some recent efforts by companies such as

Astris Energi (mentioned in further detail in the Key Player section of this report) to commercialise AFC technology the majority of systems are today found powering niche transportation applications. The space programmes still provide opportunities for AFC units and the electric power onboard today's shuttles is often still generated by AFCs.

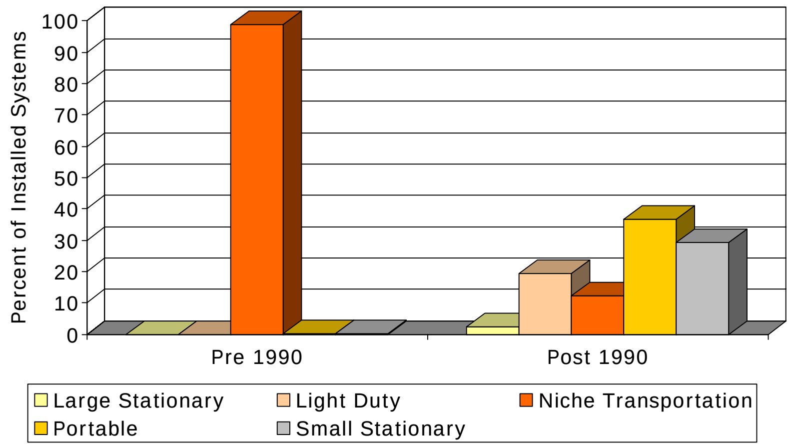
The Current AFC Market

The current market for AFC systems is somewhat limited. Compared to the other fuel cell technologies, the number of AFC units in operation is not significantly high and in 2005, only a very small number of new systems were introduced. The majority of units are used in the niche transportation sector which covers motorbikes, forklift trucks, marine, submarine and space applications in addition to others.



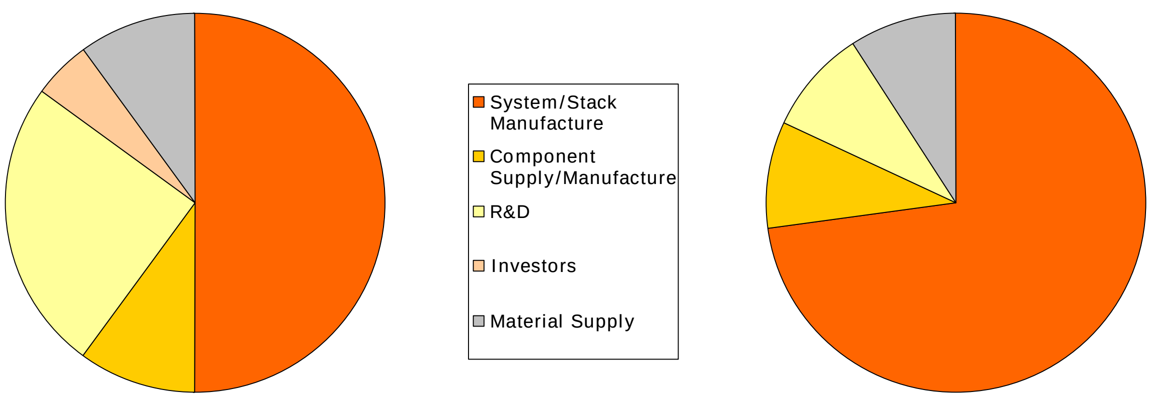
Total Number of AFC Units Installed Globally by Application

Of the units installed globally, just over 80% were introduced before 1990. Most of these systems were used in space applications with the rest installed in other one off niche transportation development and demonstration vehicles. The AFCs introduced after 1990 have mostly been installed in light duty, portable and small stationary end-uses. During the space race AFCs were the technology of choice and a high level of research and development was undertaken. This pushed the AFC to the limits of its technological capability and when PEM units were introduced in the 1980s as a new fuel cell alternative many applications, particularly the transportation sector, began to favour these PEM systems. It has only been in the last five or six years that AFC technology has enjoyed a revival as some companies began to look at the system again and further develop its capability for effective operation in stationary and portable applications.



AFC Systems Installed Globally Split by Date Introduced and Application

Geographically, Europe accounts for the lion's share of installed AFC units with around 55% of all AFCs being located in this region. The majority of European AFC companies are systems and stack manufacturers and this is reflective of a more general global trend. Unlike PEM technology, the number of AFC system/stack manufacturers and component suppliers/manufacturers are not evenly matched.



AFC Activity Globally and in Europe (from left to right) by Application. Data based on a discrete sample of companies listed in the FCT Industry Directory.

It is clear from the pie charts on the previous page that on a global level, research and development of AFC systems has an important role. This corresponds to the trend of the past five to six years for companies and organisations to re-examine existing AFC technology and further develop the potential of existing capabilities.

Approximately 70% of the organisations involved with AFC activity are operating as commercial entities. The remaining 30% of companies describe themselves to be academic institutions, government agencies or investors. This high percentage of commercial businesses compared to investors and academic groups suggests that the AFC sector has previously experienced the research and development phase (occurring during the space race) and now companies are working towards commercialisation of this technology.

Key Company Review

Although the **Allis-Chalmers Manufacturing Company** no longer exists, it would be wrong not to include the organisation in a key company review. Allis-Chalmers pioneered the commercial development of AFC technology, producing not only the world's first fuel cell powered vehicle but also the world's first fuel cell powered submersible. Allis-Chalmers developed a wide range of fuel cell powered vehicles before dispersing in 1999.

The world's first fuel cell powered vehicle. Allis-Chalmers developed the AFC tractor in 1959.

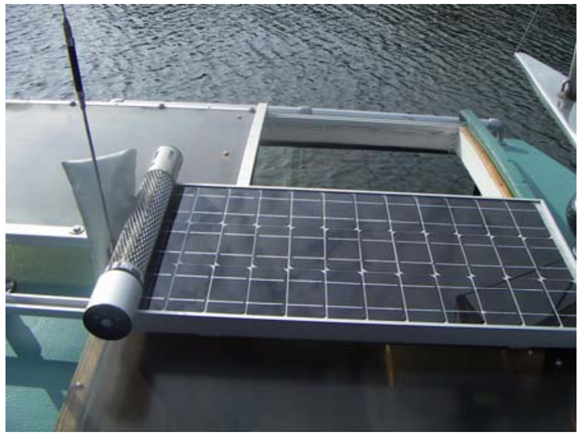
Apollo Energy Systems is an American company which has developed the "Apollo Alkaline Fuel Cell". Based on the AFC used in the Apollo moon mission, the company has developed a hybrid AFC/lead cobalt battery system designed to supply power to residential, transportation and space applications. The battery component is used to supply direct power and the AFC is used to charge the battery.

Astris Energi is a manufacturer of AFCs and fuel cell systems. Founded in 1983, the company's technology is designed primarily for use in small engine applications providing up to 10kW. Astris AFCs have been used in a variety of niche transportation applications including golf carts, forklifts and boats. In addition Astris has demonstrated its AFC in portable and stationary power generators. In February 2003, Astris jointly founded Astris Transportation Systems with Care Automotive to mass produce AFC systems. However, due to financial issues this agreement was cancelled in December 2003. In March 2006, Astris announced that it had shipped an initial order of AFC generators to Mobile Attic for use with Mobile Attic's portable storage product. Astris also has a development and manufacturing affiliate in the Czech Republic.

The Swiss company **EFFCELL** manufacturers AFC systems for use in mobile applications ranging from 2 – 50kW output. The company had planned a testing programme for fuel cell vehicles using its AFC unit between 2004 and 2005.

Eneco was founded in February 2002 after acquiring technology developed by **Fuel Cell Systems**, which went in to administration following the collapse of parent company **Zetek Power**. Eneco develops AFC systems for stationary and transportation applications, including hybrid vehicles and has worked on the production of a 3.5 tonne AFC powered bus. Eneco is a UK based company and works closely with the College of North West London, conducting a course to train engineers in hydrogen fuel cells. In March 2003, the company supplied the college with an AFC unit for education use as part of this course.

Founded in 1993, **Hydrocell** is a Finnish company producing and selling AFC units for use in niche transportation applications. Hydrocell's "HC-100" and "HC-400" products are being promoted to be used in combination with other clean energy sources to power, amongst other things, boats, electric bikes and electric scooters. Hydrocell is also working to develop metal hydride hydrogen storage systems for use with its AFC units.



The Hydrocell 'HC-100' AFC unit used in conjunction with solar panels to power an APU on a boat (Courtesy of Hydrocell)

Industrial Research is a New Zealand company developing fuel cell systems for micro-scale stationary power supply applications (up to 100kW). The company has manufactured several small (up to 5kW) AFC units and is focussing on the field demonstration and commercialisation of these systems for niche markets. The company is also involved in a NZ$6 million government funded programme to develop hydrogen fuel cell technology fuelled by hydrogen extracted from coal.

NASA is one of the major adopters of AFC technology and, as previously mentioned, the systems have been used to supply power to numerous moon missions. NASA has also been active in developing fuel cell systems and the **NASA Glenn Research Centre (GRC)** has been developing fuel cell technology for NASA and other US government agencies since the 1960s. The NASA GRC worked on the AFC systems used in the Apollo space mission.

The involvement of **United Technologies Corporation** (UTC) with AFC technology began in 1958 when **Pratt & Whitney** (the industrial gas turbine division of UTC) started to investigate AFC systems. UTC licensed some AFC patents in the early 1960s and then went on to supply AFC units (through Pratt & Whitney) to NASA for use on the Apollo moon mission. In 1985 UTC established **International Fuel Cells (IFC)** as a dedicated company for research and development in to fuel cell technology. In December 2001, IFC was renamed **United Technologies Corporation Fuel Cells (UTCFC).** Since supplying the initial AFC units for the Apollo mission UTCFCs fuel cells have gone on to supply power and drinking water for over 100 manned US space flights including those aboard the Space Shuttle. In total the systems have recorded more than 90,000 hours of operation in space. In addition to space applications, UTC produces and develops fuel cell products for the stationary, transportation and residential sectors.

Future Prospects for AFC Systems

Despite a handful of companies working to develop AFC markets, future prospects for the technology are somewhat limited. The predominance of PEM, direct methanol (DMFC) and solid oxide (SOFC) technology has left only a small market opportunity for AFC units as these other systems outperform the older AFC technology.

Attempts are being made to improve upon the already well developed and established AFC technology and in doing so create further commercial applications for these systems. However, many believe that AFCs have already reached the limits of their technological capability and in doing so will remain the least commercially successful of all the fuel cell technologies.

About the Author

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