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FUEL CELL POWER

Generating electricity, heat and hydrogen, cleanly ,quietly and efficiently

HEADLINE NEWS

Ballard Power's 1 Megawatt fuel cell ensures uninterrupted power supply for First Energy's customers in Ohio.

In Africa, Ballard is developing a home generator with an integrated low cost methanol reformer. During Hurricane Sandy, Ballard's fuel cells supplied critical electricity for the telecoms network in the Bahamas.

Intelligent Energy is working with partners in India to diversify their energy portfolio and alleviate energy poverty, with fuel cells powered by hydrogen from indigenous sources.

CONTENTS

BALLARD FUEL CELLS FOR LOCAL ELECTRICITY GENERATION

POWER FOR AFRICAN HOMES

Ballard Power Systems has announced significant progress under a Product Development Agreement with Anglo American Platinum Limited, related to fuel cell-powered electric generators for the African rural home market. Under the agreement, Anglo American Platinum has committed to fund development and testing of the planned home generator, which will be capable of providing primary power to homes in remote African communities that are without access to the electrical grid. Work to date has included a market feasibility study, testing of a proof-of-concept system based on existing technology from Ballard and Dantherm Power, Ballard's backup power company, and initial work on a prototype system.

LOW COST METHANOL REFORMER

The home generator is being developed as a means of addressing the many African households in rural communities that are currently unable to economically access the grid as a result of distance or terrain. The home generator will run on readily available methanol fuel, utilizing an integrated fuel reformer. Ballard is providing fuel reformer and fuel cell stack technology and Dantherm Power will provide the remaining system components needed for the finished product. Andrew Hinkly, Executive Head – Commercial for Anglo American Platinum said, "This is a key initiative, as part of our commitment to beneficiation in South Africa. It will create jobs, deliver clean energy to parts of Africa that go without power today, and of course promote a product that uses platinum. So, we are delighted to be working with a fuel cell market leader in Ballard." John Sheridan, President and CEO of Ballard Power Systems, added, "We are excited by the progress to date under our agreement with Anglo American Platinum. The agreement is clear evidence of their commitment to fuel cells and will enable the development of an integrated small-scale stationary power system, which could have a transformational impact in South Africa and beyond."

Once Ballard has completed development of a prototype system meeting commercial product requirements, the companies will undertake further field trials, potentially leading to the manufacture, distribution and support of a commercial product for the African market. The low-cost fuel reformer being developed for the home generator will also represent an important evolutionary step for the methanol fuel cell products recently acquired by Ballard from IdaTech.

CRITICAL ELECTRICITY DURING HURRICANE SANDY

During the difficult circumstances presented by Hurricane Sandy, Ballard's ElectraGen™-ME methanol fuel cell systems performed exactly as designed, providing critical electricity to the Bahamas mobile telephone network when the storm downed power lines and cut off grid power. Ballard's seventeen ElectraGen systems, installed in the local telecom network, began operating automatically as grid power was lost when the storm hit on October 25th.

During the three days that Hurricane Sandy passed over the Bahamas, each of the 5 kilowatt systems operated flawlessly as needed to maintain consistent power. As a group, the seventeen systems provided the equivalent of one month of backup power over a concentrated seven day period during and after the storm, producing more than 1,200 kilowatt-hours of electricity. Dr. Christopher Guzy, Ballard's Chief Technology Officer said, "Hurricane Sandy was a devastating event for a great many people. In times of emergency, backup systems have to be reliable. We are certainly pleased that our ElectraGen fuel cell systems kept the communications network up and running for people in the Bahamas when they most needed it."

The impact of Hurricane Sandy has been a further illustration of the importance of extended duration backup power capability for communication networks. For the over 347,000 residents of the Bahamas dealing with sustained winds of 80mph, up to 6 – 12 inches of rainfall accumulation and a storm surge 5 to 8 feet above normal ocean levels, continuous and reliable communications were critical. The ElectraGen system includes a fuel reformer that converts HydroPlus™, a methanol-water liquid fuel mixture, into hydrogen gas that is used as a fuel feedstock for the fuel cell system. The only outputs from the fuel cell system are electrical power, heat and water.

SUPPORTING MOBILE NETWORKS DURING GRID OUTAGES

Nokia Siemens Networks is working with Ballard Power Systems to develop mobile networks that can continue to operate during power blackouts. Japanese operator NTT DOCOMO has evaluated the Nokia Siemens Networks Flexi Multiradio base station, with integrated fuel cell backup, for potential commercial deployment. "Mobile networks can be vital when a natural disaster strikes, and power outages make other forms of communication difficult," said Mark Donaldson, head of mobile broadband energy solutions at Nokia Siemens Networks."Integrating fuel cells with our base stations can significantly increase the resilience of the mobile networks we provide."

"Our fuel cell systems provide power for extended periods during outages caused by natural calamities and commercial grid failures," added Larry Stapleton, vice president of sales at Ballard. The collaboration with Nokia Siemens Networks has helped us leverage our service and integration expertise in order to deliver an emergency-ready alternative power solution for mobile networks."

Backup power solutions based on fuel cell technology deliver a number of advantages over conventional batteries and diesel generators. These include higher reliability across a wide range of operating conditions, lower maintenance costs, longer operating life as well as reduced size, weight, installation footprint, noise signature and environmental impact. The fuel cell weight and size are significantly less in comparison to existing lead acid batteries that are typically used in many base stations to provide backup power for extended outages. The base station and fuel cell combination developed by Nokia Siemens Networks with Ballard can provide 4.5 kilowatts of power for approximately 40 hours on a single tank of fuel. The solution from Nokia Siemens Networks and Ballard has already received the Ministry of Economy, Trade and Industry (METI) statutory approval in Japan.

REDUCING ENVIRONMENTAL IMPACTS WHILE IMPROVING PRODUCTIVITY

Ballard is a 2012 recipient of the Deloitte Technology Green™ 15 Award, designed to showcase Canadian companies that are creating economically viable intellectual property in the field of green technology. "The Deloitte Technology Green 15 Award winners deliver innovative solutions that promote an efficient use of the earth's resources," said Richard Lee, National Leader, Technology, Media & Telecommunications Industry Group, Deloitte. "Ballard Power Systems is an outstanding example of a company that is creating technology solutions that reduce environmental impacts while improving operational performance and productivity." Ballard's clean energy fuel cell products enable optimized power systems for a range of stationary and motive applications – including communications backup power, material handling, distributed generation and bus applications.

"To displace incumbent technologies, new clean energy product solutions must deliver against both the economic and environmental bottom line," said John Sheridan, President and CEO of Ballard Power Systems. "Now, within our commercial stage market segments of communications backup power and material handling, end-users are experiencing a compelling return on investment." More than 150 megawatts of Ballard's fuel cell products have been deployed commercially across the globe in Europe, Asia, Africa, North America and Central America.

1.1 MEGAWATT CLEARGEN FUEL CELL SYSTEM

Ballard Power Systems has announced the commissioning of a 1.1 megawatt ClearGen™ fuel cell system installed at the Toyota Motor Sales U.S.A., Inc. headquarters campus in Torrance, California. Powered by Ballard's proprietary proton exchange membrane (PEM) fuel cells, the ClearGen system enables Toyota to satisfy peak and mid-peak power needs using electricity from either the clean energy fuel cell system or from the power grid. "Reducing our demand for electricity from the utility will create an estimated savings of one hundred thousand dollars each summer, while at the same time reducing our environmental footprint," said Doug Beebe, Toyota Administrative Services Corporate Manager. Hydrogen fuel is delivered directly to the system by means of an existing pipeline, which also supplies a local fuel cell vehicle fuelling station. Pipeline hydrogen used on Toyota's campus will be offset with the purchase of landfill generated renewable bio-gas.

"Toyota is taking advantage of the inherent load-following capability of PEM fuel cells," said Paul Cass, Ballard Vice President of Operations. "The flexibility of our scalable ClearGen system is such that it can operate intermittently to provide peak power during times of high demand or continuously to meet base load power needs."

This project represents the first deployment of a Ballard stationary fuel cell power generation platform, the development of which was supported by funding from Sustainable Development Technology Canada (SDTC), an arm's-length, not-for-profit corporation funded by the Government of Canada that helps commercialize Canadian clean technologies, readying them for growth and export markets. "This announcement clearly shows the bottom-line impacts of clean technologies: saving money, improving efficiency and making the most of resources," said Dr. Vicky Sharpe, President and CEO of SDTC. "We congratulate Ballard on reaching this important milestone and Toyota on showing leadership through early adoption." Project funding is also being provided through California's Self-Generation Incentive Program. www.ballard.com

HYDROGEN SOUTH AFRICA *(HySA)* AIMING FOR INTERNATIONAL MARKETS

Hydrogen South Africa (*HySA*) is aimed at developing South African participation in the nascent but rapidly developing international platforms in hydrogen and fuel cell technologies. The 15 year programme was initiated by the South African Department of Science and Technology (DST) in 2008. The principal strategy of *HySA* is to carry out research and development work, with the aim of achieving a 25% share of the global hydrogen and fuel cell market, using platinum group metal (PGM) catalysts, components and systems, since South Africa has more than 75% of the world's known PGM reserves. The work of *HySA* consists of five key programmes namely: combined heat and power; portable power systems; hydrogen fuelled vehicles; hydrogen filling stations; and renewable hydrogen production.

Hydrogen South Africa Systems' or HySA Systems is one of three National Competence Centres making up *HySA*. Hosted by the University of the Western Cape, it is directed by Professor Bruno G. Pollet FRSC.

HySA Systems focuses on system integration, technology validation, and product development. The long-term goal for HySA Systems is to develop key components for hydrogen and fuel cell technologies, validate technology and systems for specific applications, and facilitate the export of new technology from South Africa to international markets. HySA Systems operates in two key programmes: combined heat and power (CHP); and hydrogen fuelled vehicles. HySA Systems is also responsible for the development, validation and commissioning of membrane electrode assemblies (MEAs) for high temperature Proton Exchange Membrane (PEM) fuel cells; hydrogen purification (pd membranes); metal hydrides for hydrogen storage and compression; lithium ion batteries; and system integration of energy storage devices for domestic and automotive applications.

HySA Systems has developed, demonstrated and validated many prototype systems/ products. For example, they successfully assembled a 2kW PEM fuel cell stack from locally sourced/manufactured components, based on the technology from the Zentrum für Sonnenenergie-und Wasserstoff-Forschung (Center for Solar Energy and Hydrogen Research) in Germany.

Recently, Impala Platinum (Implats), the world's second largest producer of Platinum, has announced that it is partnering with DST to use and build local skills in the development of hydrogen and fuel cell products. Implats will initially co-fund a niche project, in collaboration with HySA Systems, to use South African raw materials to explore novel on-board hydrogen storage devices for use in utility vehicles such as forklifts.

The two other National Competence Centres are 'HySA Catalysis' and 'HySA Infrastructure'. The mandate of HySA Catalysis includes the components in the early part of the value chain, namely catalysts and catalytic devices and it also plays the leading role in the portable power systems programme. HySA Catalysis is jointly hosted by the University of Cape Town and the national mineral research organisation Mintek.

HySA Infrastructure has the mandate to develop technology for hydrogen production, storage and distribution and leads on the programmes with hydrogen filling stations and renewable hydrogen production. HySA Infrastructure is co-hosted by North West University (NWU) and the Council for Scientific and Industrial Research (CSIR). www.hysasystems.org

A TRANSFORMATIVE SHIFT IN GLOBAL ENERGY EFFICIENCY

Delegates at the UN Framework Convention on Climate Change (UNFCCC) in Doha deferred further action to reduce emissions of global warming gases. However, present commitments are not sufficient to meet the target of a maximum global temperature rise of 2°C, which is required to limit the risk of severe climate change.

The International Energy Agency's *World Energy Outlook 2012* envisages increased production of unconventional oil and gas supplies, led by the United States. However, the potential also exists for a similarly transformative shift in global energy efficiency, according to the Executive Director, Maria van der Hoeven. Energy efficiency is just as important as unconstrained energy supply and increased efficiency can serve as a unifying energy policy that brings multiple benefits. Taking all new developments and policies into account, the world is still failing to put the global energy system onto a more sustainable path. Successive editions of the *World Energy Outlook* have shown that the climate goal of limiting warming to 2°C is becoming more difficult and more costly with each year that passes. In the *Outlook 2012*, emissions in the New Policies Scenario correspond to a long-term average global temperature increase of 3.6°C.

'EFFICIENT WORLD SCENARIO'

The *World Energy Outlook 2012* presents the IEA's 'Efficient World Scenario' which shows how tackling the barriers to energy efficiency investment can realise huge gains for energy security, economic growth and the environment. Energy related CO_2 emissions would peak before 2020, with a decline thereafter consistent with a long-term temperature increase of 3°C. No more than one-third of proven reserves of fossil fuels can be consumed prior to 2050 if the world is to achieve the 2°C goal, unless carbon capture and storage (CCS) technology is widely deployed. Although the measures taken in the 'Efficient World Scenario' would not be sufficient to meet the 2°C target, the rapid deployment of energy-efficient technologies would buy time to secure a much needed global agreement to cut greenhouse-gas emissions. "It would also bring substantial energy security and economic benefits" said Fatih Birol, IEA Chief Economist.

WASTEFUL CENTRALIZED ELECTRICITY GENERATION

The central generation of electricity is wasteful. Overall electricity generation and transmission is only about 40% efficient. It is estimated that the thermal energy wasted during the central generation and transmission of electricity would be sufficient to heat every building in the UK. On the other hand, onsite electrochemical energy conversion with fuel cells can provide electricity, heat and cooling with efficiency from 80% up to 90%.

The deployment of intermittent renewable energy will require additional back-up capacity, although this could be reduced by non-generation methods such as interconnection, energy storage and load management. A report by the Bow Group entitled '*Rescuing Renewables: How energy storage can save green power*' finds that the following advantages would accrue if hydrogen were stored locally: improved efficiency as supply matches demand : the need for fossil fuel back-up is removed: lower carbon emissions : less investment in infrastructure costs : reduced stress to the system as ramping up and down is minimized : grid stability and continued freedom from blackouts: and community, business and individual self-sufficiency.

ENERGY WASTED IN BUILDINGS

Huge amounts of heat are wasted in poorly insulated buildings, although this is expected to be considerably reduced by the Government's new Green Deal. On the other hand, there is little backing for efficient combined heat and power (CHP) systems which generate electricity and heat on site. CHP systems over 2kW do not qualify for Feed-in-Tariffs (FiTs) but have to compete with less efficient technologies subsidised by the taxpayer.

It is proposed that heat pumps should be utilised in future to heat buildings. However, the peak winter demand for heat is up to three times greater than that for electricity, so the unmitigated cost of heat pumps to replace gas boilers would be prohibitive. If fuel cells are installed alongside heat pumps, they would generate electricity to power the heat pumps as well as contributing to the heat demand.

INEFFICIENT I.C. ENGINES

The internal combustion (i.c.) engine is only about 35% efficient and in stop/start urban driving efficiency is as low as 15%. Electric drive trains are generally at least twice as efficient in all driving cycles.

An i.c. engine has to be sized to meet the peak load requirements for motorway driving, and is very inefficient at low load in urban operations. In a hybrid electric configuration, a fuel cell rated at about a fifth of peak power demand can operate at constant maximum efficiency, with batteries or ultra-capacitors providing transient peak power. This enables a 20kW fuel cell operating at constant optimum to power a five seat family car that can cruise at 75mph. British small and medium enterprises (SMEs) are developing electric vehicles which are lighter and cheaper than the steel bodied cars which are currently subsidized. The Government is taking an active role in UKH_2Mobility. This aims to provide the hydrogen infrastructure to meet the requirements of the global motor companies which are planning to start commercial production of hydrogen fuel cell vehicles between 2015 and 2020. Hydrogen produced from off peak electricity is already found to be cheaper than petrol or diesel.

AIM TO HALVE PRIMARY ENERGY

As pointed out in the *World Energy Outlook 2012*, only a third of proven fossil fuel reserves can be utilised by 2050 if we are to avoid the risk of severe climate change. Instead of looking for more unconventional fossil fuel resources, we could aim to halve the fuel used for heat, electricity and transport. Further reductions in fossil fuel use could be achieved if $C0_2$ is extracted from the atmosphere and synthesized with renewable hydrogen to form gaseous or liquid fuels, in a carbon capture and recycling process (CCR). In order to expedite the commercialization of efficient energy technologies, facilities are needed for evaluation and demonstration projects. A recent EU study entitled Finance, Innovation and Growth (FINNOV) finds that there is little private investment available for innovative SMEs. A diverse low carbon energy system will include more distributed electricity production with a variety of technologies providing power, heat and energy storage for homes, industry and transport. More information can be found in the recent report entitled 'Engineers Against Climate Change' at www.fuelcellpower.org.uk

NEWS

CONSTANT, RELIABLE ELECTRICITY FROM BLOOM ENERGY

Sharks Sports & Entertainment (SSE), has announced that solid oxide fuel cell (SOFC) technology is now providing cleaner, more reliable and more affordable energy for San Jose's premier sports and entertainment venue. The installation was completed in October and the fuel cells are already in use. The Bloom boxes (two 200kW servers) replace approximately 90% of the electrical utility power at HP Pavilion used during non-event hours and approximately 25% used on a Sharks game day. Due to the efficiency of the Bloom box, HP Pavilion at San Jose will reduce its carbon footprint by 4.8 million pounds of CO_2 over a ten-year period, which equates to taking 427 passenger vehicles off the road.

In July 2011, AT&T announced an initial contract with Bloom Energy to deploy 7.5 MW of "Bloom Boxes" at 11 AT&T sites in California including data centers. With a second wave of fuel cell installations in California and Connecticut, AT&T will have 17.1 MW of Bloom Energy Servers helping to power 28 AT&T sites in California and Connecticut. Once fully operational, all of AT&T's Bloom Box installations are expected to produce more than 149 million kilowatt hours (kWh) of electricity annually, enough to power about 14,000 homes per year. "AT&T continues to be on the forefront of energy management and understands the need to find innovative ways to power the next generation." said KR Sridhar, CEO of Bloom Energy.

Displaying a fuel cell, he said "The investment they are making now not only means they will have control of their own energy destiny, but will also help ensure a brighter and more energy rich future for all." www.bloomenergy.com

INTELLIGENT ENERGY EXPANDING IN OVERSEAS MARKETS

COLLABORATION WITH INDIAN OIL

Intelligent Energy and Indian Oil Corporation Limited (IndianOil), India's largest oil and gas company, have signed a Statement of Intent to initiate demonstration projects and work collaboratively to develop the use of hydrogen in a range of fuel cell power systems in the Indian market.

The Statement of Intent was signed by Dr. S.K. Sarangi, Executive Director, Alternate Energy, IndianOil and Dr. Henri Winand, CEO, Intelligent Energy in the presence of Mr. R.S. Butola, Chairman, IndianOil. Under the agreement, IndianOil and Intelligent Energy will prepare a multi-phased programme to demonstrate and eventually deploy hydrogen-based power systems. The collaboration will demonstrate the most appropriate applications for fuel cells, using hydrogen generated by IndianOil. This will include exploring applications such as material handling, telecom towers and motive power, with direct relevance to the growing need in India to adopt low-carbon and high air-quality power system technologies.

Dr. R. K. Malhotra, Director for R&D at Indian Oil Corporation Limited, said: "IndianOil is at the forefront of exploring new technology innovations to support the burgeoning energy needs of the Indian subcontinent. We expect this relationship to be taken forward for demonstration of hydrogen for various fuel cell applications".

Dr. Henri Winand, CEO, Intelligent Energy, added: "Intelligent Energy and IndianOil share a similar vision and commitment to driving innovation in sustainable and more efficient power systems. We are very enthusiastic about the potential of this collaboration with India's largest oil and gas company to address the very large market opportunities afforded by India's continued economic growth. Intelligent Energy provides a range of technologies that are key transition assets in the move to a more diverse range of energy sources, which can co-exist alongside hydrocarbons for the provision of energy in the 21st century."

IndianOil's exploration of renewable energy is aimed not only towards the diversification of its energy portfolio but also to alleviate energy poverty and improve energy access at the 'base of the pyramid' in India.

RANKED AS UK HIGHEST ENERGY AND GREEN TECHNOLOGY COMPANY

Intelligent Energy was ranked as the highest energy and green technology company by the 2012 Deloitte Technology Fast 50. Overall the company came 33rd out of the 50 fastest growing technology companies in the UK. The company partners with some of the world's best-known names in the automotive, power and consumer electronics markets. In early 2012, Intelligent Energy and the Suzuki Motor Corporation formed a joint venture company, Smile Fuel Cell System Corporation, to develop and manufacture air-cooled fuel cell systems for zero emission vehicles and a range of other industry sectors. Intelligent Energy was also the lead partner in a consortium, delivering a fleet of zero emission fuel cell electric cabs onto London's roads in 2012.

Intelligent Energy's proprietary fuel cell systems are powerful, compact and simple to construct, which drives its resource efficient strategy to 'design once, deploy many times'. This approach enables partners to accelerate and de-risk their go-to-market plans.

David Halstead, Partner leading the Deloitte Technology Fast 50, said: "The Deloitte Technology Fast 50 gives great profile to technology companies and is internationally recognised as being one of the most important business awards in the sector".

CONTRIBUTING TO ECONOMIC GROWTH IN EUROPE

The 5th Fuel Cell Electric Vehicle 'Drive 'n' Ride' took place in Strasbourg under the patronage of Brian Simpson, MEP, Chair of the European Parliament's Transport and Tourism Committee, to demonstrate the readiness of fuel cells and hydrogen as a viable route to zero emission transport in Europe. Over two days, MEPs, political advisors and other stakeholders had test-drives of six different models of fuel cell electric cars from Daimler, Honda, Hyundai, Intelligent Energy, Opel and Toyota. Participants also had the opportunity to watch the refuelling process at a fully mobile and compact hydrogen station, the first of its kind in the city of Strasbourg, provided for the occasion by Air Liquide.

Intelligent Energy's Dennis Hayter discussed the advantages of fuel cell electric vehicles with MEP Anna Rosbach.

"The future of transport is very high on the European Parliament's agenda. We need to find ways to make our transport system more sustainable and environmentally responsible, while contributing to the economic recovery and growth in Europe. Deployment of practical and efficient clean technologies is an indispensable part of the solution for a low-carbon transport system. Europe can't miss this opportunity," stated Brian Simpson MEP.

GERMANY, UK AND SCANDINAVIAN COUNTRIES SUPPORTING FUEL CELL VEHICLES AND H_2 INFRASTRUCTURE

The 'Drive 'n' Ride' event aimed to address the challenges associated with building the refuelling infrastructure and reducing costs as larger scale production is achieved. It follows the announcements by national governments in Germany, the UK and Scandinavian countries to support the market introduction of fuel cell electric vehicles and refuelling stations. The German government, for example, has announced that the 14 stations currently available in Germany should be increased to 50 sites by 2015.

"Fuel cell electric vehicles and the refuelling technology are clean, safe and ready for deployment. They live up to expectations and are comparable to internal combustion engine vehicles in terms of range and performance. The key question now is how to bring them to the market as a competitive option," said Pierre Etienne Franc, Director of Technologies of the Future at Air Liquide. He is also the Chairman of the Fuel Cells and Hydrogen Joint Undertaking, the European public-private partnership that brings together the European Commission, Industry and the Research community working in the fuel cell and hydrogen sector.

Companies participating in the 'Drive 'n' Ride' emphasised the need to continue reinforced public-private partnerships within the European Commission's Horizon 2020 programme for R&D and to develop effective support tools for deployment. "Only strong public-private partnerships will create the stable framework needed to bridge the gap to full commercialisation and, in consequence, create jobs and growth in Europe," stressed Pierre-Etienne Franc. The 'Drive 'n' Ride' highlighted the potential of fuel cells and hydrogen technologies for tackling transport emissions and contributing to a more secure, sustainable and competitive transport system in Europe. 'Drive 'n' Ride 2012' was organised by Air Liquide, Daimler, Hyundai, Honda, Intelligent Energy, Opel and Toyota and sponsored by Linde, Hydrogenics, ITM Power, Shell, Nissan and the Fuel Cells and Hydrogen Joint Undertaking.
www.intelligent-energy.com

FUEL CELLS

This is PART III in a four part series entitled Batteries and Fuel Cells
By Prof A John Appleby

PART I was published in Fuel Cell Power Spring 2012
PART II was published in Fuel Cell Power Summer 2012
PART IV Low Temperature Fuel Cells will follow

INTRODUCTION:

What became known as "fuel cells" after the 1839 work of Grove and more particularly after the experiments of Mond and Langer in 1889 along more modern lines were cells of non-rechargeable type (i.e., primary cells), supplied by fuel and oxidant to the separate electrodes *from the outside*, with means to remove the reaction products. The classic fuel for such cells (following Grove in 1839) was hydrogen gas, and the classic oxidant was oxygen in air in ordinary applications. The water product was removed by whatever physical means was possible. Grove's cells used dipping high-surface-area flat platinized platinum (platinum black) electrodes immersed in sulfuric acid electrolyte, in which a meniscus of liquid electrolyte wetted a flat platinum-coated electrode between the upper gas phase and lower sulfuric acid medium. The two electrodes (the anode with hydrogen above the electrolyte and the cathode with oxygen above) were separated by a considerable thickness of sulfuric acid in each cell, which would lower efficiency by increasing the electrolyte resistance, resulting in less cell voltage because of the production of more heat. Mond and Langer provided the first means to optimize Grove's requirement for a "notable surface of action" referred to in the last section by making each electrode porous, fed by the reactant gases from the back side, with the electrolyte located between the facing sides of the two electrodes. The aim was to create an interface between the three components (solid electrode electronic conductor, liquid electrolyte ionic conductor, and reactive gas phase) to maximize the possibility of reaction and transport of electrons in the solid phase and ions in the liquid phase. They realized that this required means of creating a stable liquid-solid-gas interface within the thin electrode structure, so they attempted to use a partially "wet-proofed" structure incorporating paraffin wax inside a catalyzed electrode. This did not work for more than a matter of minutes, so it remained until the discovery of polytetrafluoroethylene (PTFE, Du Pont Teflon™) just before World War II and its application to this problem in the 1950s (by General Electric) to enter the modern age of low-temperature fuel cells operating at temperatures up to 80°C in alkaline electrolytes (KOH) and up to 200°C in phosphoric acid electrolyte. The electrodes for these systems consist of the catalyzed carbon materials mentioned in the last section containing about 35 wt % of Teflon™, which are fed from the back by the gaseous reactants. They require means of supply of the reactants to the back of each electrode by flow channels, and appropriate means of supplying the reactants to each cell.

Because of the requirement that electrochemical power cells must use electrolytes preponderantly containing an ion produced at one electrode and consumed at the other to achieve acceptable efficiency, fuel cells like batteries are limited by a choice of electrolyte depending on their chemistry. Since all of the fuel cells considered essentially use hydrogen as fuel and oxygen from air (or liquid oxygen in space and submarines as oxidant) the choice is effectively limited to aqueous alkalis or acids, or certain high-temperature systems conducting pure or complexed oxide ion. Alkaline electrolyte (usually potassium hydroxide, KOH solution) will be considered first, since it uses the same reaction as that in the zinc-air system at the cathode given in the last section, i.e., $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$. With hydrogen fuel supplied to the back of the anode by appropriate flow channels and manifolding, the anode reaction will be $2H_2 + 4OH \rightarrow 2H_2O + 4e^-$ We note that these reactions proceed in a series of one-electron steps, which largely explains why the 4-electron oxygen reduction reaction is so slow. Its electronic properties make its double bond very difficult to dissociate, whereas the simple single H-H bond dissociates readily on good catalysts, giving a smooth and efficient reaction.

The requirement that the ionic current must be conducted by an ion produced in one reaction and consumed in the other (by OH^- produced at the cathode and consumed at the anode in alkaline solution) limits aqueous electrolyte fuel cells to only one other possibility: acid electrolyte, in which the anode reaction is $2H_2 \rightarrow 4H^+ + 4e^-$, with $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ at the cathode. Two important points are: in normal aqueous acids, for example, sulfuric acid, used by Grove and by Mond and Lange and in other early work, the very small H^+ ion (the proton) is only mobile when it is associated with water molecules in the form of the solvated hydronium ion, $H_3O^+(H_2O)_n$. where n is at least 3 in dilute solution. The n = 3 ion ($H_9O_4^+$) with three tightly-associated water molecules is called the *Eigen ion*, and n = 1 ion (which may be the mobile species in concentrated solution at higher temperatures) is the *Zundel ion*, both named after their proposers. As a typical aqueous acid becomes more concentrated, its conductivity falls. For sulfuric acid at 20°C the maximum conductivity is at 30 weight % concentration. This falls by a factor of 2 at 60 wt %, and becomes very small at 98 wt %, where the protons are solidly attached to sulfate ion as H_2SO_4. In contrast, while the OH^- ion is also associated with water in dilute solution, very concentrated or even molten KOH still shows substantial conductivity. The second point to note is that liquid product water is produced at the oxygen reduction cathode in acid electrolyte, while it is produced at the hydrogen oxidation anode in alkaline electrolyte.

The only other electrolyte systems which will support adequate anode and cathode reaction rates are molten carbonates (mixtures of lithium and potassium) or lithium and sodium carbonates to reduce melting points and give higher oxygen reduction activity, and solid oxide-ion conducting electrolytes at sufficiently high temperatures. These electrolytes were retained within inert absorbing powders, the most effective being lithium aluminate.

MOLTEN CARBONATE FUEL CELLS:

In molten carbonates, operating between 600 and about 680°C, with a lower limit determined by conductivity considerations, and an upper limit by materials (corrosion, dissolution), cathode reaction is $O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{2-}$ and the anode reaction is $2H_2 + 2CO_3^{2-} \rightarrow 2H_2O + 2CO_2 + 4e^-$. The conducting ion is carbonate, CO_3^{2-}, and this means that carbon dioxide (CO_2) produced at the anode along with product water vapor, must be recycled to the cathode requiring some pumping and separation work for transfer. This results in a further dilution of concentration of the reactant oxygen in air, thus a reduction in cell voltage and efficiency. When the system was first devised by Broers and Ketelaar in the Netherlands in the 1950s in laboratory cells of small area, this was neither appreciated nor publicized. The system was studied in the US at the Institute of Gas Technology (IGT), Chicago, and some of its technology was transferred to Energy Research Corporation (ERC), Danbury, CT in 1968, which became FuelCell Energy (FCE) in 1999. This (and its licensees) have the only surviving system technology, which was also developed at Pratt & Whitney Aircraft (initially with IGT from 1967) until the mid 1980s, General Electric in the late 1970s-early 1980s, at IGT's spin-off MC-Power (Burr Ridge, IL) until 1999, and in Japan as part of their national fuel cell program until the mid-1990s. Stage-by-stage scale-up from laboratory cells to full size took place unexpectedly smoothly, and cell size had reached 0.78 m^2 by the mid 1990s. Because of the operating temperature, nickel is a satisfactory catalyst for both the anode and cathode, the former in the form of a sintered alloy powder (to resist creep deformation) and the latter is in the form of sintered lithium-doped conducting nickel oxide (after in-situ oxidation). The system is bipolar, with cells piled (as in the Volta pile) on top of one another in what is generally called a "*stack*" ("*empilement*" in French).

The bipolar technology consists of a corrosion-resistant stainless steel plate clad with 50 microns of nickel on the anode side. The system is designed for natural gas fuel, which cannot be used directly in either low-temperature fuel cells (in which it is inert) or in high-temperature cells (in which it breaks down to produce carbon). However, it is protected in the latter case when it is mixed with sufficient steam. The unique characteristic of the FCE technology is the use of direct internal reforming (DIR) of a desulfurized natural gas feedstock with steam (molecular ratio 1 : 2.5) by catalysts in the flow channels behind each anode. Further steam produced in the reaction at the anode completes the process, and 75% of the heating value of the fuel produces DC electrical power at about 0.7 V per cell. The equivalent of 0.55 V is available within each cell as heat, which is about twice the requirement for the heat-absorbing (endothermic) reforming process. Reforming aids in cooling the stack, and the flows are carefully adjusted to ensure that the temperature across each cell from entry to exit is within the required 600-680°C range. The anode effluent gas containing one-quarter of the hydrogen is burned with an appropriate amount of excess air to preheated oxygen-CO_2 to supply the cathode reaction. The reactants in the gas mixture are very dilute, and FCE has done an excellent job of optimization to obtain excellent performance from it. The insulated stack, to which the gases are supplied and exit from opposite sides via two pairs of insulated box-type cross-flow manifolds, is very robust, and can be thermally cycled, but the systems are best used for base-load power to avoid temperature cycling and to maintain long-term performance. The net result is a system with few expensive heat exchangers (the stack itself is a heat-exchanger), and the overall system efficiency to DC electricity is in round figures (0.7 V) x (75%) divided by the voltage equivalent of the heating value of the natural gas, or about 51%. Conversion of DC power to line AC and pumping power requirements reduce this to a practical 47%. Three units, direct fuel cell-300 (DFC300®, 300 kW); DFC1500®, 1.4 MW; and DFC3000®, 2.8 MW are offered in rapidly-installable sheet-metal industrial container units. In addition, a multi-MW unit is offered by FCE and Enbridge, Inc (Calgary, Alberta) with a non-fired heat-recovery turbine mechanical bottoming cycle allowing an overall efficiency of up to 65%. The major cost of these units is the stack, which contains materials whose cost has greatly increased in recent years. However, its negligible emissions and very low noise enable it to be sited anywhere, even in California.

SOLID OXIDE FUEL CELLS (SOFC):

These use a thin layer of solid oxide ion (O^{2-}) conducting electrolyte analogous to the solid ß-alumina sodium-ion conductor mentioned earlier. The conductor must be at a sufficiently high temperature, but not too high as to introduce materials stability problems. For the favored conductor, a zirconium oxide (zirconia) stabilized by a rare-earth oxide, yttrium oxide, (yttria) or YSZ, the upper limit is 1000°C and the lower limit (because of conductivity) is about 850°C. The system has been known in the laboratory for many years, but was developed by Westinghouse starting in the 1950s. The original version consisted of a large number of small tubular cells with air cathodes on the outside and anodes on the inside, the anode of one cell being joined to the next by an electronically-conducting tubular ceramic interconnect. .

This proved to be totally uneconomic to manufacture, and in 1981 it was replaced by a larger single tubular cell supported on an inert porous zirconia support tube sealed at one end, on which were successive layers of porous mixed oxide lanthanum strontium manganite (LSM) oxygen (in air) electrode material, a solid YSZ electrolyte, and a porous nickel-YSZ anode material. Air was supplied to the inside via an internal alumina tube, which served as a heat-exchanger. Both the YSZ and air electrodes were peripherally discontinuous, so that a band of electronically-conducting oxide (lanthanum strontium chromite, LSC, stable at both the anode and the cathode) extended along the length of the tube. The outer part of this was connected to the outside anode of the next tube via a nickel felt material, which was only exposed to hydrogen, supplied to the outside of the tube. This effectively monopolar junction (the interconnect) joined the cathode of one cell to the anode of the next. After depositing and sintering the LSM layer, the second and third layers were originally built up by a costly technology called electrochemical vapor deposition (EVD), with masking to create the interconnect zone.

As in the case of the MCFC, the system was scaled up in successive stages, with a change in the support tube to porous LSM, making the electronic resistance loss in the original thin cathode layer lower, which became an important issue as diameter increased. By 1991, the tube was 2.0 meters long (1.7 m active length), 2.2 cm external diameter, 0.22 cm thickness, and 834 cm^2 active area. The air flow was about 3.7-3.8 times the electrochemical requirement to cool the system to less than the allowable maximum operating temperature. As with the cell waste heat was used for methane reforming, this time indirectly (i.e., in an external chamber), since at the cell operating temperature the reforming reaction proceeds so rapidly that it will cool the entry to each cell, stopping its electrochemical reaction. Again, fuel utilization in each cell was about 75%, excess being automatically burned at the exit of each tube, where exiting anode and cathode gases mixed. The collection of tubular cells (called a "bundle") was insulated by alumina. The system was taken over by Siemens (Erlangen, Germany) with their acquisition of the Westinghouse generation assets in 1997, and it is now referred to as Siemens Power Generation Stationary Fuel Cells Division.

System efficiencies and emissions, and costs are generally similar to those of the MCFC, but as with the latter, a turbine (in this case, pressurized) system is also offered, increasing overall efficiency. Some semi-commercial 100-300 kW systems are in operation.

Other tubular programs exist (or have existed) in Japan, and a flat (planar) cell system proposed by the Solid State Energy Conversion Alliance, (SECA) has been in place since late 1999. Other electrolytes operating at lower temperatures are emphasized, e.g., lanthanum gallate, which may require alternative electrode materials with a matched coefficient of thermal expansion to avoid cracking on thermal cycling. Some groups advocate proton-conducting solid electrolytes operating at lower temperatures. Similar programs are in place in Japan.

ACID FUEL CELLS: PHOSPHORIC ACID (PAFC):

1950s experiments at General Electric (GE, Schenedctady, NY) attempted to oxidize hydrocarbons directly with acid electrolyte, chosen because it would not react with an product CO_2, and hence become deactivated. Sulfuric acid turned out to be unstable at higher temperatures, and in any case (as already described) became essentially non-conducting at the higher temperatures (and resulting higher acid concentrations) at which some sort of activity might be expected on the best platinum catalysts.

The GE researchers observed that phosphoric acid, H_3PO_4, did appear to have another substantial advantage over H_2SO_4 at higher temperatures. The latter is self-ionizing to produce the $H_3SO_4^+$ ion ($2H_2SO_4 \rightarrow H_3SO_4^+ + HSO_4^-$) to only a negligible extent, while phosphoric acid, H_3PO_4, which is a rather weak acid at low temperatures, apparently is unique in being able to produce large amounts of the conducting ion $H_4PO_4^+$ as its temperature rises and the amount of water it contains decreases. This large ion is not particularly mobile at low temperatures, but its mobility (therefore conductivity) increases with temperature. At 150° C and higher, phosphoric acid with platinum catalysts does start to show some activity for direct hydrocarbon oxidation, and it is very stable (except to eventual evaporation loss above 210°C).

At the Pratt and Whitney Engine Division of United Technologies Corporation (UTC), interest had rapidly grown in alkaline fuel cell (AFC) technology because of the proposed Apollo moon program after 1961. This is discussed below.

However, by 1966, the company began to see the possibility of a PAFC system to use natural gas (i.e., methane, CH_4). While this could not be used directly, it could be steam-reformed with a catalyst at about 800°C to give a mixture of hydrogen and carbon monoxide and dioxide (endothermic, requires heat), and the mixture could then be further processed with more steam to give more hydrogen and carbon dioxide from the carbon monoxide remaining (exothermic, producing heat). The steam requirement was to be provided by the waste heat of the phosphoric acid fuel cell stack operating well above the boiling point of water. Not all of the hydrogen and CO_2 with some CO could be used in the fuel cell stack, since as the hydrogen became more dilute as it was consumed, its reaction would slow, eventually resulting in diminishing returns. The remaining CO (up to 1.5% in the exit gas) was rejected. In this way, about 75% of the hydrogen was used in the fuel cell, the rest being burned to provide the heat of reaction for reforming. The result was a system with many (11 -14) expensive heat-exchangers and about 35% thermal efficiency after allowing for DC-AC conversion and parasitic power losses. The system started with the TARGET (Team to Advance Research in Gas Energy Conversion) program funded by the American Gas Association (AGA) in 1967, with IGT as a partner. Work was also conducted on the MCFC as a possible back-up system. The objective was to put a 12.5 kW peak power fuel cell system (mean power requirement 1.5 kW) powered by natural gas into non-electric grid-connected homes. A nine-year program was anticipated (3 years R&D, 3 years manufacture and evaluation, 3 years demonstration). The targeted system cost was about $1000/kW in current dollars.

The PAFC stack operating environment is very corrosive, and the only stable materials available were some of the platinum group metals (platinum, rhodium, and iridium), gold, and tantalum (which was non-conducting due to the presence of an insoluble oxide film).

The phosphoric acid was originally immobilized in fine-grained silicon carbide held together with Teflon™, which was later replaced by polyether ether ketone (PEEK), which was somewhat surprisingly stable, and gave much better wetting and retention properties than Teflon™. The best anode and cathode catalyst was platinum, and gold-plated tantalum sheet was experimented with as a bipolar plate. However, by about 1972 it was realized that graphite, while not theoretically stable, had sufficient practical stability to be used. The same pure finely-divided chemically-prepared platinum black catalyst used by Grove and Mond and Lange with an area of 20 m^2/gm could be replaced with platinum supported on graphitized high-surface-area carbon black, giving a catalyst with five times the effective area and activity. Graphite could be used for the bipolar plate and the cooling plates (one for every 5-7 cells) containing metal-tube flash steam generators using pure cooling water. The demonstration program with 50 PowerCell 11 (PC11™) 12.5 kW units was completed, but they were certainly not cost-effective for single-home use. They were very over-sized to allow peaking power (which could have been much more cheaply provided by batteries in a hybrid system), and required backup in the event of outage and/or maintenance. As a result, emphasis changed from individual home systems to so-called "on-site" units to supply larger buildings and building complexes.

A development of the late 1970s was a graphite-fiber "ribbed substrate" to hold the platinum-on-graphitic-carbon electrodes, which contained PTFE to give partial wet-proofing, with rear gas channels allowing perpendicular controlled diffusion of gases into some areas, and sufficient storage of electrolyte in others to give an effective stack life of 40,000+ hours. The units were increased to 40 kW in the PC18™ system (funded by the Gas Research Institute, GRI, Chicago in the later 1970s-early 1980s) to reduce cost, with larger cells. These were demonstrated at 42 sites. They proved to work, but they were still not economical power sources in spite of their overall 35% efficiency and extremely low environmental and noise emissions. The next stage, starting in 1985-86 was to use 0.34 m^2 cells in 200 kW units operating at 0.65 V at 0.22 A/cm^2, later scaled up to 0.47 m^2 cells at 0.25 A/cm^2, and finally at over 0.30 A/cm^2 at approaching 200°C in various PC25™ versions (A, B, and C), later called the PureCell® 200. These 35% electrical efficiency units, which could provide combined heat (hot water) and power (CHP) were successfully demonstrated and sold (with government and state subsidies) in 270+ quantities. They have operated over 9 million hours in 19 countries, showing negligible chemical and noise emissions. They could be sited anywhere without special permitting. They were particularly suitable for non-interruptible power for heavy electronic applications. Even with the subsidies, their economic costs were still marginal. Starting in 2009, they were followed by the larger PureCell® 400.

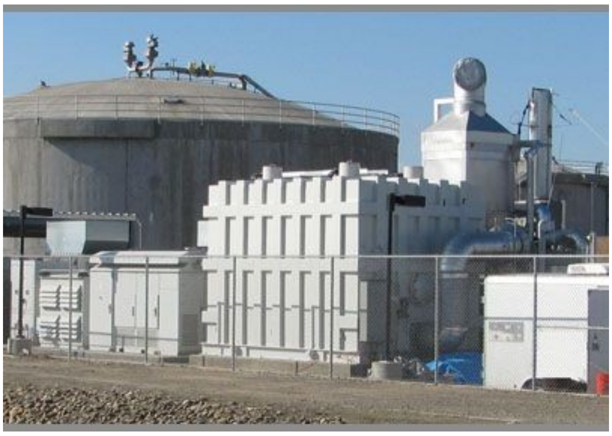
Starting in 1972, Pratt & Whitney proposed a pressurized 27 MW unit to utilities. Pressurization was intended to improve performance and efficiency. They tested a 1 MW unit in 1977, and constructed and tested successive 4.5 MW demonstrators with 0.34 m^2 cells pressurized to 3.4 atm. in New York and Japan in 1978-85. The first proved the capability of the fuel processing system and allowed permitting, while second was a successful electrical demonstration. They were followed by an 11 MW PC-23 demonstrator with 0.94 m^2 cells pressurized to 8.2 atm. which operated at 67% of capacity due to accidental loss of 1/3 of the stacks. It achieved 41.8% net AC efficiency based on the higher heating value (HHV, product water condensed) of the natural gas fuel (46% based on the more usual lower heating value, LHV, product water as vapor).

Two 670 kW PC23 stacks were used in a nominally 1.4 MW demonstrator natural gas system (engineered by Ansaldo, Genoa) in Milan, Italy, which operated well between 1995 and 1998. In Japan, Fuji Electric developed 50 kW (FP-50) and larger systems, Mitsubishi Electric Corporation (MELCO) developed 200 kW systems similar to the PC25, and Toshiba formed a partnership in 1983 with UTC called International Fuel Cells (IFC). A pressurized air-cooled, rather than water/steam-cooled program existed from 1978 at Westinghouse (Large, PA) using PAFC technology licensed from ERC (Danbury, CT). The technology was sold in 1993 to FuelCell Corporation of America, which in turn transferred it to Hydrogen LLC (Jefferson Hills, PA) in 2001. Engelhard Industries (Iselin, NJ) also had an on-site program, which was terminated in the early 1990s. None of the results of these programs has reached commercial production.

FUELCELL ENERGY PROVIDES ENERGY SECURITY AND CUTS CO_2 EMISSIONS

SELF-SUFFICIENCY FOR WASTE WATER TREATMENT CENTRE

A 2.8 megawatt DFC3000® stationary fuel cell power plant installation has started operation at a municipal water treatment facility in California that utilizes renewable biogas as a fuel source. FuelCell Energy, Inc. previously announced the sale of the power plant to Anaergia, Inc., a project developer and investor. Anaergia is selling the electricity and heat to Inland Empire Utilities Agency (IEUA) under a twenty year power purchase agreement. The power plant is an integral and unique on-site fuel cell application to convert biogas, a harmful greenhouse gas, into electricity and usable high quality heat in a carbon-neutral fashion that emits virtually no pollutants. IEUA is one of the largest wastewater treatment operators in California and is a leader in adopting sustainability initiatives as it transitions to grid-independence by the year 2020.



"This stationary fuel cell project that uses a renewable fuel source to generate clean power is helping the State of California reach our aggressive renewable portfolio standards," said Michael Peevey, President, California Public Utilities Commission. "This project illustrates how public/private partnerships are a great model for providing public benefits with private capital." "We have adopted the goal of becoming energy self-sufficient by the year 2020 in a manner that meets our sustainability goals and with competitive economics," said Thomas Love, General Manager, of Inland Empire Utilities Agency. "This fuel cell project, combined with our existing solar and wind installations, is helping us achieve these goals." Reliable on-site power generation from fuel cells combined with the credit profile of municipalities attracts private capital to fuel cell projects. Anaergia partially funded the purchase of the fuel cell power plant located at IEUA through the issuance of California Municipal Finance Authority Revenue Bonds.

REPLICABLE MODEL FOR CALIFORNIA AND OTHER REGIONS

"Setting new standards for environmental leadership with cost effective on-site power generation that is clean and renewable is a replicable model for California and other regions," said Arun Sharma, President, Anaergia Services. IEUA is prohibited from releasing the biogas generated by the wastewater treatment process directly into the atmosphere as it is a harmful greenhouse gas. Flaring the biogas emits pollutants and wastes a potential source of revenue. Using the biogas as a fuel source to generate power converts a waste disposal problem into a revenue stream. Due to the renewable nature of biogas, the power generated by the fuel cell is carbon-neutral. "This 2.8 megawatt fuel cell power plant is the world's largest power plant operating on renewable on-site biogas. Our fuel cell technology is uniquely positioned to provide what other megawatt-class power generation products can't, which is efficiently converting biogas into continuous power right where the biogas is generated and in a manner that is virtually absent of pollutants," said Chip Bottone, President and Chief Executive Officer, FuelCell Energy, Inc. "This project is a win for everyone involved, particularly the citizens of California who benefit from privately financed carbon-neutral power generation." Direct FuelCell® (DFC®) plants can be located where biogas is generated and directly use the biogas with only minimal cleaning of the gas. Biogas contains humidity, sulfur and CO_2. Prior to being used as a fuel source for the Direct FuelCell, the humidity and sulfur must be removed, but the DFC technology does not require the removal of the CO_2. This is a cost advantage because biogas injected into the gas pipeline must have the CO_2 removed.

CARBON NEUTRAL POWER PLANT FOR DATA CENTRE

FuelCell Energy has announced a proposal for a 200kW stationary fuel cell power plant to support Microsoft's latest data center research project. The power plant will utilize renewable biogas generated by a wastewater treatment facility to generate ultra-clean and carbon-neutral electricity to power Microsoft's Data Plant project in Cheyenne, Wyoming. This project enables Microsoft to evaluate the effectiveness of using FuelCell Energy power plants to efficiently use on-site biogas to power future sustainable data centers.

Gregg McKnight, general manager, Data Center Advanced Development at Microsoft said: "With the demand for renewable energy resources outstripping available power supplies, Microsoft is researching new methods to help our operations become more efficient and environmentally sustainable. We're excited by the potential for using stationary fuel cells to capture and recycle natural byproducts like biogas. This project will study methods to provide an economical and reliable power supply for data centers that is also scalable and economical for use by other industries."

The fuel cell plant will be housed in a modular IT pre-assembled component (ITPAC) that will house servers to recreate a data center environment. Excess power not used by the data center will be provided to the water reclamation facility to offset their electric costs. In the event of a grid outage, the Data Plant project and fuel cell plant will be configured to operate independently to provide continuous power. Bob Jensen, Chief Executive Officer, Wyoming Business Council said: “This is a great project and an example of our broad efforts in advanced energy technologies and clean carbon conversion in Wyoming. Our board approved this application and it will be voted on by the State Loan and Investment Board in December for its final decision."

In May 2012, Microsoft announced their commitment to become carbon neutral beginning in 2013. Reliable on-site power generation that is environmentally-friendly is a key consideration for Microsoft as they evaluate clean and renewable energy generation for their data centers which power the company's cloud services and support more than 1 billion customers and 20 million businesses globally.

PROGRESS WITH THE WORLD’S LARGEST FUEL CELL ORDER

Following upon the recent announcement by Seoul City of their plans for 230 MW of stationary fuel cell power plants, POSCO Energy, has ordered 121.8 megawatts of fuel cell kits and services to be manufactured at the FuelCell Energy production facility in Connecticut, USA. The estimated value of the multi-year contract is approximately $181 million. “This order will help us to meet demand in South Korea as well as other Asian Countries” said Jung-Gon Kim, Senior Vice President, POSCO Energy. Chip Bottone added: "The extensive market acceptance in South Korea for ultra-clean and efficient fuel cell power generation is a deployment and job creation model that can and should be replicated in other regions of the world." South Korea adopted an ambitious renewable portfolio standard (RPS) in 2012 to promote clean energy, reduce carbon emissions, and develop a local green-industry to support economic growth. Expected fuel cell applications include the Seoul City subway, municipal water treatment facilities and resource collection facilities. Electrical and thermal efficiency is important under the RPS and the fuel cell power plants are expected to be configured for combined heat and power (CHP).

EXPANDING THE ASIAN MARKET

FuelCell Energy and POSCO Energy have announced a series of initiatives to expand the market for stationary fuel cell power plants in Asia, including a license agreement for POSCO Energy to manufacture Direct FuelCell® (DFC®) power plants in South Korea and sell throughout Asia. "With growing demand in South Korea and strong interest in Asian markets for ultra-clean distributed power generation, manufacturing in South Korea is necessary to meet customer expectations of lead times and costs," said Jung-Gon Kim. "Local manufacturing is a cornerstone of our growth plans in South Korea and we will continue to work closely with FuelCell Energy to develop other Asian markets." “A second source of global supply and production capacity for our DFC fuel cell modules is important to project investors and customers," commented Michael Bishop, Chief Financial Officer, FuelCell Energy, Inc. "This licensing agreement is a key to accelerating global expansion of fuel cell power plants." The License payments are for $18 million plus $8 million for prior agreements.

POSCO Energy will also pay a 3% royalty to FuelCell Energy for each power plant they build and sell during the next 15 years. This royalty is expected to develop into a consistent and growing revenue stream as the Asian fuel cell market expands. The license agreement may be extended for two additional terms of five years each by mutual agreement.

SOFC DESIGN WILL BE SCALABLE FOR MULTI-MEGAWATTS

The US DoE has awarded 70% of the $6.0 million cost for Part III of the Solid State Energy Alliance (SECA) programme, which is a collaboration between government, industry and academia to develop megawatt-class solid oxide fuel cell (SOFC) power plants to efficiently and cleanly generate electricity from coal syngas. High efficiency power generation from coal syngas advances the nation's energy security while reducing greenhouse gas emissions. The objective for this award is to further enhance the performance and endurance of the SOFC stack through continued cell materials research and testing of a 60 kilowatt (kW) SOFC power plant connected to the electric grid at FuelCell Energy's Danbury, Connecticut facility. The results of these tests will be utilized in the design of a scalable 60 kW SOFC power plant with extended capabilities for combined heat and power (CHP) applications. The scalable design is the foundation for the larger multi-megawatt SOFC power plants. The power plant utilizes the SOFC fuel cell stack blocks manufactured by Versa Power Systems, Inc. Both the module which houses the stack blocks as well as the balance of plant for processing fuel, delivering air and producing heat and power are designed by FuelCell Energy. The SOFC module is fuel flexible, capable of operating on a variety of fuels including coal syngas, natural gas, renewable biogas or directed biogas. Tony Leo, Vice President Application Engineering & Advanced Technology Development, FuelCell Energy, Inc. said "We believe this technology can provide an industry leading electrical efficiency of approximately 60% and still provide usable heat for combined heat and power applications, resulting in total estimated thermal efficiency between 80% and 85 %." Almost half of the power generated in the USA is from coal and this coal generated power contributes over one quarter of the nation's total greenhouse gas emissions. Fuel cells operating on coal syngas can generate clean power with virtually zero pollutants and significant reductions in greenhouse gas emissions.

SECOND PHASE OF CARBON CAPTURE PROJECT

FuelCell Energy is starting the second phase of the carbon capture development project under the previously announced award from the U.S. Department of Energy (DOE). The research evaluates the use of Direct FuelCells® (DFC®) for efficiently and cost effectively separating carbon dioxide (CO_2) from the emissions of coal fired power plants. This three and a half year project that began in late 2011 involves system design, cost analysis, and long-term testing of a Direct FuelCell stack. Approximately $0.8 million from the total DOE award of $3 million was authorized to continue the development, following favorable results achieved from the technology and economic analysis conducted in the initial stage of research. “The potential for efficient and cost effective carbon capture from our Direct FuelCell power plants illustrates the versatility of our technology," said Chip Bottone. FuelCell Energy's DFC technology separates and concentrates CO_2 as a side reaction during the power generation process. In this application of the technology, the exhaust of a coal fired plant is directed to the air intake of a DFC power plant, which separates and concentrates the CO_2 in the exhaust for commercial use or sequestration. Another side reaction that occurs when the fuel cell is used in this application is the destruction of some of the nitrogen oxide (NOx) emissions in coal plant streams as the exhaust passes through the fuel cell. This reduces the cost of NOx removal equipment for coal-fired power plant operators. Since DFC power plants produce power efficiently and with virtually zero emissions, the net result is a very attractive solution to prevent the release of greenhouse gases by coal-fired power plants while simultaneously increasing the net efficiency and power output of the plant. Additional benefits include reduction of the operating cost related to removal of NOx and reduction in water usage as existing carbon capture technologies are water intensive.

Conventional technologies used for the capture of CO_2 from the emissions of coal fired power plants are energy-intensive with high operating costs. Most of the existing carbon capture technologies penalize the power plant output by as much as 30%. DFC power plants potentially represent an efficient and cost effective approach to separating CO_2, while generating ultra-clean power rather than consuming power. www.fce.com

STARTING THE CHANGEOVER TO HYDROGEN

'HYDROGEN IS THE FUTURE OF FUEL' AT ECOISLAND

When the UK Minister of State for Energy, John Hayes, arrived on the Isle of Wight he was collected from the ferry by a vehicle powered by hydrogen, before being driven by Channel 5's transport guru, Quentin Wilson, to the Ecoisland's Global Summit 2012. The vehicle in question is the first hydrogen vehicle in production, but the zero emissions, long range transport solution it provides may soon be in widespread use across the island. The Hyundai ix35 fuel cell vehicle is powered by hydrogen produced by energy storage experts, ITM Power. The hydrogen fuel was produced on site at the summit by ITM's HFuel, a self-contained module suitable for refuelling hydrogen-powered road vehicles.

Quentin Wilson is a passionate advocate of hydrogen transport and sees it as critical to the success of a low or zero carbon transport future: "Hydrogen is the future of road transport. It's going to be half the price of petrol or diesel, it's going to be completely carbon free and it's easy to make. This is here and now, it's close enough to touch. With a little more political will the manufacturers will all come together and you'll see these cars on the road."

Hydrogen fuel also has the support of the Minister's office, the Department of Energy and Climate Change, which recently awarded a Technology Strategy Board's grant to a project led by ITM Power that will see the integration of an electrolyser based refueller with the island's renewable energy. The project will design, build, install and operate two grid-connected hydrogen refuelling platforms on the Isle of Wight.

A 15kg/day refueller will be used in a marine capacity located on the south coast of the Island, and a larger 100kg/day unit will be installed on a centrally located business park for the operation of a fleet of hydrogen vehicles.
"Hydrogen will be fundamental to our future energy mix, providing a balancing mechanism that will allow for increased renewable generation", explained ITM Power CEO Graham Cooley. "As a transport fuel it provides a viable zero emissions, zero footprint solution; just like conventional fuels it takes 3 minutes to fill your car with enough hydrogen fuel to take you 400 miles".

Low carbon transport and energy storage are key components in the Ecoisland's project that will see the Isle of Wight become renewable energy self-sufficient by 2020 and sustainable by 2030. Government ministers, islands and regional delegates, sustainability experts and technology partners came together at the summit to learn how the Ecoisland's model can be replicated in communities around the world. Graham Cooley sees strong potential for national roll out following the demonstration on the island. "Island systems face significant challenges in terms of energy balancing and high fuel prices. The hydrogen test-bed that we are developing with Ecoisland will allow us to understand how to roll out these solutions across the country".

RENEWABLE POWER AND HYDROGEN

ITM Power has signed an agreement with GMI Renewable Energy Group Ltd (GMI) to offer an integrated renewable power generation and hydrogen production system for back-up power, industrial processes and refuelling solutions for materials handling equipment in commercial buildings. This agreement will offer renewable power coupled to hydrogen generation as a totally zero carbon process. Under the agreement, GMI will offer its existing and potential new customers the alternative of hydrogen generation as a use of their renewable power generated on-site. ITM Power will provide the hydrogen generation and refuelling equipment and, if required, the fuel cell systems to enable customers to produce zero carbon hydrogen at the point of use.
www.itm-power.com

LOGAN ENERGY BRINGS CLEAN FUEL CELL POWER TO LONDON

Edinburgh-based Logan Energy Ltd, the world market leader in powering fuel cell integrated systems, has announced a new contract to install a 300 kW stationary fuel cell power plant at the 20 Fenchurch Street office development in the City of London. The installation, which will be designed, integrated and maintained by Logan Energy, will support London's deployment of decentralized energy to develop a more sustainable, secure, cost-effective and low to zero carbon energy supply in the capital.

Known as the 'Walkie Talkie', the 38 storey, 690,000 square foot office building is being jointly developed by Canary Wharf Group plc and Land Securities plc and is set to open in early 2014. The building has a distinctive design that sees it widen as its height increases, providing a smaller footprint and correspondingly larger outdoor space at street level, with additional floor space for lease on the upper floors.

The Direct FuelCell® (DFC®), which will be installed in 2013, will provide electricity, high temperature heat to an absorption chiller to provide cooling, and low temperature heat for space and domestic water heating in a combined cooling, heat and power (CCHP) configuration.

The DFC300-EU, which will be supplied by German-based FuelCell Energy Solutions, is well-suited to such a highly populated area and brings several key benefits:

Reduced pollution: the power generation process of the fuel cell is an electrochemical reaction rather than combustion, to efficiently convert fuel into clean electricity and heat suitable for many tasks from underfloor heating, through chilled water provision to steam generation; and so is virtually free of pollutant emissions such as nitrous oxide, sulphur dioxide and particulate matter.

Quiet operation: This also ensures a quiet operation, about 65 dba, allowing for a normal conversational tone next to an operating fuel cell.

Efficiency and savings: Generating both electricity and heat from the same unit of fuel reduces fuel costs and drives efficiency. Fuel cells can achieve up to 90% efficiency when the heat is utilized in a combined heat and power (CHP) configuration. Logan Energy estimates the overall efficiency of this DFC installation as being 80%.

The project Construction Manager, Paul Mutti from Canary Wharf Contractors Limited, said: "The high efficiency of the stationary fuel cell power plant is very important for this building, from both an economical as well as sustainability viewpoint. The design and construction of the building incorporates the latest advances in efficiency and conservation to minimise the building's environmental impact, including re-use of the demolition material from the prior building, utilisation of solar shading and window glazing that conserves energy, and the fuel cell power plant that economically generates both electricity and heat with virtually no emissions."

25% DECENTRALISED ENERGY FOR LONDON BY 2025

The DFC power plant supports the targets established by the Mayor of London to supply a quarter of London's energy from decentralised sources and reduce CO_2 emissions by 60% by 2025, supporting the Mayor's vision for London to be the greenest big city in the world.

The high efficiency of the DFC power plant and efficient design of the CCHP scheme reduces building CO_2 emissions by approximately 351 metric tonnes per year using National Calculation Methodology (NCM) simulation software.

"This project is another example of how well integrated, fuel cell powered, distributed energy solutions can provide superior carbon and operational savings over other technologies." said Bill Ireland, Managing Director of Logan Energy Limited. "We are extremely proud to be a part of this prestigious project which further expands our portfolio of installations, supporting our business expansion plans."
Established in 1995, Logan Energy Ltd is the world leader in integrating fuel cell powered systems. It offers a full turnkey service including feasibility studies, system design, integration, installation and maintenance. To date, Logan Energy has installed over 170 fuel cell systems worldwide, including one in Transport for London's prestigious Palestra Building, which has been operating successfully since its commissioning in February 2009. They have installed over 18MWe of fuel cell installations of varying technologies, a major proportion of the worldwide independently installed fuel cells. www.logan-energy.com

EVENTS

27th February - 1st March, 2013,
FC-Expo 2013, 9th International Hydrogen + Fuel Cell Expo, Tokyo, Japan, www.fcexpo.jp

20th—21st March 2013
2020 Hydrogen & Fuel Cell Economy. The 9th International Conference, Exhibition and Partnering Event will be held for two days in Birmingham, UK. It will include renewable energies for hydrogen production.
www.climate-change-solutions.co.uk

8th –12th April 2013,
Group Exhibit Hydrogen + Fuel Cells, Hannover Fair, Germany. Includes Europe's largest hydrogen and fuel cells exhibition. www.h2fc-fr.com

22nd—23rd May 2013,
All Energy 2013,
Aberdeen, Scotland. The largest UK renewable energy event includes sessions on hydrogen and fuel cells.
www.all-energy.co.uk

16th—19th June, 2013,
Hydrogen + Fuel Cells 2013 ,
Power, Transportation and Energy Storage: An Industry on the Move. Vancouver, Canada.
www.hfc2013.com

2nd—5th July 2013,
4th European PEFC & H_2 Forum,
Low temperature fuel cells and hydrogen.
Lucerne, Switzerland. www.efcf.com

Fuel Cell Power's Blog covers all types of fuel cells and their applications in distributed power generation, portable power, CHP and transport. For millennia, energy has been obtained by burning fuels, which is changing the chemistry of the atmosphere and the oceans. Cleanly, quietly and efficiently the electrochemical conversion of fuels is now becoming a practical alternative to combustion. Fuel cells utilize fossil fuels or energy from waste efficiently. They can equally be powered by hydrogen which can be generated from intermittent renewable energy sources. Articles and features in Fuel Cell Power will help individuals, businesses and communities to plan for long term energy efficiency, price stability and cuts in harmful emissions.

www.fuelcellpower.org.uk

Fuel Cell Power provides information on the practical application of fuel cells.
It is produced by the family and friends of the late Dr F T Bacon OBE, FRS,
who dedicated his life to the development of fuel cell technology.
Information can be obtained from: Jean Aldous, Editor, Fuel Cell Power,
The Gallery, The Street, Woolpit, Suffolk, IP30 9QG.
Telephone : 01359 245073
www.hydrogen.co.uk www.futureenergies.com www.fuelcellpower.org.uk